

Exploring the phenomenon of 'change of phase' of pure substances using the Microcomputer-Based-Laboratory (MBL) system

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We examined how 1st year students (10th grade) of Greek Senior High School could conceptualize the influence of the molecular weight of saturated fatty acids on the melting and the freezing point, during the 'change of phase' phenomenon using the Microcomputer-Based Laboratory (MBL) system. Students had to freeze a melted substance, observing at the same time the change of its temperature and trying to explain the temperature vs time curve. They used different saturated fatty acids in order to understand how the molecular weight of each organic acid affects the melting - freezing point. Data about the students' conceptualizations was collected using three methods: videotape recordings, field notes and supplementary semi-structured interviews. The analysis of the students' responses to the same questions before and after the experiments showed statistically significant differences on their responses in every case. After the experiments there was a clear increase of correct responses concerning the freezing point of the saturated fatty acids, the relation of the freezing point to the molecular weight and the description of this relation.

Keywords: Phase change, melting point, freezing point, Microcomputer-Based-Laboratory (MBL) system

Introduction

Many researchers have reported students' misconceptions concerning temperature, heat and heat transmission, internal energy, melting and melting point, freezing and freezing point (Stavy and Stachel, 1984; Harrison *et al.*, 1999; Cotignola *et al.*, 2002; Paik *et al.*, 2004). Students' misunderstanding of basic concepts such as 'temperature', 'heat', and 'internal energy' has been analyzed on historical grounds. The persistence of certain ideas from the caloric model is found to be reinforced by the physical quantities and unit definitions that were derived from the early stages of the development of thermodynamics. The failure of many textbooks to draw a clear distinction between internal energy and heat has also been explored by many researchers, and related to students' learning difficulties. The conceptions of heat and temperature are usually poorly differentiated, and heat is often confused with internal energy (Cosgorve and Osborne, 1980; Mark *et al.*, 1987; Driver *et al.*, 1994; Russell, 2000).

In a previous study (Pierri *et al.*, 2006), the most common confusion detected among students was their difficulty in defining heat and internal energy. They could not associate energy with the internal structure of the system under study, partly because of ambiguities in textbooks of introductory physics (Pierri *et al.*, 2006). Data analysis showed that students preserved certain misconceptions about the meaning of temperature, heat and heat transmission, the 'change of phase' phenomenon and the latent heat of melting. These misconceptions were largely resolved throughout the process.

Most of the students perceived heat as a pure melting condition and not as energy transfer from materials of higher temperatures to materials of lower temperatures. It is very difficult for them to understand when and why temperature remains constant during the 'change of phase' phenomenon, even though there is heat transmission to the system. Also, they used melting and dissolving as synonymous and freezing and melting as 'opposites' (Pierri *et al.*, 2006).

To study such concepts, access to laboratories and experiences in experimentation have long been recognized as important aspects of school science. Most of the curricula, developed in the 1960s and 1970s, were designed to make laboratory experiences the core of the science learning process (Shulman and Tamir, 1973). Science in the laboratory was intended to provide experience in the manipulation of instruments and materials, which was also assumed to help students develop their conceptual understanding and technological literacy. Some laboratory activities encourage critical and quantitative thinking, some others emphasize the demonstration of principles or the developing of lab techniques, and some help students deepen their understanding of fundamental concepts.

Modern computer technology might help constructivist applications, in which a computer is used to make possible students' personal explorations by providing them with the tools and guidance in order to work things out for themselves. Computers, in what is called Microcomputer-Based Laboratories (MBL), can capture and display data from the real world quickly and accurately (Nakhleh, 1994). The MBL system includes hardware tools and software, which can help students learn science by experiencing it. Hardware and software allow students in science labs to control their own explorations by taking real-time measurements and generating

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graphs of physical quantities at the same time as they make measurements. This helps students make the link between concrete elements in the real world and the abstract representations in physics. The integration of computer technology in science education has been proven to be much more effective in producing consistent learning of concepts than any other traditional method (Redish *et al.*, 1997). Visualization could facilitate students' formulation of their representations of physical and chemical phenomena and procedures (Bowman *et al.*, 1999; Wu *et al.*, 2001). The MBL system has demonstrated its ability to improve students' apprehension of science concepts and cognitive skills such as observation and prediction (Brasell, 1987; Friedler *et al.*, 1990; Thornton and Sokoloff, 1990), whether the students are in middle school, high school, or college.

