ENHANCING FOURTH GRADERS' ABILITY TO INTERPRET GRAPHICAL REPRESENTATIONS THROUGH THE USE OF SENSORS IN THE CONTEXT OF PHASE TRANSFORMATIONS (MELTING AND FREEZING)

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ABSTRACT

Sensors constitute a powerful tool in physical science as far as the rapid collection and analysis of data is concerned. In addition to the rapid collection of data, sensors are valued for their capability in the simultaneous representation of this data in the form of a graphical plot. Previous research has shown that elementary school students encounter various difficulties in their attempt to construct and interpret graphs. This article reports on a research effort through which we aim to investigate whether the use of sensors in the specific context of phase transformations (melting and freezing) contributes to the development of fourth grade (9-10 year old) students' ability to interpret, comment on and explain graphs. The subjects of the study were sixty five (65) 4th grade students (organized into an experimental and two control groups) studying at two technologically well-equipped public elementary schools in Larnaca and Nicosia. Data collection was accomplished through a specially designed pre-test and post-test, which were administered to the students before and after instruction, respectively. The implementation of inquiry-based (reconstructed curriculum) lessons, which incorporated the use of instructional technology in the experimental group as opposed to the application of traditional lessons in the first control group and the application of the reconstructed curriculum without the use of computer resources in the second control group, revealed a statistically significant difference between the experimental group and both control groups in students' understanding of phase transformations as well as their ability to interpret graphs. In view of these findings we elaborate on the sequencing of instructional materials that aim to develop conceptual understanding concerning the phenomena of melting and freezing. The findings of this research suggest that there is a significant added value in employing sensors in an instructional effort to enhance students' ability in interpreting graphs and as a tool that enhances learning in the specific context of natural sciences.

KEYWORDS

Data-logging, microcomputer-based laboratories (MBL), sensors, melting and freezing, phase transformations, graphical representations, graphs

INTRODUCTION

Interpreting graphs is a learning objective of great value if students are to be considered as thinking participants in a society (Wavering, 1989). The domain chosen in this research project (states of matter, phase transformations such as melting, freezing, boiling, evaporation) is one in which children have the opportunity to observe important everyday phenomena. Moreover, the practical investigation in the unit of phase transformations that concentrates on the measurement of temperature and the simultaneous representation of the data in the form of a table and a line graph is investigating a physical variable to which the children are directly sensitive so that their recordings, displayed dynamically on the computer screen and their own direct sensory experience are contiguous. An excellent way to guide students to develop an appropriate graph schema and linkages between graph, concept, and real-world phenomena

in laboratory settings, where they generate their own data and graphs, is through the use of sensors and data logging (Brasell, 1990).
The present research took place over the second and third term of 2003. Three fourth grade classes (one experimental and two control groups) in two primary schools were identified. The subject matter chosen was the unit "phase transformations (melting and freezing)" from the Natural Science Curriculum of the Cyprus Ministry of Education and Culture, for fourth grade. An epistemological analysis, in which pre-requisite knowledge was identified, preceded the reconstruction of this curriculum unit. The basic aim of the research was to investigate whether implementing the reconstructed curriculum unit has a positive effect on students' understanding of melting and freezing (first research question), and whether using sensors for real time analysis of data and the simultaneous presentation of this data on a table and graph improves students' understanding of melting and freezing (second research question) and their ability to interpret graphical representations (third research question).

THEORETICAL PERSPECTIVE

"Graphs are powerful as a visual display of quantitative information and they are particularly effective in communicating relationships. They are a powerful and flexible medium for a wide variety of tasks, from describing data and revealing relationships to communicating comparative results" (Brasell, 1990, p.69). Graphs are used in science as tools to display data and aid in the analysis of relationships between variables, as a result, they have become a part of our daily existence with their common use in all media.

