EFFECTS OF PHYSICAL AND VIRTUAL EXPERIMENTATION ON STUDENTS` CONCEPTUAL UNDERSTANDING IN HEAT AND TEMPERATURE

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ABSTRACT
The purpose of this study was to compare the effect of Physical Manipulatives (PM), Virtual Manipulatives (VM), and two sequential combinations of PM and VM, on pre-service students' understanding of scientific concepts in the domain of heat and temperature. A pre-post comparison study design was conducted that involved 182 undergraduate students in an introductory physics course that was based upon the *Physics by Inquiry* curriculum (McDermott and The Physics Education Group, 1996). The participants were assigned to three experimental groups (EG1=59 students, EG2=33 students, EG3= 34 students) and a control group (CG=56 students). The CG used PM to conduct the experiments, whereas the EG1 used VM. The EG2 and EG3 used a combination of PM and VM to conduct the same experiments. In the case of EG2, the use of PM preceded the use of VM, whereas, in the case of EG3, the use of VM preceded the use of PM. Conceptual tests were administered to assess students' understanding. The data collected through the pre- and post-tests were analyzed both qualitatively and quantitatively. Findings revealed that PM, VM, and the combination of the two methods appeared to be equally effective in promoting students' conceptual understanding in the domain of *heat and temperature*.

KEYWORDS
Physical manipulatives, virtual manipulatives, conceptual understanding.

INTRODUCTION

During the past decade a series of empirical studies revealed the potential of VM to enhance students' skills, attitudes, and conceptual understanding (e.g., Tao & Gunstone, 1999; Swaak et al., 1998; Triona & Klahr, 2003; van der Meij & de Jong, 2006; Zacharia, 2003; Zacharia & Anderson, 2003; Zacharia et al., 2008). In spite of these findings, some researchers began to seriously question whether laboratory experimentation, as we experience it through the use of Physical Manipulatives (PM), should be redefined and restructured to include VM (e.g., Finkelstein et al., 2005; Triona & Klahr, 2003; Zacharia, 2007).

In contrast to the popularity and potential advantages that the use of VM might contribute to experimentation, are researchers that disapprove the use of VM on the grounds that it deprives students of experiences involving "hands-on" manipulation of concrete/physical materials which are essential for learning (e.g., Lunetta & Hofstein, 1991; NSTA, 1990). According to these researchers, VM should be used for experimentation only when: (a) a 'real' laboratory is unavailable, too expensive or too intricate; (b) the experiment to be conducted is dangerous; (c) the techniques that are involved are too complex for the students; or (d) there are severe time constraints. These perspectives clearly imply that experimenting with VM should be regarded as a surrogate for experimenting with PM and that the use of VM could not be considered as a viable method of experimentation in its own right (Kirschner and Huisman, 1998). On the other hand, the advocates of the use of VM claim that it is manipulation, rather than physicality, as such, that may be the important aspect of instruction (Clements, 1999; Resnick, 1991; Triona & Klahr, 2003; Klahr *et al.,* 2007). Clements (1999) has argued that VM could provide representations that are just as personally meaningful to students as PM and may even be more “manageable, ‘clean,’ flexible, and extensible than their physical counterparts”. He further discussed the need to redefine “concrete” manipulatives to include those digital manipulatives that preserve many of the features of physical manipulatives.