The aim of this study was to explore how 1st grade Senior High School students (10th Grade) could conceptualize the relation between the characteristics of pure substances and their melting - freezing point during the 'change of phase' phenomenon, by using the Microcomputer-Based Laboratory (MBL) system.

Methodology

A random sample of seventy-nine students (almost exactly half of them male and half female) was taken from the prefecture of Achaia (Greece). Their mean age was 14.79 years old (st. dev. 0.54); they were studying in the first year of Senior High School (10th Grade). When the research took place, students had already been taught the phenomenon 'change of phase' and the connection between the molecular weight of a pure substance and the melting - freezing point.

The experimental procedure of the research project took place in each school's science laboratory. Students worked in groups of four for two consecutive sessions (within the same day) using a suitable worksheet (see Appendix). Every group of students used all the substances and followed the same experimental procedure each time. Two researchers prompted students to work together, using the worksheet, in order to exchange ideas and reach a conclusion while working.

The worksheet used comprised the following sections: the aim of the experiment, the basic concepts of the phenomenon 'change of phase', the apparatus and the materials used, basic technical instructions, and the drawing of students' attention to particular points they should focus on throughout the experiment, as well as the main questions asked during the procedure. Nevertheless, the worksheet helped students cooperate in a constructive context by judging, exchanging views and drawing conclusions after the completion of the experiment.

The devices used for each experiment were: a thermometer, 10 g each of five different saturated fatty acids (decanoic acid, dodecanoic acid, tetradecanoic acid, hexadecanoic acid, octadecanoic acid), glass vessels, water bath, glass tubes, temperature sensors, the MultiLog system, and a laptop with DBLab software. According to the suggested experimental procedure, each of the acids was melted by immersing the tube containing 10 g of the acid in the 80°C water bath. After that, the glass tube was immersed in a glass vessel containing

water at 12°C. Stirring the content of the glass tube with the temperature sensor, the data acquisition and the temperature recording were started. Students were observing both the experimental process and the graphics registering the temperature changes on the computer screen, simultaneously. Students had to cooperate in order to freeze a molten substance whilst observing temperature changes and trying to compare the curves (temperature vs time) and explain the differences. They used the five fatty acids in a sequence so as to comprehend how the structure of each compound might affect the melting - freezing point (Kind, 2004). The general chemical formula of the five acids is the same ($C_nH_{2n+1}COOH$), and the different length of the carbon chain results in different molecular weights.

It is important to note that the generalization about increasing molecular weight leads to increased melting points is not strictly true, since fatty acids with odd numbers of carbon atoms tend to have lower melting points than those with even numbers of carbons one carbon less. Nevertheless, if one looks at the general trends, it is clear that increasing the chain length, and therefore the molecular weight, of fatty acids tends to lead to increasing melting points. It is also well known that this is only one factor involved in the relationship between molecular structure and melting point, but we wanted students to get an appreciation of a link between molecular structure and physical properties, which was clearly demonstrated by the examples chosen for study.

The data related to students' perceptions were collected by using three methods: videotape recordings, field notes and supplementary semi-structured interviews during the experimental procedure. The analysis of data was performed by: transcribing the data recorded on videotape, integrating the data from the three sources (transcripts, field notes, and supplementary interview data). Then students' conceptions were extracted and categorized by type (Bogdan and Bilken, 1982; Jacobs *et al.*, 1999).

The resulting categorization was validated by three researchers, two of whom were science educators and one was an ICT specialist. The science educators were present in the laboratories during the experimental procedures with the students and kept the field notes. All of them watched the video recordings, and worked together in order to produce the data analysis.

The main questions for the interviews during the different stages of the experimental procedure were related to the objectives of the subject matter, according to the curriculum. These were as following:

After presenting the five saturated fatty acids to the students: 'Can you observe any difference concerning the physical properties of the five substances?', 'Do you think that the melting-freezing point of decanoic and octadecanoic acid are the same?'