The significance and value of understanding graphs is identified by Wavering, who argues that "in order for students to be thinking participants in society, they need to understand graphs" (p. 373). According to Brasell (1990) "the ability to use graphs is an important basic process skill. Along with literacy, numeracy, and articulateness, it is considered one of the basic intellectual skills" (p.74). It is therefore not surprising that graphing is generally taught in science programs at the elementary level.

Previous research has shown that elementary school students encounter various difficulties in their attempt to interpret relationships between variables and to construct and interpret bar or line graphs (Swatton and Taylor, 1994; Taylor and Swatton, 1990 cited in Mcfarlane et al, 1995). "Students have difficulties making connections among graphs of different variables and making connections among physical concepts and the real world. They also often perceive graphs as just a picture" (Linn and Nachmias, 1987; McDermott, Rosenquist and van Zee, 1987, cited in Svec, 1999). Brasell identified three main types of difficulties in students' understanding and use of a specific graphing representation: difficulties associated with (a) concepts, (b) grammar and (c) linkage (Brasell, 1990). Research has also indicated that "pupils tend to find difficulty in reading analogue scales correctly" (Rogers, 1995, p.33) and in "describing the relationship between variables in a generalized manner, which is the key to developing scientific ideas from the graphs" (Rogers, 1995, p.36). As far as students' ability to construct and interpret graphs, line graphs, compared with other types of graphical representations, are the most difficult to interpret because of the sparseness of information and their more abstract representation (Wavering, 1989).

The value of sensors

"Researchers who are concerned with the students' misconceptions of graphs and the quality of their performance maintain that students can only develop an appropriate graph schema and linkages between graph, concept, and real-world phenomena in labs where they generate their own data and graphs." (Brasell, 1990, p.83). The use of sensors and data logging (also referred to as "Microcomputer-Based Labs-MBL") provides an excellent way to accomplish that. Sensors constitute a powerful tool in physical science as far as the rapid collection and analysis of data is concerned. In addition to the rapid collection of data, sensors are valued for their capability in the simultaneous representation of this data in the form of a graphical plot. The value of sensors lies in the fact that "the contiguous experience of manipulating variables, while watching a dynamic graphical representation between those variables in real time, provides a concrete link between these abstract concepts" (Taylor and Swatton, 1990) and helps students to explore the connection between graphing skills and learning science concepts (Svec, 1999).

Microcomputer-based labs automate the procedures of collecting data and constructing graphs, and they have also proven very effective in improving graphing skills. (Brasell, 1990). Several characteristics contribute to their effectiveness:

a) students have the opportunity to visualize the elements of graph construction in a way that is complementary to having to draw their own graphs. Additionally, most computer programs provide the capability of altering parameters of the graph, hence they can concentrate on the overall features without getting lost in the details.

b) by predicting the graph and then directly confronting possible discrepancies between their predictions and the actual outcomes, students learn about the fundamental properties of graphs and concepts.

c) real-time graphing, made possible by computers, helps to make the abstract properties being graphed behave as though they were concrete and manipulable. Displaying a graph at the same time as the real-world event generating the data helps students establish a cognitive link between the event and those properties (Brasell, 1990). In other words, "the graph is more easily associated with the phenomena it represents" (Rogers, 1995, p.31).

In addition to these, Rogers (1995) refers to the fact that in the use of sensors "qualitative display precedes quantitative analysis. This is less complex than the traditional process, which requires the management of numerical data as a pre-requisite of the graphical display". Moreover, "freed from the need to record the data item by item, pupils have more time to make careful observations of the phenomena in the experiment" (p.31) and to relate those to patterns in the graph. It is argued that these attributes have great potential in shifting the emphasis in pupils' activity away from the collection of data and towards interpretation. Interpretation skills refer to viewing the graph qualitatively, reading, describing and relating values and making predictions. MBLs also allow more time to be spent interpreting data than is common in conventional labs. In other words "they allow students to use graphs as a milestone instead of the end point of an investigation" (Brasell, 1990, p.83).