Given this disagreement, a number of questions are raised. For instance, is discriminating against VM experimentation justifiable? Are the two mediums of experimentation equally conducive to learning, particularly, physics learning? Is really manipulation, rather than physicality, as such, the important contributor to learning? In an attempt to answer these questions both the theoretical and empirical underpinnings of the domain (PM versus VM) were examined. Theoretically, even though PM and VM differ in nature, both put the learner in an active role; the use of PM actively engages the learner within a context that is “real”, whereas, the use of VM actively engages the learner within a context that is not “real” but simulates (aspects of) reality. It is difficult to passively experience either PM or VM. In both cases, the learner must process input information, make decisions, monitor progress, and coordinate his/her efforts to accomplish the learning goal(s). This “participatory” element within a learning environment has been advocated by many theoretical perspectives in the educational sciences. John Dewey, Jean Piaget, and Jerome Bruner have all argued that involvement in the learning process is crucial for success. For example, Piaget (1960) emphasized the importance of learning “by doing”; a learning experience should involve “direct” manipulation of materials, and allow individuals to learn on their own and to discover things for themselves. Both PM and VM meet these criteria. Additionally, it is difficult to derive an unambiguous prediction from current major learning or cognitive theories about the effect of manipulation of PM or VM on learning. According to Triona and Klahr (2003), the general assumption that only the use of PM enhances learning is not well-grounded in either constructivist or cognitive learning theory. Constructivist theory emphasizes the importance of learners taking an active role in their own learning, but it does not specifically require physical manipulation. Cognitive theory focuses on the need for learners to actively process information and practice the target skill. However, neither a theoretical nor an empirical justification exists that portrays physical manipulation of materials as a requirement for active processing and practice, unless the target skill is perceptual-motor [see Triona & Klahr (2003) and Klahr *et al.* (2007) for details].

Findings of recent empirical studies in physics education that involved comparisons between VM and PM, although limited, revealed instances where the use of VM would appear to be more beneficial to learning than the use of PM (Finkelstein *et al*., 2005; Zacharia, 2007) and vice versa (Marshall and Young, 2006). In an attempt to examine why the findings of these studies appear to be discrepant to each other, we have taken a closer look at the experimental designs and manipulatives (virtual or real) of these studies, which revealed that the findings vary due to differences in the treatments used in the experimental design of a study (e.g., the method of instruction or curriculum materials were not controlled) or in the affordances that PM and VM could offer. For example, the findings of the Finkelstein *et al.* (2005) study, which revealed that the students that experimented with VM outperformed the students that experimented with PM on a conceptual survey of the domain and in the coordinated tasks of assembling a real circuit and describing how it worked, could be attributed to the fact that only the use of VM (a computer simulation) allowed students to explicitly model electron flow.

In order to arrive at valid conclusions concerning the comparative value of VM and PM in learning, as well as, whether manipulation or physicality is the important aspect of learning, all factors related to the method of instruction/experimentation should be controlled and the manipulatives, virtual or physical, should be stripped of any differing affordances. Needless to say, PM would have an advantage over VM in a study where the acquisition of specific perceptual-motor skills (e.g., exploring the operation of an electromagnetic see-saw or making precise incisions during dissections) is involved, because the difference in movements that are required for manipulating a keyboard or a mouse and an apparatus would interfere with perceptual-motor skills needed in the target domain. On the other hand, experimenting with VM involves virtual manipulation of not only real objects (objects that look and act like their counterparts in the real world, e.g., train) but also of conceptual “objects” (objects that have no perceptual fidelity but are represented visually by using arrows, dot-trails, sounds, and so forth, (e.g. vectors) and (representational) “objects” which represent relations between properties of other objects (e.g., graphs, equations), (Teodoro, 1993). The manipulation of conceptual objects and objects that represent relations between properties of other objects is a unique characteristic of VM. Consequently, in a study where abstract constructs (physical and mathematical, e.g., velocity) are to be manipulated, VM offers additional affordances and hence would have an advantage over PM (Windschilt, 2000).

Therefore, given the theoretical perspectives described above and the contradictory findings of the empirical studies of this domain, the question remains about whether the two modes of experimentation are equally conducive to learning when stripped of their differing affordances. In this study, only the experimentation manipulative – virtual or physical – used in a physics learning environment was contrasted, while controlling their affordances and the method of instruction such that other factors that may influence learning through physics experimentation were the same for both VM and PM.

