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Quebec Elementary Pre-service Teachers' Conceptual Representations about Heat and Temperature

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***Abstract*—**This article identifies the conceptual representations of 128 students enrolled in elementary pre-service teachers' education in the Province of Quebec, Canada (ages 19-24). To construct their conceptual representations relatively to notions of heat and temperature, we use a qualitative research approach. For that, we distributed them a questionnaire including four questions. The result demonstrates that these students tend to view the temperature as a measure of the hotness of an object or person. They also related the sensation of cold (or warm) to the difference in temperature, and for their majority, the physical change of the matter does not require a constant temperature. These representations are inaccurate relatively to the scientific views, and we will see that they are relevant to the design of teaching strategies based on conceptual conflict.

***Keywords*—**Conceptual representations, heat, temperature, pre-service teachers, elementary school.

I. Introduction

CHILDREN constructed conceptual representations relatively to different physical science phenomena before any formal teaching, through interactions with their environment. Those conceptual representations are generally incompatible with established scientific theories; for example, related to heat and temperature concepts their representations are: (1) Heat is a substance that has properties attributed to material objects (e.g. [1]); (2) Hot and cold are distinct and opposite phenomena (e.g. [2]); (3) The word "heat" is associated with sources of heat, with the degree of heat of an object and with its effects on objects such as changes of state, expansion (e.g. [3]); (4) The temperature is the measure of heat (e.g. [4]) and (5) The temperature of a boiling water will increase since it will take the heat (e.g. [5]).

Several studies have highlighted the poor conceptual understanding of heat and temperature concepts by students even after instruction [6]-[11]. The present research appears in this perspective and aims to construct the representations of pre-service teachers of elementary schools.

II. Methodology and Population

A. Population

The pre-service teachers who will be teaching at the elementary level (grade 1 to 6) are future general practitioners because they must teach several subjects like French, Mathematics, Human science, Science, and Technology. Most of the 80 pre-service teachers participated in this study have a diploma of collegiate school in liberal arts (3 years of education after their secondary schools of five years). Their training in science is deficient since they only completed one or two courses in their secondary studies on fundamental notions of physics, chemistry, and biology. Unfortunately, the concepts studied in secondary school do not cover all the necessary subjects to teach at the elementary level. Finally, note that more than 90% of the students participated in the present research are female, and their age varies between 19 and 24.

B. Paper-Pencil Questionnaire: Development and Analysis

To construct the pre-service teachers' conceptual representations on phenomena related to heat and temperature concepts, they answered a questionnaire including four questions (see Table I) and had to choose, from the suggested answers, which one is correct, by justifying their choice. Their justifications were essential to identifying their conceptual representations. Indeed, it allowed knowing that their selection of answer is not random and based on given reasoning.

TABLE I
PAPER-PENCIL QUESTIONNAIRE

QUESTION # 1
Using a thermometer, one notes 100ºC when the water is boiling. If the amount of heat is increased while the water is boiling, the temperature indicated by the thermometer will be:
□ Equal to 100ºC □ Greater than 100ºC □ Less than 100ºC
Explain your choice of answer.
QUESTION # 2
How to explain that sometimes, when you come out of a swimming pool, you shiver and have goosebumps?
QUESTION # 3
Put a cross in the box that corresponds to your choice of answer:
□ Sweat would tend to warm us up
□ Sweat would tend to cool us
Explain your choice of answer.
QUESTION # 4
Is there a difference between heat and temperature?
□ Yes □ No
Explain your choice of answer:

The selected questions reflect the work of primary and secondary students' conceptions identified in the literature review [1]-[5] and the notions prescribed in the study of the physical world in the Quebec Education Program [12] synthesized in Fig. 1. As well, the selected questions consider the students' environment.

III. Construction and Data Analysis

The construction and analysis of each of the four questions will be presented below.

