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Fundamental Thermal Concepts: An Assessment of University College Students' Conceptual Understanding of Everyday Perspectives

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Abstract

Addressing students' alternative conceptions draws out a conceptual change that leads to the quality of learning processes. Fundamental thermal concept phenomena are a challenging topic within the initial instruction of thermodynamics. A physically adequate concept of thermal is crucial for grasping the processes underlying everyday perspectives. This research was conducted to investigate students' understanding of fundamental thermal concepts from everyday perspectives. The 19 open-ended multiple-choice items in the questionnaire used in this study required written justifications for students' choice of responses. The items involving topics in fundamental thermal concepts about heat transfer, temperature change, heat conductivity, and equilibrium were based on a previously developed questionnaire and from students' alternative conceptions obtained from the research literature. The items, which were based entirely on everyday perspectives with scientific terminology avoided, were administered to 244 university college students of Leyte Normal University Tacloban City, Leyte, Philippines. Students' responses in each of the four conceptual groups were identified into different categories of understanding. The study showed that students' written responses have some common specific alternative conceptions. The majority of the students could not offer a valid reason for their answers. The results of this study may imply the teaching style in Philippine junior and senior high schools that may be problematic. Also, the students' alternative conceptions could be used as a guide for developing proper teaching strategies on the introductory physics course, especially in fundamental thermal concepts.

Keywords: Alternative conceptions; Assessment; Conceptual Understanding; Thermal.

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1. Introduction

The authors in [1], students' conceptual understanding forms the basis for their transfer of learning from one context, such as their jobs, to another, such as classrooms. Cultivating conceptual understanding is challenged by the preconceptions students hold based on their prior experiences. Despite the diversity of these preconceptions and theories, different researchers have repeatedly reported similar results and patterns across age groups. It is also generally agreed that the traditional teaching method that does not consider students' existing beliefs is primarily ineffective in changing their naïve ideas. Many students drop out of school (and even University) with their misconception that physics is unaffected or exists alongside more accepted scientific interpretations [10, 14, 15]. The previous studies of the authors [4] involving university students enrolled in a bridging program have indicated that students experienced problems making connections between their everyday life experiences and scientific concepts. Also, learners could not apply scientific concepts from different perspectives even though the same scientific theories were involved [5]. It is essential to elicit the students' alternative conceptions that prevent them from applying the same scientific concepts from different everyday perspectives. To elicit the students' preconceptions is considered a relevant approach gave the growing emphasis in several sciences on the relevance of contextualized science at elementary, high school, and college levels. The authors [16] developed the 26 multiple-choice Thermal Conceptual Evaluation (TCE) items. They used it in different studies to assess how learners have systematically understood basic thermal concepts like temperature, heat, phase changes, and heat conduction. The TCE was used as a pre-test and post-test to explore the effectiveness of a cognitive conflict-based physics instruction over the traditional method of physics instruction on primary school teachers' perception of thermal physics [11]. Also, the authors [3] could not determine what kinds of particular alternative conceptions and factors hinder students' conceptual understanding of thermal concepts because the TCE contains typical multiple-choice items. So in this study, 19 of the TCE items were adapted, needing students to require reasons for the student's choice of responses, and the instrument was renamed the *Thermal Conceptual Survey (TCS).*

2. Literature review

The concepts of heat and temperature are considered together in science, which are somewhat related but unrelated. The ideas are prevalent due to their total usage in our day-to-day life. According to the authors [7], heat and temperature concepts are found throughout science curricula, at senior high school and college levels, and in the study of author [8]. Also, in the study of author [6], students were confused about the concepts of heat and temperature and could not explain the differences between heat and temperature. Some students still regard the words "heat" and "temperature" are the same. It has also been found that students hold a variety of alternative conceptions [2, 13]. The study of author [13] found five (5) alternative conceptions about heat and temperature, repeatedly established in the literature, subsequently labeled by author [6] as "conceptual themes" (p. S2G-1). These themes included ideas about the equivalency of heat and temperature; the temperature measures how cold or hot something feels, and the application of heat always makes a body warmer. Also, through condensed educational literature, learners at various grade levels frequently think that temperature is a good measure of the energy in a system [9, 12]. Several studies have documented that engineering students have difficulty understanding heat and temperature [9]. Based on the result, some recurrent areas where engineering students have had difficulty and alternative conceptions include rate versus the amount of heat transfer, temperature versus perceptions of hot and cold, temperature versus energy, and the effects of surface properties on heat transfer by radiation [9]. According to the author [9], with Time versus Amount of heat transfer, several students conflate factors impacting heat transfer rate with the amount of heat transferred. Learners exhibiting this alternative conception have responded that any condition that made a glass of water cold faster would also cool it to a lower temperature. This paper presents the study results, which assessed university college students' conceptions of thermal concepts. Specifically, this study was conducted to answer the following question:

A. What is University College students' alternative conception of thermal concepts?
B. What factors hinder students' conceptual understanding and their ability to apply the same thermal physics concepts in different contexts?

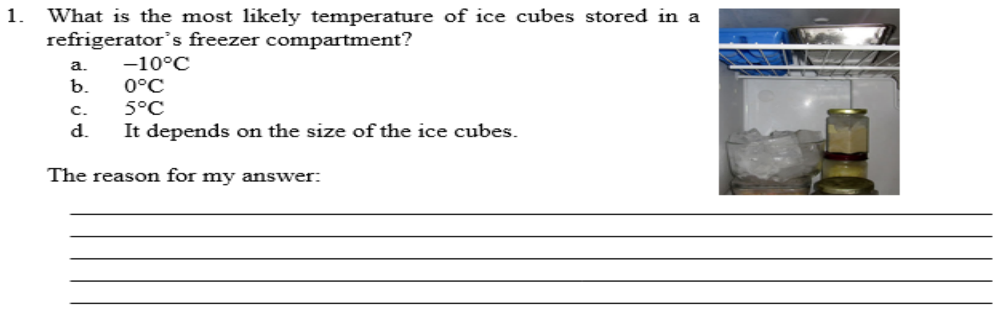
3. Method

3.1. The Participants

Approval of the Human Research Ethics Committees of the University before conducting the research with respondents or their data. Leyte Normal University faculty and students conducting research with or about students, teachers, their data, or specimens, will need to apply for the ethics approval. Moreover, this study has applied to the ethics committees for human research ethics review exemption. The study uses only existing data collections containing non-identifiable data about human beings and are of negligible risk and was exempt from the review. Two Hundred Forty-four (244) University college students in Leyte Normal University participated in this research. They studied physics (Force, Motion, and Energy) and had previously achieved passing grades in physics ranging from 79% to 85%. Thermal physics concepts taught in junior and senior high school involve microscopic view and the heat capacity of thermodynamics and molecular motion caused by heat energy.

3.2. The Instruments

The Thermal Conceptual Survey (TCS) is a paper-and-pencil test consisting of 19 multiple-choice items that assess conceptions of thermal. The distractors represent common alternative conceptions. The test requires explanations for every answer selected. The students gave reasons to reveal or confirm their alternative conceptions. Such an instrument was evaluated in terms of its content validity. Content validity focused on the relevancy and clarity of each item. The item's relevance refers to how each item is relevant to the thermal physics concepts. While clarity refers to the structure of the items if it is well constructed and can be understood by the respondents. Five (5) physics education teachers evaluated the instrument using the scale indicated in the determining the content validity index (Lynn, 1986). The entire instruments generated a relevancy index of 0.9895 and a clarity index of 0.9789, and both were interpreted as acceptable. This result justifies the utilization of the instrument in the conduct of the study.



1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment?
   a. −10°C
   b. 0°C
   c. 5°C
   d. It depends on the size of the ice cubes.

   The reason for my answer:

Figure 1: illustrates an example of one of these items.

Figure 1 An Example of Thermal Conceptual Survey (TCS). The items were categorized into four conceptual groups specifically, (1) temperature changes and heat transfer, (2) boiling, (3) heat equilibrium and heat conductivity, and (4) Freezing (see Table 1).