Not many researchers investigated the impact of the use of sensors in the context of a science investigation. Mcfarlane et al. (1995) monitored the impact of data logging on the development of children's ability to read, interpret and sketch temperature/time graphs in classes of seven and eight-year-olds. The results of their research suggest that seven and eight year old students who have been exposed to data logging showed an increased ability to read, interpret and sketch line graphs when compared to students of the same age who had performed the same investigations using traditional apparatus.

Svec (1999) demonstrated that MBL and its use of graphs have been shown to improve understanding of science concepts, content knowledge specific to graphing problems and graphing skills of middle school, high school and college students. Svec's research indicates that "MBL provides an excellent medium for helping students develop a more thorough understanding of natural phenomena" since his results indicate significant differences between a traditional laboratory and a Microcomputer-Based Laboratory.

Context difficulties and misconceptions

According to Piagetian theory we might expect children at the elementary school level to have difficulties with the abstractions of the graph symbol system, and possibly even temperature as a measurable phenomenon (Erickson, 1985). Tiberghien (1993) argues that "very often the idea of temperature is not taught as such, except for the temperature of change of state. Most pupils (80%) aged between 10 and 13 do not know about the stability of the temperature of change of state of water or ice unless they have already been taught about it." (p.67) Moreover, the same research indicates that students think that ice has the *property* of melting or of cooling something, and very seldom do they consider that the ice itself can warm, heat or cool, i.e. it can change temperature.

According to Driver (1998), research suggests that only 70% of 10-year-old students support the idea of the conservation of mass when observing a solid material object turn into liquid. The rest of them may think that the mass of the solid material object is reduced. The same idea, that the conservation of mass holds considerable conceptual difficulties for pupils, is supported by Andersson (1990). Cosgrove and Osborne (1980) cited in Driver et al (1998) have found that many students of age 8-17 thought that the phenomenon of melting is similar to the one of dissolution because the former is also a procedure that is gradually taking place and it is almost irrelevant to a specific temperature (melting point). The same research also indicated that students do not consider that a phase change is connected to a specific temperature as far as freezing is concerned.

Despite the fact that "scientists recognize that when an object is heated, its temperature increases except if there is a physical or chemical transformation, the causal relation "when a substance is heated, its temperature increases" is not recognized systematically by all pupils. For some of the pupils, this relation depends on the substance." (Tiberghien, 1993, p.70)

CURRICULUM DEVELOPMENT

We chose to teach the topic of changes of state for several reasons: (a) it involves investigation of a physical quantity to which the children are directly sensitive so that their recordings, displayed dynamically on the computer screen and their own direct sensory experience are contiguous (b) there are no conflicts with the Cyprus National Curriculum for Science for this age group, (c) there is no requirement for additional specialist equipment for the parallel non-computer based activities of the second control group, and (d) the investigation involved a dynamic change, which was reliably reproducible in the classroom.

Epistemological Analysis of the Concepts of Melting and Freezing.

An epistemological analysis, preceded the reconstruction of this curriculum unit in which pre-requisite knowledge was identified. Specifically, it is considered that in order for students´understanding of phenomena of melting and freezing to take place, students need to differentiate among the *states of matter* and then to understand the concept of *heating*. At the next level, students need to be able to understand the role of measurement as a procedure for finding the value of a specific quantity at an instant in a situation. They also need to develop a reliable procedure for making temperature measurements and to construct an operational definition of the concept of room temperature, (in order to safeguard real understanding of this concept. They should then experience the results of providing heat to a material object and identify the different effects of heating, namely burning, changes in temperature and phase changes. By identifying differences and similarities between chemical and physical changes, students can realize that one of the characteristics of the latter is reversibility. At this stage in the learning process, students have the pre-requisite background to begin to differentiate between the concepts of heat and temperature. Only after achieving this can they develop a full understanding of melting and freezing as phenomena that can be controlled for numerous substances.