This study is significant because it could potentially provide further insight on the debate about Virtual versus Physical and Manipulation versus Physicality. Research in this area is particularly scarce across the science education literature (Klahr *et al.*, 2007), especially, physics education (Zacharia *et al.,* 2008). Therefore, any contribution towards this direction is important. For instance, we are far from reaching consensus about the circumstances that the use of PM in physics is preferable to VM and vice versa, as well as, whether their difference, one being virtual and the other physical, promote differences in the physics learning process. Additionally, we are far from understanding what elements or differing affordances of the PM and VM are critical for imparting educational benefit and how VM and PM should be integrated in a physics curriculum.

THIS STUDY

Drawing on the methodological underpinnings of prior research (Klahr *et al.,* 2007; Triona & Klahr, 2003; Zacharia *et al*., 2008) a conscious effort was made to design a study controlling for any variable affecting the experimental design of the study, including, the method of instruction and curriculum materials that, according to Klahr, Triona and Williams (2007), appear to be the most important limitations of the studies that examined the effect of VM on learning. Moreover, the study's manipulatives were carefully selected in such a way so that both could offer the same possibilities for experimentation to the participants.

As a result, this study was contextualized through the *Physics by Inquiry* curriculum (McDermott and The Physics Education Group, 1996) aiming to compare the effect of four instructional conditions that differ only in the medium (e.g., PM) and mode (alone or in combination) of experimentation on undergraduate students' learning in physics, particularly, their conceptual understanding in the domain of heat and temperature. The first condition involved the use of PM (Control Group or CG), the second condition involved the use of VM (Experimental Group 1 or EG1), the third condition involved initially the use of PM and later on the use of VM (Experimental Group 2 or EG2), and the fourth condition involved initially the use of VM and later on the use of PM (Experimental Group 3 or EG3), (see the *Experimental Design* part below for more details). The purpose of including the CG and EG1 was to investigate whether the two modes of experimentation (PM alone and VM alone) are equally conducive to physics learning when stripped of their differing affordances. The purpose of including the EG2 and EG3 was to investigate if switching the medium of experimentation (PM to VM and vice versa), while following the same sequence of instructional activities and conditions as CG and EG1, would have a different effect on students' conceptual understanding than that of CG or EG1, and if so, to also examine whether the influence is different when PM experimentation precedes VM and vice versa. In other words, the inclusion of the EG2 and EG3 aimed to provide evidence on how two sequential combinations of PM and VM experimentation compare between them and to PM and VM alone. Additionally, the comparison of the two sequential combinations to PM and VM experimentation alone could provide information on whether it is possible to combine PM and VM and have a smooth transition from the one medium of experimentation to the other, and if not, to better understand what the consequences are, positive or negative, on students' conceptual understanding in doing so. The nature of transition from the one medium to the other, is also an indicator of equivalency or variance between

VM and PM, thus, making the experimental design and outcomes of the study more informative than just comparing PM alone and VM alone.

METHODOLOGY

Sample

The participants of the study were 182 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 assigned to three experimental groups (EG1=59 students, EG2=33 students, EG3= 34 students) and a control group (CG=56 students).

The students in all groups were randomly assigned to subgroups (two or three persons in each subgroup) as suggested by the curriculum of the study (McDermott & The Physics Education Group, 1996). The particular curriculum is grounded upon a social constructivist framework that facilitates a constructive, situated and collaborative learning process that assures that the engagement is truly collaborative and helps all students make explicit their ideas. Knowledge and understanding is co-constructed among peers through complementing and building on each others ideas.

Curriculum materials: Physics by Inquiry

The selection of the *Physics by Inquiry* curriculum was based on the fact that through numerous studies it appeared to enhance undergraduate students' conceptual understanding across physics subject domains (e.g., McDermott & Shaffer, 1992; Redish & Steinberg, 1999; Zacharia, 2007), including the subject domain of heat and temperature (Zacharia *et al.*, 2008). This success of the *Physics by Inquiry* curriculum is grounded on three foundational components that were found to support conceptual understanding, namely, inquiry, socio-constructivism and the POE (Predict-Observe-Explain) strategy.