Table 1: Depiction of items in the four conceptual groups

No.	Conceptual group	Item No.	Item description
1	Heat transfer and temperature changes	4	Predicting the direction of heat energy transfer
		6	Evaluating the temperature of a cold can of soda with the temperature of the countertop beneath the can
		7	Finding the direction of heat transfer
		9	Finding the direction of heat transfer of egg from boiling into a bowl of cold water
		12	Predicting room temperature based on the cooling effect of bottles wrapped with wet and dry washcloths.
		17	Wearing a coat in cold weather
		14	Predicting the temperature inside the oven
		15	Comparing the temperatures of our skin and sweat lying on our skin
		16	Finding the direction of heat energy transfer
2	Boiling	2	Predicting the initial temperature of boiling water
		3	Predicting the temperature of continuously boiling water
		8	Predicting the bubbles that form in the boiling water
3	Heat conductivity and equilibrium	5	Evaluating the temperature of a plastic soda bottle with the temperature of the drink in the plastic bottle
		10	Evaluating the "warmness" and "coldness" of plastic and metal chair
		18	Evaluating temperatures of the wooden and ice parts of a popsicles
		11	Evaluating the "warmness" and "coldness" of plastic and wooden ruler
		13	Comparing the "warmness" and "coldness" of cartons of chocolate milk
		19	Measuring the temperature of toy dolls enclosed in blankets
4	Freezing	1	Predicting the temperature of the ice cubes stored in a refrigerator's freezer compartment

4. Data Analysis

Students'correct and incorrect responses were coded 1 and 0, respectively, for the multiple-choice items, along with when their justifications were taken into account. The explanation was considered correct when it coincided with the scientific view. Furthermore, each idea in students' responses in the explanation part was identified. Similar ideas were grouped or classified according to their dominant characteristics, e.g., tautomerism and direct observation. The classification was further verified by two physics education specialists from the University. Frequencies of ideas were also recorded. Qualitative and quantitative analysis was done on their multiple-choice questions and explanations, respectively. This analysis will provide percentages of students' correct responses to each of the 19 items separately and the justification in the four conceptual groups.

5. Results and Discussion

In the following discussion, the results are presented in groups according to the four conceptual groups using the survey instrument consisting of a 19-item open-ended alternative conceptions test. The categorization of alternative conceptions gathered was limited to the survey's situations and the student's written responses. After a comprehensive collection, tabulation, and analysis of students' responses, the following results were obtained.

In the multiple-choice items, 244 or 100% of the respondents provided their answers on all of the items. But among these items, only a few respondents explained. Of the number of respondents who provided explanations, only a few got the correct explanations. Item number 1 had the most (14%) respondents who tried to explain the concept of boiling, while item number 18 had the most minor (16%) number of respondents with explanations.

Table 2: Distribution of Respondents who provide explanations on the different items (n = 244)

Items	**Frequency** ***(provide an correct answers)***	**Frequency** ***(provide answers)***	**Percentage**
1	18	130	14
2	11	121	9
3	8	110	7
4	15	112	13
5	10	103	10
6	5	76	7
7	3	79	4
8	2	78	3
9	2	92	2
10	10	51	20
11	6	49	12
12	5	26	19
13		35	0
14	12	25	48
15	9	18	50
16	3	25	12
17	5	36	14
18	4	25	16
19	2	26	18

On the test about thermal concepts, questions 2, 3, and 8 involve the concept of boiling. Table 3 below shows the number of students who got the correct answer to questions about the concept of boiling. In item 2, more than half of the students (90 or 68.7%) were able to apply the correct concept of boiling to a particular situation. Unfortunately, in questions 3 and 8 (30 or 22.9% and 37 or 28.2%), students encountered confusion and identified a wrong answer in some situations. These results manifest that most of the students could not understand the application of the concept of boiling.