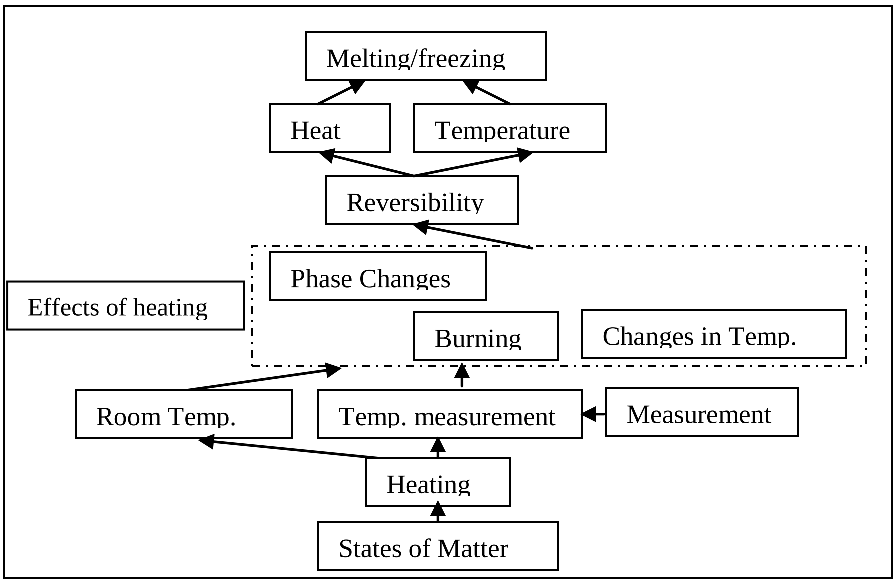

Figure 1: Epistemological Analysis

Learning Objectives
Following the epistemological analysis of the content of the unit, we then formulated learning objectives as follows: Students should: (a) gain experiences related to *phase transformations (melting and freezing),* (b) understand that melting and freezing are reversible phenomena (physical change), (c) be able to measure temperature using sensors, and (d) design and interpret a graphical representation of temperature and time.

It is important to note that there had been no formal instruction related to the convention for data presentation in a line graph in the fourth grade curriculum up to this point. However, the use of graphs is so widespread in the mass media that it is likely that the children had seen such diagrams previously. Formal instruction on the use of bar charts had taken place. The students did not have any previous experience using a data logging system or sensors but they were familiar with using the keyboard and mouse to perform basic functions in a graphical user interface.

Sample
The research was conducted in three fourth grade classes (students of 9-10 years of age) of two primary schools situated in Larnaca and Nicosia during the second and third term of 2003. In the primary school in Larnaca one class was nominated by the school to be the experimental class (N=23 students) with sole access to portable computers and data logging equipment and the parallel class formed the first control group (N=20 Students), which followed the lesson strictly as this is described in the Natural Science National Curriculum of the Cyprus Ministry of Education and Culture. The class in the Nicosia primary school which formed the second control group (N=22 students) followed the same activities and worksheets as the experimental group but used non-computer based resources and had no access to portable computers. All three groups were taught by the same teacher. Data was collected through specially designed pre- and post-tests which were administered to students before and after instruction, respectively.

Project curriculum for the three groups
Table 1 shows the sections of the teaching intervention for each of the three groups. The content of each intervention is further analyzed below.