After informing the students about the chemical formula of each saturated fatty acid: 'Is the melting-freezing point the same for all substances?', 'Why is the melting-freezing point of each substance different?', 'Which acid has the higher melting-freezing point based on the physical properties you can observe?', 'Arrange the substances according to their

Table 1 Types of students' conceptions

Type	Students' conceptions
Type 1	They associated the phenomenon of melting - freezing with chemical reaction.
Type 2	They are aware that the different substances have different freezing points but they can't correlate it with the molecular weight of the substances.
Type 3	They correlate the molecular weight with the freezing point of a substance.
Type 4	They can explain the relation between molecular weight and the freezing point of a substance (intermolecular interactions).

melting-freezing point, 'Explain the reason of this order', 'How does the molecular weight affect the melting-freezing point?'

After the experimental procedure: 'Finally, is the melting-freezing point the same for all substances?', 'Why is the melting-freezing point of each substance different?', 'Which acid has the highest melting-freezing point based on the physical properties you can observe?', 'Arrange the substances according to their melting-freezing point', 'Explain the reason for this rank', 'How does the molecular weight affect the melting-freezing point?', 'Will acids with lower molecular weight than decanoic acid remain solid at the room temperature?'

In addition, a short semi-structured interview concerning the evaluation of the procedure took place. Typical questions were: 'What is the new thing that you learnt today?', 'Is there anything you understood better today?', 'What did you like most during the experimental procedure?', 'Did you like the experimental procedure using the MBL system?', 'Is there any advantage to the use of the MBL system instead of classical experimental procedure (thermometers, timers...)?'

Results

In this study, an attempt was made to explore students' conceptions of the influence of the molecular weight on the freezing point due to the increasing aliphatic chain in the fatty acid. Despite the fact that students had been taught these concepts, most of them failed to explain that the increase of molecular weight of a pure substance entails the increase of the freezing point.

Students' conceptions were classified into four types (Table 1).

The following results derived from analyzing, grouping, testing and comparing students' responses before and after the procedure (Table 2).

Students' correct responses before and after the procedure were analyzed using the chi-square test. Results showed a statistically significant difference ($p < 0.01$) in every question. After the experiment more students responded correctly to all questions concerning the freezing point of the saturated fatty acids, the relationship of the freezing point to the molecular weight and the description of this relationship. This finding shows that the relationship between the freezing point and the molecular weight became clearer for the students after the

Table 2 Students' responses to the questions

Questions	Students' correct responses (%) before the experiment	Students' correct responses (%) after the experiment	κ^2 p
1. Is the melting-freezing point the same for all these substances?	53.2	89.9	7.87 <0.01
2. Why are the melting-freezing points of each of these substances different?	29.1	72.2	10.64 <0.01
3. Which acid has the highest melting-freezing point, based on the physical properties you can observe?	32.9	74.4	11.22 <0.01
4. Why does this acid have the highest melting-freezing point?	19.0	51.9	14.86 <0.01
5. Order these substances according to their increasing melting-freezing points	25.3	70.9	9.19 <0.01
6. Explain the reason of this order	12.7	53.8	7.16 <0.01
7. How does the molecular weight affect the melting-freezing points of these compounds?	3.8	10.1	10.36 <0.01

experiment. It is also important to note that there was no statistically significant difference concerning students' responses and gender ($p > 0.05$).

The following illustrative dialogues between the researcher (R) and the students (S1, S2...) were recorded in the video tapes and the field notes gathered in different interviews before the experimental procedure:

R: *Is the freezing point the same for all these substances?*

S1: *... they will have the same freezing point because they are similar...*

S2: *... they will have the same freezing point because they have the same general chemical formula...*

S3: *I think that one substance differs from the other so they do not have the same freezing point...*

Students' responses similar to S3 were considered correct. Students' responses like S1 may be influenced by the visual characteristics of the substances while students' responses like S2 tried to correlate the general chemical formula with the freezing point.

R: *Why are the melting-freezing points of each of these substances different?*

S1: *I think that octadecanoic acid can't dissolve easily...*

S2: *I think that one substance differs from the other in the group - CH₂ -, so they do not have the same freezing point...*

S3: *... because they have different molecular weight...*

S4: *... because their chains have different number of carbon atoms...*

Students' responses similar to S2, S3 and S4 were considered as correct. It is noted that many students gave the response S1, or similar to S1. These responses show the existence of confusion between dissolving and melting.

