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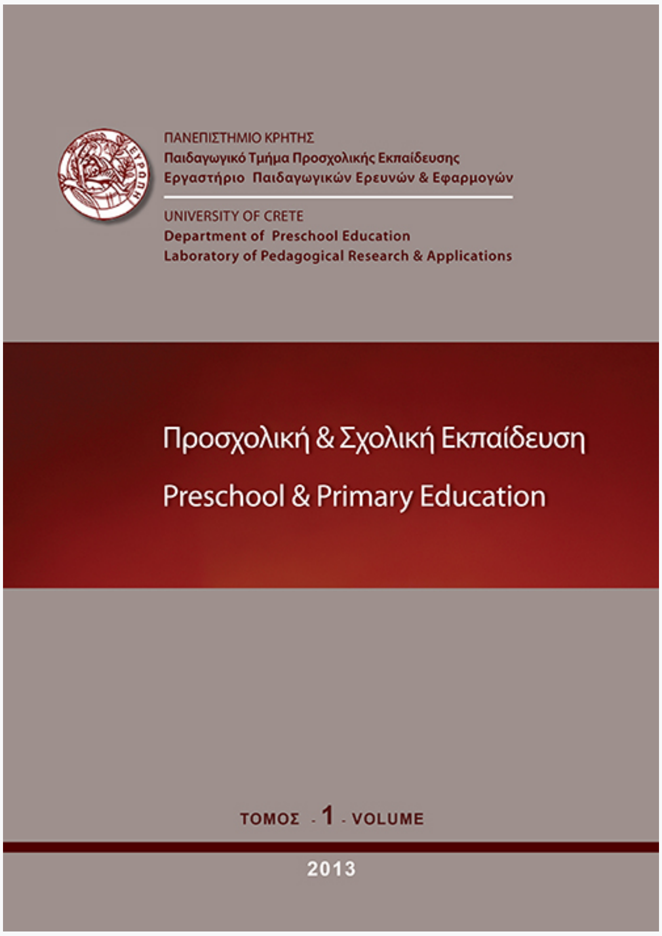

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Mental representations and obstacles in 10-11 year old children's thought concerning the melting and coagulation of solid substances in everyday life

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Abstract. Children construct representations of concepts and physical phenomena and these representations are critical to education. For the physicist, the change of state is a transformation of matter due to the transfer of energy as heat. In several studies focused on children's representations we find that these representations are often incompatible with the scientific model. In this research, we studied the representations of the fusion and freezing of salt and of ice and 110 children aged 10 to 11 years participated. The results of the interviews show that these children use different types of representations, the majority of which are dominated by the nature of the substance under study.

Keywords: Representations, primary education, melting, congelation

Introduction

Research in Science Education commenced with the study of children's mental representations and has since devoted a large part of its attention to this specific case (Koliopoulos, Tantaros, Papandreou, & Ravanis, 2004; Ravanis, 1996). It is known that these representations are very often at a distance or opposed to models used for the instruction of the Sciences. That is why much weight is given to their detection as well as their treatment, which, through properly organized teaching interventions, leads to new representations compatible with those of the models that are used for the instruction of the Natural Sciences (Tsatsaroni, Ravanis, & Falaga, 2003).

Theoretical framework

Children from 5-12 years old have a fundamental difficulty in accepting both the connection between the state of the materials and their temperature, and the general framework of thermal balance; this difficulty leads to a completely phenomenological approach to changes in states of matter. This is due to the fact that children face specific situations and problems. Consequently, this approach directs children's thinking to the following basic misconceptions (Laval, 1985; Skoumios & Hatzinikita, 2008; Zimmermann-Asta, 1990):

- as long as a body of water is heated, its temperature rises;

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- a substance's temperature cannot exceed its boiling point;
- the temperature of ice is unchangeable;
- vaporization, liquefaction, solidification and melting are all terms exclusively related to water;
- the materials' freezing point is 0°C and their vaporization temperature is 100°C;
- during changes in state of matter, temperature is fixed.

The majority of research carried out internationally treats the subjects of water boiling and vaporization, the melting of ice or visible changes in the state of matter of substances, as familiar in everyday life. The empirical content of these familiar situations affects children's reasoning as the perceptive data of day to day life play a decisive role in the formation of their representations concerning changes in state of matter. For this reason, in this research we attempted to compare the same children's mental representations of change in the state of matter of materials such as ice and salt. On the one hand, these materials are familiar but on the other hand, they behave differently under conditions encountered in everyday life. For example, ice can very quickly change its state of matter when heated with camping gas, while salt does not and is also never encountered in liquid form.