Table 1: Sections of the teaching intervention for each group

Sections	Experimental group	Control group 1	Control group 2
Temperature measurements	√	-	√
Use of sensors to measure temperature	√	-	-
Use of thermometers to measure temperature	√	-	√
Predictions and their verification in a graphical form	√	-	√
Results of providing heat to material objects	√	√	√
Interpretation of line graphs [temp=f (time)]	√	-	√
Control of the variable of mass on melting time	√	√	√
Control of the variable of heat on melting time	-	√	-
Design of melting and freezing experiments with given materials	-	√	-
Definition of melting and freezing	√	√	√
Examples of melting and freezing in everyday life	√	√	√

Project Curriculum: experimental group
The reconstructed curriculum unit comprised of four main subunits taught in four independent lessons of eighty minutes each. In the first two subunits, students were encouraged to make predictions and verify their correctness concerning the expected form of graph, through experimentation with the sensor placed in water that was (a) at room temperature (stable temperature), (b) continually heated up (increase of temperature) and (c) cooled down (decrease of temperature). This gave a concrete

introduction to the link between the events which occurred and the representation of those events in a line graph. In the worksheets we developed, students were asked to compare the graph they obtained with the one they expected and make inferences concerning the accuracy of their predictions. In the third section, students explored the results of providing heat to various material objects (paper, metal and candle) and differentiated between physical and chemical change. They also arrived at the definition of melting and freezing. Finally, in the fourth section, students interpreted line graphs that showed the relationship between the variables of temperature and time while a quantity of matter is melting or freezing and examined the effect of increasing or decreasing the mass on the time needed for it to melt. Examples of melting and freezing in every-day life were also given.

The experimental group was divided into five mixed-ability groups, each of which had a portable computer and data logging system. The software used is "Sensing Primary Science" (http://www.data-harvest.co.uk/datalogging/pri_sscience.html). Strategies for managing the computers and related equipment in the classroom were decided and implemented.

Project curriculum: first control group

The first control group was taught strictly following the corresponding lesson plans provided in the Natural Science Curriculum of the Cyprus Ministry of Education and Culture. Students suggested ways in which they could transform solids into liquids and designed experiments with given materials. They arrived at the definition of melting through a teacher led discussion. Students were led to the conclusion that "when a solid object is heated one possible outcome is that its state will be transformed into liquid". An identical procedure was followed for the concept of freezing. Examples of melting and freezing in every-day life were given. Students also investigated two factors that affect the time needed for a material object to melt: a) the amount of heat provided and b) the quantity of the matter. It is interesting to note that the activities described are actually planned for an eighty-minute lesson while in our research project the same activities were carried out in two eighty-minute lessons. The lessons were based on simple observations and did not include the use of any instruments to measure temperature.

Project curriculum: second control group

The activities followed by the second control group paralleled those of the experimental group since the students carried out the same activities and investigation, using conventional instruments (thermometers). Graphs were produced by plotting each measurement directly on to a given chart. To make recordings over time the second control group periodically recorded temperature measurements on a table at the teacher's probe. The students then used pre-drawn axes to plot points directly onto the graph.

RESULTS

Students' responses to the pre- and post-test were analyzed, using phenomenography, and evaluated. The answers were categorized as false (score=0), partially correct (score=1) and correct (score=2). In order to address the research questions formulated for this study One-Way ANOVA and Paired-Samples T-test was conducted. More specifically, (a) One-Way ANOVA was used to analyze (i) the achievement of the three groups on the pre-test to verify equivalence of groups and (ii) the achievement of the three groups on the post-test to identify differences among them, and (b) Paired-Samples T-test was used to compare the achievement of each group on pre- and post-test in order to determine whether the learning objectives of the redesigned curriculum had been achieved.

Equivalence of the three groups:

Results of the One-Way ANOVA analysis on students' performance in the pre-test are shown in table 2:

Table 2. ANOVA pre-test

SCORE	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	128.619	2	64.309	0.877	0.421
Within Groups	4545.781	62	73.319		
Total	4674.400	64			

One-Way ANOVA, carried out across groups, revealed differences that were not statistically significant with an F-value of 0.877 and a p-value of 0.421 (>0.001). The Scheffe test for homogeneity of variance indicated that there is no statistically significant difference when any given combination of groups is compared (mean difference of the experimental group and the control group 1= 1.43, mean difference of the experimental group and the control group 2 = 3.37, mean difference of control group 1 and control group 2=1.94 with all p-values greater than 0.05). Therefore, it is safe to assume that the three groups were equivalent prior to teaching.