R: Which acid has the highest freezing point, based on the physical properties you can observe?

S1: ... they have the same colour... there is no difference...

S2: ... octadecanoic acid may have the higher freezing point...

S3: ... octadecanoic acid...

Students' responses similar to S3 were considered as correct. In responses like S1, students probably correlated natural characteristics (as colour) and freezing point. Many students gave also, uncertain responses like S2.

R: Why does this acid have the highest freezing point?

S1: ... octadecanoic acid needs a low temperature to become similar to decanoic...

S2: ... decanoic acid will have the lowest freezing point because it is soft like butter...

S3: ... octadecanoic acid will have a higher freezing point than decanoic acid, because I think it is harder...

Students' responses similar to S2 and S3 were considered correct. Responses like S2 and S3 might have been influenced by the natural characteristics like appearance and texture.

R: Order these substances according to their increasing freezing points.

S1: I think that octadecanoic acid has the lowest freezing point...

S2: I think that there is no difference in their freezing point...

S3: Decanoic acid, Dodecanoic acid, Tetradecanoic acid, Hexadecanoic acid, Octadecanoic acid...

Students' responses similar to S3 were considered correct. Their opinion probably was based on their prior knowledge regarding these concepts. Responses such as S1 and S2 provide evidence that students either were confused or guessed wrong regarding the phenomenon.

R: Explain the reason for this order.

S1: I can't think why.

S2: Octadecanoic acid has a higher freezing point because it has a higher molecular weight...

In this question, only a few students gave a response that could be considered correct (e.g. like S2).

R: How does the molecular weight affect the freezing point?

S1: I can't think why...

S2: Octadecanoic acid has a longer chain, so it may need more energy to break down...

S3: ... there are fewer attractions between chains...

S4: ... the bonds between the molecules are stronger...

As it appears from most of the responses (S1, S2, S3, S4), students were not able to correlate what they observed at the macroscopic level with what is happening at the microscopic level.

The most remarkable groupings of students' responses during the dialogues between the researcher and the students and among the students as well, before the experimental procedure were: 10 students stated that during the melting phenomenon chemical bonds are broken up that's why the substance becomes liquid, while 12 students stated wrongly that increasing the molecular weight of the substance needs more energy to break up the chemical bonds (because the

carbon chain is longer) and this causes the increase of the melting-freezing point.

The groupings of students' responses after the experiments were: the majority (65 students) seemed to comprehend that during the 'change of phase' phenomenon there was no chemical reaction that led to the decomposition of the substance, 15 students seemed to conceptualize the processes that took place at the microscopic level (changes of internal energy) and how they were related to the macroscopic data, while 4 students predicted that substances with lower molecular weight than the decanoic acid should be liquid because their melting-freezing points will be lower than the temperature of the surroundings.

At the end of the experiment, in order to enhance students' conceptualization about the processes in the microscopic level, the researcher took the opportunity to explain that molecules which strongly interact with each other through a variety of intermolecular forces can not move easily or rapidly and therefore do not achieve the kinetic energy necessary to escape the solid state. So, substances with stronger intermolecular forces will have a higher melting-freezing point.

Analyzing and grouping students' responses during the interviews for the evaluation of the procedure, the following groupings derived: 19 students stated that the only gain was a better understanding of ambiguous concepts which had been taught to them, 6 students stated that they merely comprehended just a few things about certain concepts and procedures, 9 of them stated that they became familiar with how an experiment is carried out, as well as how certain phenomena develop; they also admitted they were highly motivated by using sensors and computers and only one student reported that this type of experiment could not help him more than the traditional ones.

Most of the students stated that they preferred to experiment with the MBL system because:

- They take real time measurements and generate the graph of temperature vs time at the same time as the phenomenon occurs.
- In order to draw the curve they need much experimental data, which takes time to collect, and it is boring for them.
- It is almost impossible to collect data at such a sampling rate as the MBL system does.
- It is difficult to collect data using a thermometer and a timer at the same time, and they are not sure that their data are accurate.