We therefore attempted to study the representations of children aged from 10 to 11 concerning the problem of change in the state of matter of ice and salt, emphasizing the potential differences in their reflections on the two materials. Based on the research data, we then attempted to elaborate on the structural data of a teaching intervention intended to deal with the difficulties and obstacles that children face when thinking about changes in the state of matter (Martinand, 1986; Skoumios & Hatzinikita, 2007; 2008).

Methodology

Subjects

The research sample consisted of 110 subjects (55 boys and 55 girls aged 10-11 years, mean age was 10 years and 9 months, S.D. 3 months) and stemmed from five classes of the first grade. The five classes were selected from an urban area of the town of Patras with a population of mixed socio-economic status. The sample subjects had not worked on the change of state of matter in solid bodies beforehand, but had discussed the melting and freezing of ice in the previous school year.

Procedure

Tracking children's representations was carried out with individual guided interviews. Each interview lasted about 20 minutes. For each of the materials, three virtual tasks were presented to the children, namely tasks that were not carried out. The questions posed to the children concerned recognizing the results of heating and freezing of a quantity of ice or salt. The interviews were carried out in a room inside the school. We will subsequently present the tasks to which we requested answers from the children, a categorization of the representations that we formed, as well as basic answers.

Tasks and results

In this section, we present the tasks, representation categories, examples of the children's answers and an answer incidence rate board for each category.

Task 1 (ice cube)

Each subject is posed with the question "What will happen if we light a very powerful gas stove and heat a vessel containing ice cubes?". With this question, we attempt to ascertain if the children link the powerful and obvious flow of heat with the melting of the ice. We sorted the answers into three categories:

a) Sufficient answers, where the ice melting is clearly predicted. For instance, Subject 48 (S. 48): "The ice cube is heated up a lot and it melts" S. 101: "The flame is strong... It will melt immediately".

b) Intermediate answers. In the answers that we rank as intermediate, the melting of the ice is not clearly attributed to heating. For instance:

S. 69: "The ice cube will melt... because it is on the stove... it will always melt though... doesn't matter if it is on the stove or not..."
R: "Does that mean that fire has an effect or not?"
S. 69: "... maybe it accelerates it? ... I guess..."
R: "What's your answer on that?"
S. 69: "I'm not sure..."

c) Insufficient answers. Here we rank the answers that attribute the melting of the ice to its nature, regardless of thermal conditions. For instance:

S. 12: "It will heat it up... but it will melt as it always does..."
R: "Does this mean that fire has no effect?"
S. 12: "... It does but... the ice cubes melt on their own..."

Task 1 (salt)

Each subject is posed with the question "What will happen if we light a very powerful gas stove and heat a vessel containing salt?" With this question, we attempt to ascertain if the subjects have any particular notion regarding the result of continuous heating of salt. We sorted the answers into three categories:

a) Sufficient answers, where the melting of salt is clearly predicted. For instance:

S. 32: "The salt will get warm ... that will happen."
R: "What else could happen to it except for it getting warm?"
S. 32: "... It could... It could be liquefied... and then turned into gas if we still continued to heat it..."

b) Intermediate answers. In the answers that we rank as intermediate, the subjects, although they are actually referring to melting, cannot formulate a concrete explanation. For instance:

S. 14: "The salt gets warm, but not too warm... it won't melt (?)"
R: "Will it melt on the gas stove or not?"
S. 14: "Yes it might melt... No, I don't think so because it's not... It's not... The heat isn't strong enough."
R: "If we had a really, really strong fire and waited for many hours?"
S. 14: "... I don't know... I'm not sure'."

c) Insufficient answers. These are answers where no connection between heating and change in the state of matter is recognized, nor is there is any mention of the rise of the salt's temperature. For instance:

S. 61: "... I don't know"
R: "And what will you feel if you touch the salt?"
S. 61: "... It might... Be hotter."

Task 2 (ice cube)