Comparing achievement in post-test

Table 3 shows the results of the One-Way ANOVA analysis on students' performance in the post-test, where the F-value is 11.596 and the p-value is 0.000 (<0.01), which shows a statistically significant difference between the three groups.

Table 3. ANOVA for post-test

SCORE	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3285.098	2	1642.549	11.596	0.000
Within Groups	8782.041	62	141.646		
Total	12067.138	64			

The Scheffe test for homogeneity of variance indicated that there is a statistically significant difference between both (a) the experimental group and the control group 1 at the 0.05 level (mean difference=16.55), and (b) the experimental group and the control group 2 at the 0.05 level (mean difference=12.64).

Comparing students' performance in pre- and post-test

The results of the Paired-Samples T-Test analysis on students' performance on the pre-test compared to their performance on the post-test are shown in table 4.

Table 4. Paired Samples t-test for each class separately, on the pre- and post-test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Experimental group	**mean1 – mean2**	-0.5585	0.23034	0.04803	-0.6581	-0.4589	-11.628	22	0.000
Control 1	**mean1 - mean2**	-0.1305	0.28003	0.06262	-0.2616	0.0005	-2.085	19	0.051
Control 2	**mean1 - mean2**	-0.3101	0.32691	0.06970	-0.4550	-0.1651	-4.449	21	0.000

The mean difference of students' performance on the pre- and the post-test is statistically significant with a p value=0.000 (<0.05) both for the experimental and the control group 2. Table 4 also indicates that the mean difference of students' performance on the pre- and the post-test is not statistically significant, with p value=0.051 (>0.05) for the control group 1.

Analysis of students' responses in identical test items in the pre- and post-test

Multiple T-Test analysis was performed in order to identify any differences on students' performance on each item identical in the pre- and post-test. In table 5 the "✓" symbol indicates a statistically significant difference. The "-" symbol indicates differences that were not statistically significant between pre- and post-test.

Table 5. Paired Samples T-Test on each test item (pre- and post-test)

Group / Tasks	**Experimental**	**Control 1**	**Control 2**
Increase/decrease of mass and its effect on melting	✓	-	-
Effects of heat on different materials	✓	✓	✓
Construction of a table	✓	✓	✓
Construction of a graph	✓	-	✓
Combining information from a table and a graph	-	-	-

The results shown in table 5 indicate that the overall performance of the experimental group can be characterized as superior compared to the performance of both control groups 1 and 2. It is worth mentioning that none of the groups has shown a statistically significant difference as far as the item that refers to "combining information from a table and a graph" is concerned and that all three groups have shown a statistically significant difference as far as the tasks that refer to the "effects of heat on different materials" and the "construction of a table" are concerned. The fact that the control group 1 did not have a statistically significant difference in the pre- and post-test score (table 4) does not imply that the gains resulting from the instructional effort were minimal. As shown in table 5, the control group 1 has shown a statistically significant difference in two of the five tasks.

Comparing students' performance on constructing and interpreting graphs

Table 6. ANOVA for items related to graphs understanding

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	6.143	2	3.072	15.312	0.000
Within Groups	12.437	62	0.201		
Total	18.580	64			

A One-Way ANOVA carried out across groups was found to be statistically significant with an F-value of 15.312 and a p-value <0.001. The Scheffe test for homogeneity of variance indicated that there is a statistically significant difference between the experimental group and both the control groups 1 and 2. The mean difference of the experimental group and control group 1, and the experimental group and control group 2 is 0.7126 and 0.5525, respectively, at a level of 0.05. The Scheffe test for homogeneity of variance indicated that there is not a statistically significant difference between the control groups 1 and 2. The mean difference of the control group 1 and the control group 2 is -0.1601.

Students' reactions.