Table 3: Frequency Distribution of Respondents who got the correct answer to the questions about boiling in the four conceptual groups (n=244)

Questions	**Frequency (Correct Answer)**	**Percentage**
Question 2: (*On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about:)*	90	68.7%
Question 3: *(Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is about:)*	30	22.9%
Question 8: *(Mel is boiling water in a saucepan on the stovetop. What do you think are in the bubbles in the boiling water?)*	37	28.2%

Questions 4, 6, 7, 9, 12, 17, 14, 15, and 16 are situations that deal with heat transfer and temperature change. Among these situations, question 4 obtained the highest percentage, 105 or 46.3% of the students. And questions 6, 9, 12, and 17 reflect a low proportion of the students who could get correct answers. This items attained 22.5%, 16.7%, 21.1% and 15.4%, respectively. But, questions 9, and 17 involved situations in which only a small proportion of respondents could get the correct answer. It means that few of the students cannot understand the concept of heat transfer and temperature change. Students' correct responses in multiple-choice were taken into account are summarized in Table 4.

Table 4: Frequency Distribution of Respondents who got the correct answer to the questions about Heat transfer and Temperature Change (n=244)

Questions	**Frequency (Correct Answer)**	**Percentage**
Question 4: *(James takes two cups of water at 40°C and mixes them with one cup of water at 10°C. What is the most likely temperature of the mixture?)*	105	46.3%
Question 6: *(A few minutes later, Alfredo picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter.)*	51	22.5%

Question 7: *(Pamela asks one group of friends: "If I put 100 grams of ice at 0°C and 100 grams of water at 0°C into a freezer, which one will eventually lose the most significant amount of heat?)*	69	30.4%
Question 9: *(After cooking some eggs in the boiling water, Mel cools the eggs into a bowl of cold water. Which of the following explains the cooling process?)*	38	16.7%
Question 12: *(Amy took two glass bottles containing water at 20°C and wrapped them in washcloths. One of the washcloths was wet, and the other was dry. 20 minutes later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18°C, and the water in the bottle with the dry washcloth was 22°C. The most likely room temperature during this experiment was:)*	48	21.1%
Question 17: *(Why do we wear sweaters in cold weather?)*	35	15.4%
Question 14: *(Pat believes her Dad cooks cakes on the top shelf inside the electric oven because it is hotter at the top than at the bottom.)*	73	32.2%
Question 15: *(Ben is reading a multiple-choice question from a textbook: "Sweating cools you down because the sweat lying on your skin:)*	77	33.9%
Question 16: *(When Zack uses a bicycle pump to pump up his bike tires, he notices that the pump becomes quite hot. Which explanation below seems to be the best one?)*	70	30.8%

Table 5 shows that the thermal physics conceptual understanding test had questions 5, 10, 18, 11, 13, and 19 for heat conductivity. These questions reflect meager proportions among the number of students. Questions 10 and 13 appear to be situations where students were not able to comprehend the correct concept of heat conductivity. Though questions 5, 18, 11, and 19 still obtained low percentages on understanding the concepts but seems higher than the other items on heat conductivity.

Table 5: Frequency Distribution of Respondents who got correct answers to the questions about Heat Conductivity (n=244)

Questions	Frequency (Correct Answer)	Percentage
Question 5: *(Sam takes a can of cola and a plastic bottle of cola from the refrigerator, where they have been overnight. He quickly puts a thermometer in the cola in the can. The temperature is 7°C. What are the most likely temperatures of the plastic bottle and cola it holds?)*	66	35.5%
Question 10: *(Jane announces that she does not like sitting on the metal chairs in the room because "they are colder than the plastic ones.")*	22	11.8%
Question 18: *(Vic takes some Popsicles from the freezer, where he had placed them the day before, and tells everyone that the wooden sticks are at a higher temperature than the ice part.)*	43	23.1%
Question 11: *(Kim takes a metal ruler and a wooden ruler from his pencil case. He announces that the metal feels colder than the wooden one. What is your preferred explanation?)*	55	29.6%
Question 13: *(Dan simultaneously picks up two cartons of chocolate milk, a cold one from the refrigerator and a warm one sitting on the countertop for some time. Why do you think the carton from the refrigerator **feels** colder than the one from the countertop? Compared with the warm carton, the cold carton)*	29	15.6%
Question 19: *(Four students were discussing things they did as kids. The following conversation was heard: Ami: "I used to wrap my dolls in blankets but could never understand why they didn't warm up.")*	64	34.4%

Distribution of Respondents who got the correct answer to the questions about Freezing (n=244)

Question 1 (21 correct answer) – 20.9%

There is only 1 question that involves the concept of Freezing. Such a question reflects a low proportion of students who could get the correct answer. Empirically, only 18 of the students could get the correct answer. This implies further that students do not have a grasp of knowledge in applying the concept of Freezing.