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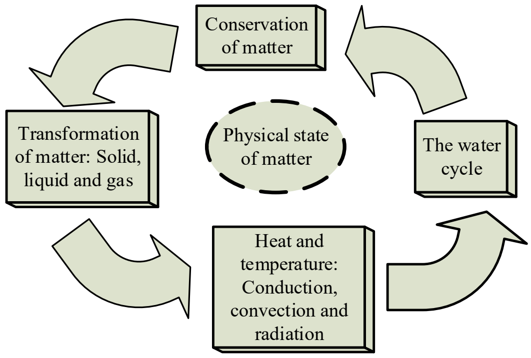

Fig. 1 Scientific notions prescribed in the curriculum related to the physical world

A. Construction and Data Analyses of the First Question

Using a thermometer, one observes 100 ºC when the water is boiling. If the amount of heat increases while the water is boiling, we want to know, if, for the students, the temperature indicated by the thermometer will be equal to 100 ºC, greater than 100 ºC or less than 100 ºC. This question is used to see if they differentiate the notions of heat and temperature when increasing the heat of boiling water. On this subject, we know that under atmospheric pressure, boiling water occurs at a constant temperature (100 ºC) by absorbing heat. We also know that the heat supplied to boiling water does not raise its temperature (molecule movement), but keeps it bubbling. Thus, the temperature remains constant throughout the change of state. As for the increase of the heat during this change of state, it accelerates the boiling of the water. Thus, the analysis of data permitted us to identify two conceptual representations:

- Conceptual representation 1.1: During a physical transformation, the temperature indicated by the thermometer remains constant.
- Conceptual representation 1.2: During a physical change, the temperature indicated by the thermometer increases with the heat.

Table I illustrates the percentage of each representation and the pre-service teacher's justifications.

TABLE II
CONCEPTUAL REPRESENTATIONS DERIVED FROM QUESTION 1

Conceptual Representation 1: During a physical transformation, the temperature indicated by the thermometer remains constant (66%).
"The temperature will remain the same since to evaporate the water must be at 100 ºC. From the beginning to the end of the evaporation, the necessary temperature is the same." (P_{55})
"The thermometer does not need to indicate more than 100 ºC, because 100 ºC is the level of heat required to evaporate the water. So long as the water is not completely evaporated, it will indicate 100 ºC because less than 100 ºC, there is more evaporation." (P_{125})
"The temperature remains the same from one state to another so that the water will be 100 ºC." (P_{126})
"For me, that there is 100 ml of water or 10 ml that evaporate, the temperature remains the same." (P_{127})
Conceptual Representation 2: During a physical transformation, the temperature indicated by the thermometer increases with the heat (34%).
"The boiling point of the water is 100 ºC; it is at this moment that it begins its evaporation process." (P_3)
"As the quantity of liquid water decreases, the temperature will increase faster and faster." (P_{10})
"Since starting at 100ºC the water begins to evaporate, at the end of the process, due to the heat of the heating element and time, the temperature is higher than 100 ºC." (P_{14})
"Higher than 100ºC, it evaporates more and more." (P_{15})
"The temperature is higher, because the more we heat, the higher the temperature." (P_{19})
"The temperature will be higher. The water heats up more and more before being completely evaporated." (P_{28})

The students in representation one do not distinguish between the terms evaporation and boiling. Also, several of them confuse heat and temperature ("100 ºC is the level of heat required to evaporate water"- P_{125}). The students in the second representation, as those in the first representation, confuse the terms evaporation and boiling. Some students associate the increase in the temperature of boiling water to the quantity of water. Others talk about warm temperature following the warming of the water.

B. Construction and Data Analyses of the Second Question

The main objective of the second question is to construct the pre-service teacher conceptions related to the shiver sensation and the goosebumps when a person comes out of a swimming pool. The problem is related to the phenomenon of cooling by evaporation. Indeed, leaving the pool, the droplets of water on our body are in movement because of our heat. Thus, the feeling of cold results from the loss of heat. Moreover, this feeling will be more intense if it's windy. Four conceptual representations of responses emerged from the examination of answers:

- Conceptual representation 2.1: We shiver because the water on our body evaporates on contact with cold air.
- Conceptual representation 2.2: We shiver because of the difference in the temperature of our body (or water on our body) and that of the ambient air.
- Conceptual representation 2.3: We shiver because it is cooler outside than in the pool (or vice versa) and
- Conceptual representation 2.4: We shiver because the water on our body in contact with the cold air chills us.

Table II illustrates the percentage of each representation and the pre-service teacher's justifications.

Only three of the students of the first representation (P_{67}, P_{70}, and P_{106}) stated that the evaporation of water on our body is accomplished by the transfer of our heat to the water droplets, which explains the resulting chill. For many, it is only the air that causes this evaporation.