Students' reactions and attitudes towards the integration of technology, and specifically sensors, in the curriculum were assessed through a specially designed questionnaire. The questionnaire was administered to the experimental group after the teaching intervention. The following table includes the percentage of students supporting each idea:

Table 7. Experimental group: students' reaction and attitudes

Ideas	**Percentage (%)**
Ease of sensors' use	79.35
Value of computers in understanding the content	84.06
Usefulness of computers	89.86
Usefulness of sensors	73.91
Value of sensors in understanding graphs	93.48
Value of computers in facilitating collaborative learning	71.74

DISCUSSION

The first research question refers to the value, if any, of reconstructing the curriculum unit of melting and freezing. After the confirmation of the equivalence of all three groups (see table 2), a comparison of students' scores at pre- and post-test was feasible. The analysis showed that there is a statistically significant difference between the mean score of students at pre test compared to their score at post test both in (a) the experimental and (b) the control group 2 (table 4). This indicates that the reconstruction of the curriculum was valuable and produced measurable improvement in the learning outcomes. Consequently, students' mastering of the concepts that have been identified by the epistemological analysis can be considered as a pre-requisite for students' understanding of the phenomena of melting and freezing.

Moreover, the superiority of the reconstructed curriculum is reinforced by the analysis shown in table 5. Students' performance on the item related to the "construction of a graph" had a statistically significant difference in both the experimental group and control group 2 and students' performance on the item related to the "increase/decrease of mass and its effect on melting" had a statistically significant difference in the experimental group. The fact that all three groups have shown statistically significant improvement concerning the item "effects of heat" indicates that both the reconstructed curriculum and the traditional curriculum were successful in that particular objective.

The second research question refers to the value of implementing new technologies and specifically sensors in (a) students' understanding of the phenomena of melting and freezing. After the confirmation of the equivalence of all three groups, a comparison of students' achievement in post-test was justifiable. The analysis of the results indicated that there is a statistically significant difference between the experimental group and both control groups (see table 3). It is therefore safe to conclude that there is a significant added value in employing sensors as a tool that enhances learning in the specific context of Natural Sciences.
This finding of the present research contradicts Brasell's (1990) suggestion that "experience with graphing activities improves graphing skills whether the activities are demonstrated-discussion, simulation, hands-on laboratory or microcomputer-based laboratories" (p.83).

The third research question refers to the value of implementing sensors in students' ability to construct and interpret graphical representations. A repetition of the analysis that was used for the second research question including only the items evaluating students' performance on graphs showed that there is a statistically significant difference between the experimental group and control groups 1 and 2 (see table 6). Consequently, there is a significant added value in employing sensors in an instructional effort to enhance students' ability in interpreting graphs.

“Comprehending most graphs requires that the reader relate information represented elsewhere, e.g. in a data table and the ease of translating from one format to another depends on the reader’s comparative familiarity with the given formats” (Brasell, H. M., 1990, p.76). When students’ performance concerning “combining information from a table and a graph” was assessed (see table 5) none of the three groups showed a statistically significant difference. A hypothesis of the present research was that when students are instructed on how to extract information from (a) a table and (b) a graph, the two procedures being independent, they will subsequently be able to combine information from those two sources, when faced with a question whose answer can only be given when using both sources. This hypothesis was not verified by the results of the research. It can therefore be assumed that there is a need for improving the curriculum in terms of the development of this ability.

The fact that all three groups have shown a statistically significant difference concerning the students’ performance on the item “construction of a table” (see table 5) demonstrates that all three groups did have learning gains out of their corresponding interventions.

Students’ reactions.
Students’ reactions and attitudes towards the integration of technology, and specifically sensors, in the curriculum can be characterized as extremely positive (see table 7). As expected, students found no difficulty in their use of sensors. The vast majority of students (above 90%) were positive in their appreciation of the value of sensors in understanding graphs. Students also seemed to value the usefulness of computers as well as their value in understanding concepts. The majority of students also identified the value of computer technology in facilitating collaborative learning.