For the purposes of this study the first four parts of the module of *Heat and Temperature* were used (McDermott and The Physics Education Group, 1996, p.163). Specifically, the curriculum parts 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), on heat and heat transfer (section 3) and on the concepts of heat capacity and specific heat capacity (section 4).

Physical and Virtual Manipulatives

Physical manipulatives include 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, whereas, virtual manipulatives are regarded 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), and Psillos *et al.* (2000)]. ThermoLab was selected because of its fidelity and the fact that it retained the features and interactions of the domain of Heat and Temperature as PM did. In its open-ended environment, students of the EG1, EG2 and EG3 were able to design and conduct any experiment mentioned in the module of Heat and Temperature by employing the ''same'' material as the ones used by the CG.

Figure 1. Thermolab

Experimental Design

A pre-post comparison study design was used for the purposes of this study that involved four groups, EG1, EG2, EG3 and CG, according to Figure 2. The CG used PM in a conventional physics laboratory throughout the study, whereas, EG1 used VM to conduct the study's experiments on a computer. The EG2 and EG3 used two different sequential combinations of PM and VM to conduct the experiments of the curriculum. The EG 2 used PM in a conventional physics laboratory for section 1 and section 2 whereas for section 4 used VM to conduct the study's experiments on a computer. The EG 3 used VM for section 1 and section 2 whereas for section 4 used PM in a conventional physics laboratory (*Physics by Inquiry* curriculum, McDermott and The Physics Education Group, 1996, p.163). Section 3 of the curriculum did not include any experiments that required experimentation either with PM or with VM.

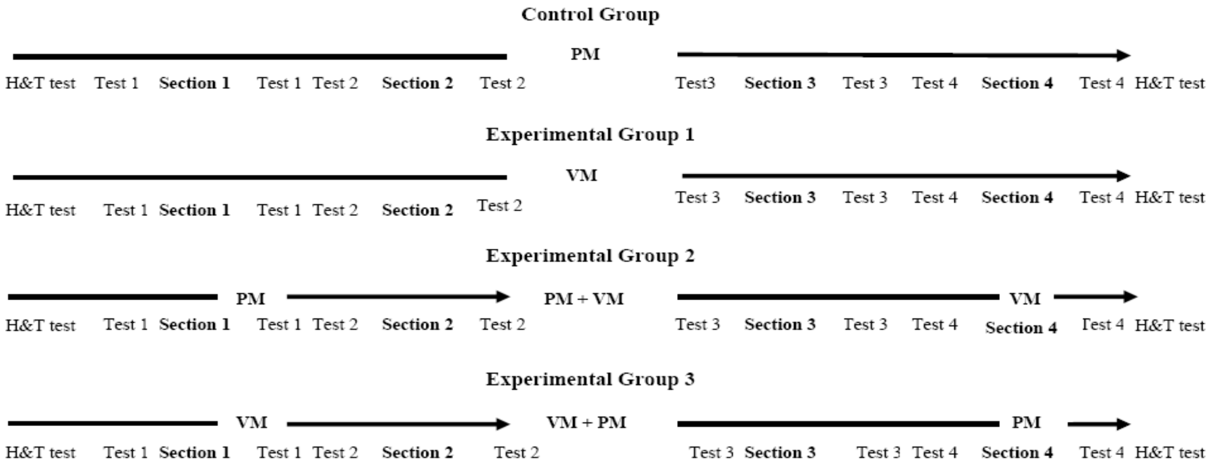

Figure 2. The experimental design of the study

Data Collection

Conceptual tests were administered to assess students' understanding of the concepts of heat, temperature, heat capacity and specific heat capacity, both before and after the study (Temperature, Change in Temperature, Heat transfer, Heat Capacity and Specific Heat Capacity, Test or H&T Test), as well as, both before and after introducing each section (1, 2, 3 και 4) 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). All tests (1, 2, 3, 4) contained open-ended items that asked conceptual questions all of which required explanations of reasoning (see Appendix for a sample of items of Test 2). The H&T test included 6 open-ended items assessing all parts (1, 2, 3, 4) of the study's curriculum, whereas, tests 1, 2, 3 and 4 were used for the assessment of section 1, section 2, section 3 and section 4, respectively. No identical items were included in the H&T

test and the rest of the tests (1, 2, 3, 4). Each item of each test was scored separately; however, a total correct score was derived from each test and used in the analysis.