Note that for 12% we could not identify their conceptual representations because their answers were incomplete, or indecipherable as illustrated below:

- "Because our body cooled in cold water, goosebumps are a reaction of the skin." (P_{38})

- "Because we are wet, and we do not move. Therefore, there is no heat coming out of our bodies." (P_{42})
- "It's surely a question of heat transfer, the pores of the skin expand to capture heat external to the body." (P_{46})
- "The heat accumulated in the pool escapes when the air is cooler. Wet skin no longer retains heat." (P_{64})

TABLE III
CONCEPTUAL REPRESENTATIONS DERIVED FROM QUESTION 2

Conceptual Representation 1: We shiver because the water on our body evaporates on contact with cold air (13%)
"It is the evaporation of water on the body that makes us feel cold and fresh." (P_{56})
"The water on our body tends to want to evaporate, especially when it's windy. Water, therefore, draws the necessary heat directly from our bodies." (P_{67})
"It is because of the layer of liquid water that is on the skin now, which, to evaporate, uses the heat of the surface of the body." (P_{70})
"The water that remains on the surface is like sweat. In contact with air, the heat of the water decreases because the water evaporates, and it cools down our skin." (P_{86})
"As we emerge from the water, our body becomes the hottest element and the droplets absorb our heat by evaporating, which reduces our body temperature and makes us cold." (P_{89})
"It's the same principle as sweat but on a larger scale. The water on our body gradually evaporates and uses our heat to pass from the liquid state to the gaseous state, and this cools us." (P_{106})
"The air is cold and evaporates the water on the body, and this makes us cold." (P_{112})
Conceptual Representation 2: We shiver because of the difference in the temperature of our body (or water on our body) and that of the ambient air (41%).
"Our body had become used to the temperature of the pool, and we put it with a colder temperature." (P_{16})
"The change of temperature. Our body is hot; the air is cold." (P_{37})
"The temperature of our body is different from the ambient temperature (colder on the exterior)." (P_{68})
"For the water that is on our body is colder than the outside temperature." (P_{81})
"There is a difference of temperature between the water and outside of the water." (P_{97})
"When we come out, the ambient temperature is colder than the temperature of our body in the water. Then our body is cold due to this rapid change in temperature." (P_{99})
"Because the water of the pool has cooled the temperature of our body and when we go back out of the water, our body is in contact with a temperature opposite to its own." (P_{113})
Conceptual Representation 3: We shiver because it is cooler outside than in the pool (or vice versa) (14%)
"It's the contact with the air that is colder." (P_{3})
"Because the pool water is warmer than the ambient air." (P_{17})
"It's because the air is colder than the water." (E_{18})
"The ambient air outside the pool is colder. Therefore, we shiver to warm our body." (E_{49})
"The outside air is probably colder than the pool water. Therefore, we feel the coldness that manifests itself by having goosebumps." (P_{53})
"For our body has cooled itself in the water. We do not realize it when we are in the water. When we come out, the contrast between our cold body and the warm air can make us shiver." (P_{103})
"Our body get used to the temperature of the water. If the outside air is cooler, our body will shiver." (P_{104})
Representation 4: We shiver because the water on our body in contact with the cold air chills us (20%).
"Because the water is colder than the temperature of our body. Also, when coming out of the water with the wind or the air, it cools even more the water on our body." (P_{8})
"The temperature change between water and air. The water still on us that becomes colder." (P_{12})
"The water on our skin gets cold and cools us afterward." (P_{44})
"For when we come out of the water, our body is wet, and in contact with the wind, the air, the water is cold and makes us shiver." (E_{63})
"Leaving the pool, in contact with air, the water deposited on the skin cools." (P_{109})
"When we get out of the pool, I imagine that fresh air allows the water on our body to then become cold." (P_{114})
"It's the same phenomenon that happens when we sweat. Water droplets on the surface of the body brought into contact with air or wind cool the body." (P_{125})

C. Construction and Data Analyses of the Third Question

The objective is to identify the students' conceptual representations of the phenomenon of the formation of sweat linked to the notions of heat and temperature. They have to explain if the sweat would tend to warm us or to cool us. The evaporation of sweat causes the body to refresh following the loss of heat by the body. This sweating by the body has the function of fighting against hyperthermia. Sweat evaporates much better in a dry environment than in a humid climate. Thus, the evaporation of sweat on a windy day will provide us with more freshness. Five conceptual representations of responses emerged from the analysis of answers:

- Conceptual representation 3.1: The evaporation of sweat cools our body.
- Conceptual representation 3.2: The hot sweat in contact with ambient colder air became colder and refreshed us.
- Conceptual representation 3.3: The evacuation of sweat brings out the surplus of heat.
- Conceptual representation 3.4: Sweat is a reaction of the body to stabilize the body temperature when it is hot or during physical activities.
- Conceptual representation 3.5: Sweat tends to warm us because temperature (or the production of heat) in the body rises.