In this task, we begin the conversation with the following question: "What will happen if we leave the vessel containing the ice cubes on the gas stove overnight, and come back in the morning?" In this question, we also sorted the answers into three categories:

a) Sufficient answers, where the subjects explain the changes in the state of matter that will occur; aside from the melting, they sometimes predict the vaporization that will succeed it. For example, S. 77: "The ice cubes will melt immediately when heated... but if you come back tomorrow morning they will have evaporated... their water, that is...", S. 23: "The ice cubes will melt and they will then become gas... later on."

b) Intermediate answers, where the connection between the heating and the change in the state of matter of the ice is recognized with doubt and hesitation. For example, S. 21: "... If we come back tomorrow the ice cubes will be really hot and burning... Scratch that... They will have melted... Just like the ice does under the sun."

c) Insufficient answers. Some subjects do not recognize that continuous heating will lead to the liquefaction of the ice. For example:

S. 106: "Its temperature will rise continually... I don't know about the other day... Will it be hot?"
R: "The ice cube will be hot?"
S. 106: "... I don't know... It'll probably be heated up."

Task 2 (salt)

Each subject is posed with the question "What will happen if we leave the vessel full of salt on the gas stove overnight, and come back in the morning?". The answers to this question were sorted into three categories:

a) Sufficient answers, where the subjects explain that continuous heating will lead to the melting of the salt. They are sometimes hesitant, as if they have doubts concerning the power of the gas stove flame, but generally recognize a qualitative relation between heating and the liquefaction of salt. For example, S. 7: "It will melt... It will become liquid-like...", S. 23: "It will be heated continually until... the flame's temperature... but... I don't know if it'll melt."

b) Intermediate answers, where a connection between heating, increase in heating and change in the state of matter is realized, but this realization is hesitant or incorrect. For example, a subject thinks that the salt's state of matter will be directly altered from solid to gas. S. 60: "... Salt is like... it's like dust... I'm not sure... But it might turn into gas."

c) Insufficient answers, where subjects do not recognize that the temperature of salt will rise when heated, and they fail to establish a connection between heating and change in state of matter. For example:

S. 11: "... The pot will go red and the salt will stay as it was..."
R: "What do you mean by that?"
S. 11: "It will stay... a little warmer but ... ordinary salt."

Task 3 (ice cube)

Each subject is asked to predict "what will happen to the ice cubes if we turn off the camp stove and come back in the morning?" Concerning this question, we expect different answers based on the representations that were expressed in the previous tasks. We sorted the answers into three categories:

a) Sufficient answers where the phenomenon's development based on the system's thermal balance is predicted in a satisfactory manner. For example:

S. 44: "If we leave it for many hours? ... What if it's vaporized?"
R: "We turn the camping stove off while there's still water in it."
S. 44: "Then there will be water but it will be cold if we stop heating it."

b) Intermediate answers. In this case, the subjects are hesitant, even if their predictions are generally correct. For example:

S. 48: "Umm... It'll turn into cold water? ... I think."
R: "What comes in mind?"

S. 48: "What I'm saying is that if in the beginning the ice cube is warm... No... It'll be cold... but it probably will have turned into water, warm water..."

R: "What if we come back tomorrow morning?"

S. 48: "The water will probably be cold... but it'll still be water, not ice cubes."

c) Insufficient answers. A few subjects that were previously unable to predict the melting of ice due to heating continue to talk about ice cubes. For example, S. 106: "... We would see the ice cubes..."

Task 3 (salt)

Each subject is posed with the question "What will happen to the salt if we turn off the camping stove and come back in the morning?" Concerning this question, we expected differences corresponding to the representations expressed in the two previous tasks. The answers were sorted as follows:

a) Sufficient answers, where the salt's coagulation according to thermal balance is predicted in the same way as its melting was predicted in tasks 1 and 2. For example, a subject (S. 32) who knew that the objects that were in the same room had the same temperature responded immediately: "The salt will grow cold... Like the container and the room." Another subject (S. 81) explains: "It will grow cold... It will reach room temperature. Because... if it stays for a long time... it will adopt room temperature... it will be solid again..."

b) Intermediate answers, where subjects fail to comprehend the salt's liquefaction-solidification cycle, but are clearly referring to heat flow and thermal balance. For example, S. 27: "It will grow cold... first of all the upper part (the surface) will grow cold and slowly the lower part will follow... because it is the part that's close to the air... Tomorrow morning it will have reached room temperature."

c) Insufficient answers, where subjects do not use the terms 'heat transfer' and 'thermal balance'. For example:

S. 40: "... The thermometer temperature will start to fall and if we come back tomorrow morning... the salt will have its original temperature... the container will have the same temperature as the salt... the salt will be colder than the air in the room... because the pots are always colder."