Finally, some students could not associate what they were observing with what they had been taught about the change of phase phenomenon and the relationship between the molecular weight and the freezing point. It is also noteworthy, that some of the students who were reluctant to participate initially, showed a particular interest in getting involved in the rest of the experiment and the discussion later on. Maybe the whole procedure stimulated their interest.

Conclusions

The above findings provide us with evidence that most of the students comprehended the relationship between the

characteristics of fatty acids and their melting - freezing point, by experimenting with the Microcomputer-Based Laboratory (MBL) system.

Analysis of the students' responses before and after the procedure showed statistically significant differences ($p < 0.01$). After the experiment, there was a clear increase of correct responses concerning the melting-freezing point of the saturated fatty acids, the relationship of the melting -freezing point with the molecular weight, and the description of this relation. There are no statistically significant differences concerning students' responses in relation to gender ($p > 0.05$). The way students responded during interviews offered us with evidence that the achieved knowledge was not simply reproduction of memorized facts.

Based on the analysis of the researchers' field notes and the conversation between the students and the researcher, we formed the impression that most of them understood that during the 'change of phase' phenomenon there was no chemical reaction that led to the decomposition of the substance. The majority of the students, observing the experimental curves, seem to realize that the freezing point is not necessarily lower than the environment's temperature. Some students seemed to conceptualize the processes that take place at the microscopic level (changes of internal energy) and how they are related to macroscopic properties (melting-freezing point).

Data analysis of students' responses during the short, semi-structured interview for the evaluation of the procedure, showed students' preference for sensor use and computer assisted experiments over traditional lab experiments. They supported that using MBL system they can take many real-time and accurate measurements, and generate graphs at the same time.

There is no doubt that using a computer in a chemistry lab might provide students with faster and easier access to various information data, thus they have more time to deal with the concepts of the experiment.

In conclusion, the MBL system, when used in appropriately established educational settings, might help students to comprehend more effectively the concepts being studied.

Appendix

Worksheet

First/Last Name: _____

Gender: _____

School: _____

Concept

Our aim is to determine the relation between the characteristics of the pure substances and their freezing point. For this purpose the temperature of saturated fatty acids (decanoic acid, dodecanoic acid, tetradecanoic acid, hexadecanoic acid, octadecanoic acid) is measured while cooling. A temperature versus time plot is made. The freezing point of the substance can be determined from this plot.

Introduction

In the previous experiment we observed that the temperature of a pure substance remained constant at its freezing temperature, as it was frozen. In this experiment, using a computer - interfaced temperature probe, we will observe what happens when different pure substances (saturated fatty acids) freeze.

Apparatus and materials

- laptop with the DBLab software
- 10 g of five different saturated fatty acids (decanoic acid, dodecanoic acid, tetradecanoic acid, hexadecanoic acid, octadecanoic acid)
- data logger
- serial box interface
- a calibrated temperature probe
- 1-liter beaker
- thermometer (optional)
- ring stand
- 1 utility clamp
- test tube

Technical instructions

Connect the Multilog adaptor to the laptop.

Connect the temperature sensor probe to input port 1 of the Data Logger.

Prepare the computer for data collection following the steps:

- Data Recorder
- Communication Settings
- Control Panel
- Experimental points
- Data Rate Acquisition
- Start

Fill a 1-liter beaker about 4/5 full with water at a temperature in the range.

Heat until 15 °C above the melting point.

Exchange the heater with a magnetic stirrer.

A testtube (20 x 150 mm) half filled (15 g) with a saturated fatty acid is put into a warm water bath until all the substance has melted and the temperature has risen about 15°C above the melting-freezing point of the substance. Switch off the heating of the water bath and remove the tube into a cooling bath. While cooling, the temperature is measured every second. The acquired data leads to a temperature versus time plot.

Questions

- Do you think that the melting-freezing points of the decanoic acid and the octadecanoic acid are the same?
- Is the melting -freezing point the same for all substances?
- Why the melting-freezing point of each substance is different?
- Which is the highest melting-freezing point and why?
- Arrange the substances according to their melting points.
- Explain the reason of this ranking.
- How does the molecular weight affect the melting point?
- What is the melting point of our substance?
- Finally, is the melting point the same for all substances?
- Would you expect fatty acids with molecular weights less than that of decanoic acid to be solids at room temperature?

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