The heat transfer conceptual group consisted of two sub-categories: heat transfer and temperature changes. Fifty-nine students correctly responded to the open-ended justification for the temperature change sub-category in Items 2, 4, 6, 7, 9, 14, 15, 16, and 17. Students' correct responses when their justifications were taken into account are summarized in Table 6.

Table 6: Students' correct responses to their justification were considered in the four conceptual groups

Conceptual Group	**Item No.**	**Correct responses**	**Percentage of correct responses**
1. **Heat transfer and temperature changes**			
1.1 Heat transfer	4	When two objects at different temperatures are in contact, heat energy flows from a region of higher temperature to an area of lower temperature until the thermal equilibrium has been achieved.	13
	6	When two objects at different temperatures are in contact, heat energy flow from a region of higher temperature to an area of lower temperature. Hence heat energy has been transferred from the counter to the cola.	7
	7	Since ice is still present in a mixture of water and ice, the ice temperature should be the same (thermal equilibrium) as the temperature of the water at 0°C.	4
	9	The direction of heat energy transfer is always in one direction: from hot to cold and never from cold to hot. Coldness then cannot be transferred.	2
	12	The room would have to be quite dry. Water evaporates and cools down one bottle; the other bottle tends toward thermal equilibrium, which occurs at 26°C.	19
1.2 Temperature change	14	When fluid, such as Air, is heated and then travels away from the source, it carries the thermal energy. The fluid above a hot surface expands less dense and rises.	48
50	15	When sweat evaporates, it needs the energy to convert it from a liquid state to a vapor state. This energy is drawn from the skin. Since the skin losses heat energy, the skin feels cold.	50
	16	When pumping air inside a bicycle, performing mechanical work on the Air; hence, the internal energy of air increases, resulting in increased temperature in the pump.	12
	17	An insulator delays the rate of heat energy transfer from a region of higher temperature to a region of lower temperature. So, the coat delays the heat transfer process of the man as heat energy from the body takes a longer time to reach the surroundings.	14
2. Heat			

conductivity				
		5	Different objects made from different materials feel different because the rate of heat energy transfer is different for different materials, although their temperature is the same or equal.	10
		10	If placed long enough in a particular environment, all materials will acquire the same temperature, which is the temperature of that environment. Thermal equilibrium has been achieved.	20
		11	Different objects made from different materials feel different because the heat transfer rate is different for different materials, although their temperatures are the same.	12
		18	If placed long enough in a specific environment, all materials will acquire the same temperature, which is the environment's temperature.	16
		19	Different objects made from different materials feel different because the rate of heat energy transfer is different for different materials, although their temperatures are the same.	8
3.	**Boiling**			
		2	The most likely temperature of water boiling in a kettle is 98°C. The boiling point of water is 100°C only at sea level. Any location above the sea level will have lower pressure.	9
		3	The boiling point of water remains constant during boiling as there is no change in pressure> If water is boiling at 98°C, then its boiling point will stay the same five minutes later.	7
		8	Liquid water undergoes a phase conversion (called boiling) at 373K = 100°C to steam (water in the vapor, or gaseous state of matter); this because of the water pressure of the steam = the pressure of the earth's atmosphere (mainly containing Nitrogen and Oxygen gases) at 100°C. When this happens a tiny gas bubble "nucleases" spontaneously within the liquid water and the bubble grows and rises in the liquid until it pops out 1 bar of water vapor pressure. These bubbles are Air.	3
4.	**Freezing**			
		1	The ideal temperature range of the freezer compartment is -18°C or below	14

The categorization of students' alternative conceptions

To identify students' alternative conceptions of thermal concepts, responses from University college students (n=244) were analyzed.