In the following table we present the frequency of the subjects' answers in the three tasks that were introduced.

Table 1 Frequency of the subjects' answers in the three tasks

Representations	Task 1		Task 2		Task 3	
	Ice	**Salt**	**Ice**	**Salt**	**Ice**	**Salt**
Sufficient	75	8	77	12	63	11
Intermediate	19	33	22	38	25	30
Insufficient	16	69	11	60	22	69

Discussion and implications for teaching

In the research presented in this article, we compared the representations of 10-11 year old students concerning the melting and coagulation of ice and salt. To begin with, the majority of the subjects evidently approached the changes in state of matter of the materials differently. Even if the two materials are familiar and encountered in day-to-day life, their different behaviour in common temperature conditions creates discernible representations.

In the first two tasks, where the subject was liquefaction, 7 out of 10 children predicted the transition from a solid to liquid state concerning ice, while only 1 out of 10 children predicted the change in salt. In the third task, the subject was the behaviour of water and the hypothetically liquefied salt when they reach the usual environment temperature. Concerning water that came from ice, 6 out of 10 answers were sufficient, whereas only 1 out of 10 children were able to predict the transition of salt from a liquid to a solid state. Furthermore, it is of particular interest that for both materials and in all of the tasks, a large number of children, in a hesitant manner and with a degree of uncertainty, tended to provide answers that complied with the scientific model used in education (2 out of 10 subjects regarding ice and 3 out of 10 regarding salt). However, concerning salt, around 6 out of 10 subjects did not seem to be able to approach the issue of change in the state of matter.

From both an instructive and a pedagogic point of view, these data lead us to two observations. The first one relates to the kind of cognitive impediment that children's thinking faces between the ages of 10 and 11. It is revealed that the primary difficulty concerning the change in the state of matter is the issue of the thermal balance restoration mechanism between two bodies, namely the heat transfer from the warm body to the cold body. This procedure is behind every change in the state of matter and is essentially a prerequisite to becoming familiar with the concept and being able to generalize about it. The second observation is based on the need to construct set rules in the children's thinking process concerning the changes in the state of matter of all materials, in other words the recognition of the normalcy of the reversible course 'solid-liquid-gas'.

The results of our research are compatible with those of relative research (Laval, 1985; Zimmermann-Asta, 1990; Skoumios & Hatzinikita, 2008). Indeed, we have encountered almost all of the difficulties listed in those studies, simply based on interviews with three virtual tasks that were presented to the subjects without them being carried out. The main obstacles for the students of that age are as follows: (a) each substance is in a 'normal' state, regardless of temperature; (b) the absence of recognition of the general power of thermal balance; and (c) temperature is a property of matter and not a product of its relationship with the environment.

Those obstacles need special instructive treatment, as we know that the transformation of students' mental representations is not arbitrary. However, within the frameworks of research in Science Education we also know that by utilizing a systematic guidance, we can transform children's thinking (Koliopoulos & Ravanis, 2000; Larcher, 2009). From this aspect, a sequence of subjects and activities could go through the following phases:

- All materials, if left for a prolonged period of time in an environment with a steady temperature, will reach that temperature.
- The change in the state of matter that depends on its change of temperature is a stable and reversible procedure, regardless of the nature of the substance which, as far as its quality goes, remains the same.
- When in normal environment temperatures, we are not able to establish the changes in the state of matter of familiar materials. For this to happen, we need the creation of special conditions.

Finally, in this discussion we also need to pay attention to the stability of the temperature during the change in the state of matter, a subject particularly discussed in the relative bibliography. This phenomenon is semi-quantitative and is difficult to approach, as children that are 10-11 years old cannot sufficiently use a microscopic model of interpretation which is necessary. Therefore, it does not constitute a phenomenon fit for discussion at this stage.

Our research now has two directions. It is focused on the study of 5- to 13-year-old children's development of the representations on the change of the state of matter. Also, it concentrates on the creation of instructive procedures for a first initiation of kindergarten and primary education students to qualitative phenomena of change in the state of matter.

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