Table III illustrates the percentage of each representation and the pre-service teacher's justifications.

Note that in the case of students in category 1, it is right to refer to the evaporation of sweat to explain the sensation of cold that follows. However, only three students (P_{65}, P_{70}, and P_{71}) indicated that this evaporation occurred because of a loss of heat by the body, resulting in a feeling of cold. As for student P_{67}, his explanation is partially correct by considering the action of the air. Relative to the category 3.5, students were experiencing difficulties in elaborating on the subject. They referred to the rise of temperature or the production of heat in the body without explaining the origin of the sensation of freshness:

TABLE IV
CONCEPTUAL REPRESENTATIONS DERIVED FROM QUESTION 3

Conceptual Representation 1.1: Sweat would tend to cool us because evaporation of sweat cools our body (9%).
"We sweat when we are hot but when evaporating from our skin, it cools us." (P_{51})
"Sweat makes us wet. When wet, the water molecules take our heat to turn into steam." (P_{65})
"In contact with the air, the sweat tends to evaporate since the ambient humidity is less than the sweat itself. It will therefore draw the necessary heat directly on our body." (P_{67})
"The sweat on the body is a liquid layer that takes the heat energy from the body to evaporate in the air, which cools us." (P_{70})
"Sweat appears when we are hot. The water in our body evaporates and our body heat will decrease." (P_{88})
"Sweat is a secretion that makes it possible to evaporate the water of our body which cools it." (P_7)
Conceptual Representation 1.2: Sweat would tend to cool us (1) because hot sweat in contact with the cooler ambient air or (2) because its temperature will become less cold than our body (22%).
"Because the warm sweat comes from our warm body. It cools us because in contact with the ambient air which is colder it cools." (P_{17})
"It is the contact between the heat of the body and the outside air that creates sweat. Being liquid, the sweat cools itself in contact with this outside air which is cooler." (P_{22})
"The sweat that is released is hot, but as soon as it encounters the outside air, it cools." (P_{66})
"One sweats when one is hot, but the heat tends to cool us, because in contact with the ambient air that has a lower temperature than the body, the sweat cools down and cools the body." (P_{78})
"The water that forms on our skin cools us because in contact with air it will become less warm than the temperature of our body." (P_{86})
"The sweat that settles on the surface of the skin cools in contact with air and wind." (P_{109})
"Sweat comes from the body when we feel hot, but being a liquid, it is cooled by the ambient air and when cooled, it cools our skin that touches it." (P_{120})
Conceptual Representation 1.3: Sweat would tend to cool us because evacuation of sweat brings out excess heat to lower the temperature (or heat) of our body (19%).
"To cool ourselves, we sweat when we are hot, it is a way to keep our body temperature stable. The hot sweat comes out." (P_2)
"It allows our body to evacuate the heat and therefore lower its temperature. It then cools us down." (P_7)
"Sweating allows our body to extract the extra heat in our body. If we do not sweat, it would not be possible to control the body heat." (P_{15})
"When it gets too hot or we engage in sports, our body gets hot but, we have to cool it. Sweat is the heat of our body that comes out of us." (P_{35})
"It is the body that expels the heat of our body to maintain its body temperature, therefore cools the body." (P_{46})
"When our body becomes too hot, it evacuates this excess of heat by sweating, which reduces our body heat." (P_{89})
"Sweat is our body that lets out the extra heat in our body to bring it back to its usual temperature." (P_{112})
Conceptual Representation 1.4: Sweat would tend to cool us because sweat is a reaction of the body to stabilize the body temperature (26%).
"Sweat is a body defense mechanism that is activated when the temperature exceeds a limit. The object is to cool down the body so that it maintains a stable temperature." (P_4)
"Sweat is secreted through the skin pores to allow our body to lower its temperature when it is too hot." (P_5)
"Sweat comes out of our body and then it cools us so that our body keeps its temperature." (P_{10})
"Sweat is the water of our body that comes out of sweat pores when our body temperature rises. Its utility is therefore to lower our body temperature." (P_{52})
"Sweat is actually, evacuating hot liquids to lower the body temperature that is too high." (P_{58})
"Our body produces heat when we are hot; the sweat cools us to keep our body temperature normal." (P_{60})