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 pre-test scores to the post-test scores of each group, (b) ANCOVA for the comparison of the H&T post-test scores of the four groups, and (c) ANCOVA for the comparison of the post tests that were derived from the application of different kind of manipulative. The aim of the first procedure was to investigate whether the use of PM and VM, and the use of PM in two different combinations with VM, within the context of the first four parts 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 substituted or combined with VM. The aim of the third procedure was to investigate whether the substitution of VM for PM or their combination had a different effect on students' conceptual understanding of Heat and Temperature.

The qualitative data analysis focused on identifying and classifying students' scientific and non scientific conceptions concerning temperature, changes in temperature, heat transfer, heat capacity and specific heat capacity. The analysis followed the procedures of open coding (Strauss & Corbin 1996). 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 each section because of the substitution of VM for PM, or because of the different combination that was used. 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 0.8.

RESULTS

The quantitative analysis showed that the two combinations of PM and VM and PM and VM alone improved students' conceptual understanding after the study (see table 1).

Table 1. Paired sample t-test results

Group	Conceptual Tests	t	Df	Sig
CG	H&T Post test – H&T Pre test	24,4	55	.000
EG1	H&T Post test – H&T Pre test	25,2	58	.000
EG2	H&T Post test – H&T Pre test	16,3	32	.000
EG3	H&T Post test – H&T Pre test	14,8	33	.000
CG	Post test 1 – Pre test 1	28,5	55	.000
EG1	Post test 1 – Pre test 1	26.5	58	.000
EG2	Post test 1 – Pre test 1	22	32	.000
EG3	Post test 1 – Pre test 1	27.5	33	.000
CG	Post test 2 – Pre test 2	28.2	55	.000
EG1	Post test 2 – Pre test 2	27.6	58	.000
EG2	Post test 2 – Pre test 2	16.6	32	.000
EG3	Post test 2 – Pre test 2	17.5	33	.000
CG	Post test 3 – Pre test 3	25.3	55	.000
EG1	Post test 3 – Pre test 3	23.8	58	.000
EG2	Post test 3 – Pre test 3	20.6	32	.000

EG3	Post test 3 – Pre test 3	22.1	33	.000
CG	Post test 4 – Pre test 4	22.7	55	.000
EG1	Post test 4 – Pre test 4	21.2	58	.000
EG2	Post test 4 – Pre test 4	17.2	32	.000
EG3	Post test 4 – Pre test 4	20.2	33	.000

The ANCOVA procedure designated that the development of students` conceptual understanding of heat and temperature (difference between pre and post H&T tests) seems to be similar between the four groups, when their pre-existing knowledge is controlled (F(3,177)=1.9, p=0.14). A second ANCOVA revealed the same results regarding the students` performance in the posttest scores of the four groups for the tests 1, 2, 3 and 4 of the study (see table 2). This finding suggests that the use of physical and virtual manipulatives were equally effective in promoting the students' understanding of concepts concerning temperature, changes in temperature, heat transfer, heat capacity and specific heat capacity.

Table 2. One way ANCOVA results

Test	df1	df2	F	Sig.
H&T Test	3	177	1.9	0.14
Test 1	3	177	1.07	0.36
Test 2	3	177	0.04	0.9
Test 3	3	177	1.09	0.35
Test 4	3	177	0.74	0.52

The qualitative analysis (open coding) revealed that the conceptions of CG and EG1, EG2, and EG3 appeared to be organized in ten categories (see Table 3): (1) temperature measurements of materials at the same environment, (2) temperature as an intensive quantity, (3) thermal interactions and changes in temperature, (4) thermal interaction of water and ice, (5) proportional reasoning in heat transfer, (6) changes in temperature after heat transfer, (7) heat capacity and specific heat capacity in changes in temperature, (8) factors that affect heat transfer, (9) how specific heat capacity affects changes in temperature, (10) thermal interactions between several materials and calculation of heat transfer and of changes in temperature.