CONCLUSION

Rogers argues that data-logging software offers significant benefits towards helping pupils overcome a range of difficulties in using graphical techniques. However, these software tools and the skills to use them are not enough on their own. Misconceptions cannot be removed by mere “exposure” to the information contained in graphs. Fortunately, “the computer is good at providing time because it performs its tasks so rapidly and it frees students to devote more attention to observation, reflection and discussion.” (Rogers, 1995, p.39).

Data-logging is merely an electronic method of gathering and recording physical measurements. However its value in practical science refers not in the process of automated data gathering but in the processes of analyzing and interpreting the data. With data-logging, the graph is a starting point for thinking. “The graph need no longer be regarded as the end-product of an investigation as often occurs in conventional practice. It is important to recognize the implications of this for the design of classroom activity; it provides new opportunities but also new challenges.” (Rogers, 1997, p.61).

It is therefore necessary for teachers to challenge students with key questions by which the graph is considered as a resource and starting point for thinking activity rather than an end point of lesson activity. Developing students’ graphical skills through the use of sensors requires extra time and effort, but on the other hand, graphing skills can help students learn difficult science concepts. It is therefore worthwhile to spend some time along the way nurturing graphing competence in order to enhance students’ skills in learning, analyzing, and communicating.

FUTURE RESEARCH

Directions for future research may include a repetition of the present study by developing and integrating activities that enrich students’ graphing skills as well as their understanding of the functions of graphs. Examples of these activities include encouraging students to ask questions during the process of interpreting, comparing and reflecting on graphs, derive inferences, draw conclusions, formulate hypotheses and communicate ideas through both group and whole class interaction. The curriculum will need continuing improvements particularly with respect to the skill of combining information from two separate sources.

REFERENCES

Andersson, B. (1990) Pupils' Conceptions of Matter and its Transformation (age 12-16). *Studies in Science Education.* 18, pp. 53-85.

Brasell, M. H. (1990). Graphs, Graphing and Graphers. In Rowe, B. M. (ed) The Process of Knowing. Washington D. C.: National Science Teachers Association.

Driver, R., Guesne, E., and Tiberghien, A. (1985), Children's Ideas in Science. Milton Keynes: Open University Press.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making Sense of Secondary Science: Research into Children's Ideas*. London, UK: Routledge.

Erickson, G. L. (1985). Heat and Temperature. Part A, An Overview of Pupils' Ideas. In Driver, R. (ed.) Children's Ideas in Science. Milton Keynes: Open University Press.

McFarlane, A. E., Friedler, Y., Warwick, P. and Chaplain, R. (1995). Developing an Understanding of the Meaning of Line Graphs in Primary Science Investigations, Using Portable Computers and Data Logging Software. *Journal of Computers in Mathematics and Science Teaching.* 14 (4), 461-480.

Rogers, T. L. (1995). The Computer as an Aid for Exploring Graphs. *The School Science Review*, 76(276), 31-39.

Rogers, T. L. (1997). New data-logging tools-new investigations. School Science Review, 79 (287), 61-68.

Taylor, R. M. & Swatton, P. (1990) Assessment Matters: No. 1, Graph Work in School Science. London, England: Her Majesty's Stationery Office.

Tiberghien, A. (1993). The Development of Ideas with Science. In Driver, R. (ed) Children's Ideas in Science. Milton Keynes: Open University Press.

Wavering, M.J. (1989). Logical Reasoning Necessary to Make Line Graphs. *Journal of Research in Science Teaching.* 26 (5), 373-379

Svec, M. (1999). Improving Graphical Interpretation Skills and Understanding of Motion Using Microcomputer Based Laboratories. *Electronic Journal of Science Education*. [On-line]. Available: http://unr.edu/homepage/crowther/ejse/ejsev3n4.html. v.3 n.4.

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