Finally, for 24% of the students their explanations are incomplete, indecipherable or unknown. So, we could not identify their conceptual representations by analyzing their answers illustrated below:

- "There is opposition. When we get hot and we become wet, we are cold." (P_{37})
- "It creates a moist environment on the body." (P_{43})
- "To warm us, the body needs water, if our body temperature is too high, we lose water which cools us." (P_{85})
- "Sweat creates a state of moisture. Therefore, our body is more likely to cool down." (P_{98})
- "The body burns calories. Consequence → sweat." (E118)
- "It is used to remove toxins from the body, so it must cool us down." (P_{126})

D. Construction and Data Analyses of the Fourth Question

The purpose of this question is to identify the representations of students on the notions of heat and temperature. We know that these terms are confounding in the everyday language, but in scientific knowledge, they are two distinct words. Indeed, thanks among others to the physicists Boltzmann [13] and Maxwell [14], we know that temperature is a measure of the average kinetic energy of agitation of the particles (atoms or molecules) that make up the matter. As for heat, it represents the amount of energy transferred between two objects at different temperatures: The transfer of energy takes place from the hot object to the cold object. All students say that there is a difference between heat and temperature. The analysis of the explanations put forward to justify their choice enabled us to identify three conceptual representations:

- Conceptual representation 4.1: The temperature is the measure of the degree of heat.
- Conceptual representation 4.2: The temperature may be hot or cold. On the other hand, heat represents, only what is hot: heat is part of the temperature (heat corresponds to high temperature), and
- Conceptual representation 4.3: Heat is a sensation (or a state, a phenomenon, a situation, etc.) that cannot be measured.

On the other hand, the temperature is a quantifiable quantity with a thermometer. Table IV illustrates the percentage of each representation and the pre-service teacher's justifications.

Note that only 15% of pre-service teachers have advances incomplete, indecipherable or unknown answer as indicated below. Thus, we could not identify their conceptual representations.

- "Yes. The heat is due to a chemical reaction while the temperature is related to the seasons." (P_{29})
- "Heat represents ambient air. The temperature → means to obtain a precision inside and outside." (P_{72})
- "Yes, the temperature is related to air, water, food. Heat is another element. I do not know exactly how to explain it, but it's two different things." (P_{99})

- "Heat is one of the manifestations of temperature." (P_{73})

TABLE I
CONCEPTUAL REPRESENTATIONS DERIVED FROM QUESTION 4

Conceptual Representation 1: The temperature is the measure of the degree of heat (24%).
"Yes, the temperature is the unit of measure of heat." (P_2)
"Temperature is a unit of measurement. The temperature is used, for example, to calculate heat or cold." (P_{13})
"Yes. Heat is a source of energy. Temperature is the unit of measure of this energy source." (P_{17})
"Temperature considers several factors (wind, humidity) while heat is a reading taken from a thermometer." (P_{48})
"The temperature allows you to calculate the heat level in degrees." (P_{58})
"I think the temperature can quantify the heat." (P_{78})
"The heat is when it's hot, and the temperature is a tool to measure the degree of heat it makes." (P_{111})
"Yes. A temperature is a number that indicates the degree of heat of something." (P_{121})
Conceptual Representation 2: The temperature may be hot or cold. On the other hand, heat represents, only what is hot: heat is part of the temperature (heat corresponds to high temperature) (38%).
"The temperature can be hot or cold. While heat is on the order of what is hot." (P_{32})
"The heat is when the temperature is high." (P_{36})
"Yes, the heat is a sensation that one feels, and the temperature is in degrees, it is a precise measurement." (P_{50})
"Yes, the temperature, it can be cold or hot while the heat is hot." (P_{60})
"Yes, the heat is hot, and the temperature can be hot or cold. The temperature reacts to change; It increases in the presence of hot and decreases in the presence of cold." (P71)
"Yes, because the temperature can be constituted, for example, of heat or coldness. Heat is a level of temperature and not the same as a temperature." (P_{82})
"Yes, the temperature can be cold (- ºC) or warm (+ ºC), while heat is necessarily a temperature (- ºC) above 0ºC." (P_{88})
"Heat is a high degree of temperature. The notion of temperature encompasses the terms heat and cold (- 45ºC), it is a temperature even if it is cold." (P_{107})
"The temperature can vary below or above 0ºC while the heat is above 0ºC." (P_{113})
Conceptual Representation 3: Heat is a sensation (or a state, a phenomenon, a situation, etc.) that cannot be measured. On the other hand, the temperature is a quantifiable quantity with a thermometer (23%).
"Yes. The temperature can be measured objectively with a thermometer and can be positive or negative. Heat is not measured objectively." (P_7)
"Yes, the temperature is the climate (hot or cold) and can be measured scientifically. Heat is a sensation and is very relative from one person to another." (P_{23})
"Yes, the heat is a sensation that one feels, and the temperature is in degrees, it is a precise measurement." (P_{50})
"Yes, the heat is hot, the temperature is the degree, the number." (P_{75})
"Yes. Heat is a sensation that may differ from person to person. On the other hand, the temperature: these are tools that will indicate us this or that temperature." (P_{91})
"Heat is not measurable, temperature, yes." (P_{93})
"In my opinion, heat is rather a sensation. We feel the heat, whereas the temperature is a measure, something concrete, observable." (P_{122})