The qualitative analysis revealed that all groups shared mostly the same conceptions either scientifically accepted or not, both before and after the research intervention (see Table 3). The prevalence of each conception does not seem to differ between the four groups. In all parts of the study, a shift was observed from the non-scientifically accepted conceptions to the scientifically accepted conceptions. This finding complies with the results of the quantitative analysis.

DISCUSSION & CONCLUSIONS

The findings of this study indicate that the use of PM and VM, and their combination when used in the framework of the Physics by Inquiry curriculum and when controlling as completely as possible the range of variables that influence the learning process and outcomes, can provide equally interactive experiences that enhance students understanding of concepts related to heat and temperature. Both the quantitative and qualitative analysis showed that the learning outcomes regarding conceptual understanding do not change substantially when PM are substituted by VM in the domain of heat and temperature, while controlling for the method of instruction, the curricular materials and the resource capabilities afforded by PM and VM. This provides further credence to the idea that VM can be used (in some contexts and given specific conditions) to provide authentic laboratory experiences that are not substantially different to the methods employed in using PM. However, this call for reform creates the need for understanding how both modes of experimentation should be integrated in activity sequences for physics teaching and learning.

On the whole, it is essential to expand the empirical base through similar research in order to test further these perspectives as well as to ground theoretical conjectures regarding a framework for integrating PM or VM within physics learning environments.

Table 3. Sample of students` conceptions in the domain of heat and temperature

The most dominant conceptions	**CONTROL GROUP**		**EXPERIMENTAL GROUP 1**		**EXPERIMENTAL GROUP 2**		**EXPERIMENTAL GROUP 3**	
	Pre tests % (n)	***Post tests % (n)***	***Pre tests % (n)***	***Post tests % (n)***	***Pre tests % (n)***	***Post tests % (n)***	***Pre tests % (n)***	***Post tests % (n)***
Conception 1 Materials that are in the same environment for hours do not have the same temperature. In order to find their temperature several measurements must be taken.	71% (40)	5% (3)	70% (41)	7% (4)	73% (24)	15% (5)	71% (24)	12% (4)
Conception 2 The temperature depends on the mass of each material (the temperature is proportional to the mass of each material).	23% (13)	0% (0)	39% (23)	12% (7)	21% (7)	3% (1)	15% (5)	0% (0)
Conception 3 Appropriate calculations regarding temperature changes in thermal interactions of different samples of water (different masses and different temperatures).	7% (4)	30% (17)	12% (7)	41% (24)	12% (4)	39% (13)	6% (2)	41% (14)
Conception 4 Water and ice cannot coexist at the same temperature.	70% (39)	16% (9)	76% (45)	24% (14)	15% (5)	6% (2)	32% (11)	12% (4)
Conception 5 Proportional reasoning in tasks out of the concept of heat and temperature.	14% (8)	39% (22)	9% (5)	34% (20)	21% (7)	39% (13)	21% (7)	35% (12)

Conception 6 When two samples of water are heated with the same hot plate for the same time they do not have the same change in temperature, because the bigger mass has the bigger change in temperature.	71% (40)	20% (11)	80% (47)	17% (10)	55% (18)	12% (4)	56% (19)	6% (2)
Conception 7 When iron, aluminium and water are heated above the same hot plate for the same time, iron will have the highest temperature change because of its low specific heat capacity	32% (18)	66% (37)	24% (14)	64% (38)	18% (6)	73% (24)	6% (2)	44% (15)
Conception 8 The amount of heat transferred from a hot plate to a sample of a material, depends on the kind of the material.	45% (25)	23% (13)	41% (24)	22% (13)	33% (11)	12% (4)	50% (17)	12% (4)
Conception 9 When the same masses of iron and water interact thermally, iron changes its temperature 10 times more than water does.	20% (11)	50% (28)	31% (18)	49% (29)	18% (6)	52% (17)	9% (3)	53% (18)
Conception 10 Appropriate calculations regarding the heat transferred and the changes in temperature in thermal interactions between several materials.	20% (11)	50% (28)	31% (18)	49% (29)	18% (6)	52% (17)	9% (3)	53% (18)