TABLE VI
SUMMARY OF PRE-SERVICE TEACHER'S CONCEPTUAL REPRESENTATIONS AND OF THEIR CORRESPONDING SCIENTIFICALLY ACCEPTED COUNTERPART

Pre-service teachers' conceptual representation	**Scientific conceptual representation**
The sensation of cold (or warm) is related to the difference in temperature.	The sensation of cold (or warm) is related to the amount of heat transferred.
The impression of freshness will be the same in water at 20ºC as in air at the same temperature.	The impression of freshness will be more pronounced in water at 20ºC than in air at the same temperature.
When water boils, its temperature increases if one continues to heat it.	When the water boils, its temperature ceases to increase even if one continues to heat it.
The temperature is the number that indicates the degree of heat of an object.	The temperature is a quantity that tells us how warm or cold an object is.
The water boils at 100 Celsius degree and if one continues to heat it, its temperature will increase: during a physical transformation, the temperature increases with the heat.	The water boils at 100 Celsius degree and if one continues to heat it, its temperature remains constant: during a physical transformation, the temperature doesn't increase with heat.
There are two types of temperature: cold temperature and hot temperature.	Temperature is a measure of the average agitation kinetic energy. Depending on the measurement carried out, it referred to as low temperature (e.g. 0 Celsius degree.) or high temperature (e.g. 100 Celsius degree).
Temperature is a measure of the degree of coldness or warmth of a substance.	Temperature is related to the random motion of the atoms and molecules in a substance.
Temperature is the intensity of heat.	Temperature is related to the random motion of the atoms and molecules in a substance (solid, liquid or gas).
Heat is a substance.	Heat is the thermal energy transferred from one object to another due to a temperature difference between the two objects.
Heat can be measured in Celsius degree.	Heat can be measured in joules.
Heating always results in an increase of temperature.	Heating results does not always result in an increase in temperature: The temperature of the boiling water remains constant with heating.
Sweating helps the body to cool: The "hot sweat" in contact with ambient colder air becomes colder and cools us.	Sweating helps the body to cool by evaporating, the water absorbs heat, which is then evacuated from the body.
Leaving a swimming pool, people shiver because the droplets of water on their body in contact with the cold air chills them.	Leaving a swimming pool, people shiver because heat is taken from the body to evaporate the droplets of water on the body.
Matter contains heat.	Matter contains thermal energy, not heat.

IV. CONCLUSION

A brief review of the literature related to students' conceptual representations of heat and temperature has been presented. It has been demonstrated using a paper-pencil questionnaire that tiny percentage of pre-service teachers in Quebec answered correctly, based on scientific reasoning. Others have provided incorrect answers. They have considerable conceptual difficulties in determining the relation between heat and temperature.

Many studies demonstrate the ineffectiveness of traditional interventions to enhancement students' scientific literacy [12], [13]. For that, we must favor constructivist interventions [14], [15]. In this process, students' false representations should be a point of departure in teaching. It is, therefore, necessary that

Starting from Table VI, one can create situations confronting the erroneous pre-service conceptions with those scientifically accepted. Such an approach based on the idea of conceptual conflict is essential for meaningful learning [16].

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