REFERENCES

Clements, D. (1999). ‘‘Concrete’’ manipulatives, concrete ideas. Contemporary Issues in Early Childhood, 1, 45–60.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., Reid, S., and 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.

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

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

Klahr, D., Triona, L. M. and Williams, C. (2007). Hands on What? The Relative Effectiveness of Physical Versus Virtual Materials in an Engineering Design Project by Middle School Children. Journal of Research in Science Teaching, 44, 183–203.

Lefkos, I., Psillos, D. and 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. and Hofstein, A. (1991). Simulations and laboratory practical activity. In B. E. Woolnough (Ed), Practical science (pp. 125–137). Milton Keynes: Open University Press.

Marshall, J.A. and Young, E.S. (2006). Preservice Teachers’ Theory Development in Physical and Simulated Environments. Journal of Research in Science Teaching, 43, 907-937.

McDermott and the Physics Education Group at the University of Washington, (1996). Physics by Inquiry, Volume II. Wiley, New York.

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. Am. J. Phys. 60, 994-1002.

National Science Teachers Association. (1990). Position statement on laboratory science, Retrieved July 6, 2005 from: http://www.nsta.org/positionstatement&psidO16(1990).

Piaget, J. (1960). The child's conception of physical causality, New Jersey: Littlefield, Adams.

Psilos, D., Argirakis, P., Vlahavas, I., Hatzikraniotis, E., Bisdikian, G., Refanidis, I., Lefkos, I., Korobilis, K., Vrakas, D., Galos, L., Petridou, E. and 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).

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

Resnick, B. L. (1991). Shared Cognition: Thinking as Social Practice. In L.B. Resnick, J.M. Levine and S.D. Teasley (eds.), Perspectives on Socially Shared Cognition (pp. 1-20). Washington, D.C: American Psychological Association.

Rosenquist, M., Popp, B. and 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.

Strauss, A. and Corbin, J. (1996). Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. London: Sage Publications.

Swaak, J., van Joolingen, W. R. and de Jong, T. (1998). Supporting simulation-based learning; the effects of model progression and assignments on definitional and intuitive knowledge. Learning and Instruction, 8, 235-253.

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.

Teodoro, V. (1993). A model to design computer exploratory software for science and mathematics. In D. Towne, T. de Jong and H. Spada (Eds.), Simulation-based experiential learning (pp. 177–190). Berlin: Springer-Verlag.

Triona, L. M. 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(2), 149- 173.

van der Meij, J. and de Jong, T. (2006). Learning with multiple representations: Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. Learning & Instruction, 16, 199-212.

Windschilt, M. (2000). Supporting the development of science inquiry skills with special classes of software. Educational Technology Research and Development, 48, 81–95.

Zacharia, C. Z., Olympiou, G. and Papaevripidou, M. (2008). Effects of Experimenting with Physical and Virtual Manipulatives on Students` Conceptual Understanding in Heat and Temperature. Journal of Research in Science Teaching, 45(9), 1021-1035.

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(8), 792-823.

Zacharia, Z. and Anderson, O. R. (2003). The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students’ conceptual understanding of physics. American Journal of Physics, 71(6), 618–629.

Zacharia, Z. C. (2007). Comparing and Combining Real and Virtual Experimentation: An Effort to Enhance Students’ Conceptual Understanding of Electric Circuits. Journal of Computer Assisted Learning, 23(2), 120-132.

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