Heat transfer and temperature change the conceptual group

The alternative conception "cold and hot as the ends of the continuum" keep appearing all items in Heat Transfer and Temperature Change conceptual group. Also, 74% of students understood heat energy could be easily transferred from one object to another because of their everyday experiences. Table 7 shows categories that were drawn from students' incorrect open-ended responses in temperature changes and heat transfer conceptual group.

Table 7: Percentage of incorrect students' open-ended justifications in categories of the heat transfer and temperature changes conceptual group (N=244)

Categories	Examples of students' open-ended justifications	Item number in HT			Item numbers in TC					
		Item 4	Item 6	Item 7	Item 9	Item 12	Item 14	Item 15	Item 16	Item 17
The nature of the material	The sweater can generate heat and reduce heat loss									10
Temperature movement	Temperature attracted from higher object to lower object				3		9			
Considering cold and hot at the ends of a continuum	Cold is transferred	5	2		3	5	5	5	8	7
Everyday observation	The heat energy absorbed from the skin In the canteen, there was no difference		4	5				10	55	
Other categories	I read it in my high school science textbook Question/choice reiteration	68	80	70	74	55	60	40	20	75
	The answer cannot be understood	20	10	15	13	25	20	15	10	5
	No choice and no explanation	7	4	10	7	15	6	30	7	3

Item number in TC & HT: Item numbers in Heat Transfer and Temperature Changes sub-conceptual group

Boiling conceptual group

Table 8 shows the categories drawn from students' incorrect open-ended justifications in the boiling conceptual group. Most students (83%) believed that the boiling point of water is always stable (100°C) without considering the location. If it is above the sea level will have lower pressure. Except for two students, a student could not connect between the boiling point of water in an everyday context and water boiling point under atmospheric pressure.

Table 8: Percentage of incorrect students' open-ended justifications in the categories of the boiling conceptual group (N=244)

		Item number in BW (Boiling Water)		
Categories	Examples of students' open-ended justifications	Item 2	Item 3	Item 8
Constant Boiling point	The boiling point of water is always 100°C	65	83	
	The boiling point of water exceeds 100 °C after 5 minutes			
Occurrence of impurities	In the water, some impurities turn it into gas			25
	Hot water has substances that make it hot			
	Something is going out of hot water			
Other categories	No choice and no explanation	20	10	56
	Question/choice reiteration	10	4	9
	The answer cannot be understood	5	3	10

Item numbers in the Boiling Water conceptual group

Heat conductivity and equilibrium conceptual group

Students' alternative conception that "we feel some objects colder than other objects at the same temperature because of the properties of materials" kept repeated in items 5, 10, 11, 13, 18 and 19. In item 10 about comparing metal and plastic chairs, 80% of students showed these alternative conceptions. Table 9 shows categories drawn from university students' incorrect open-ended explanations in the heat conductivity and equilibrium conceptual group.

Table 9: Percentage of incorrect students' open-ended justifications in the categories of heat conductivity and equilibrium conceptual group (N=244)

Categories	Examples of students' open-ended justifications	Item 5	Item 10	Item 11	Item 13	Item 18	Item 19
Heat gained/lost from surroundings	Heat gained from surroundings			6			
	Heat lost from surroundings						
Intrinsic properties of material	Metal is a good conductor	57	80	76	43	87	78
	Plastic is a good insulator						
	Insulating properties of the blanket						
	Heat transfer properties of the blanket						
Different amounts/volumes	Different amounts of coke results in different heat capacity	7					
Other categories	No choice and no explanation	26	8	6	45	8	15
	Question/choice reiteration	5	10	9	7	2	4
	The answer cannot be understood	5	2	3	5	3	3

Freezing Conceptual group

Table 10 shows the categories drawn from students' incorrect open-ended justifications in the Freezing conceptual group. Seventy-five percent of students in Item 1 suggested that the temperature inside the freezer was the same as ice inside the freezer.

Table 10: Percentage of incorrect students' open-ended responses in the categories of melting conceptual group. (N= 244)

Categories	Examples of students' open-ended justifications	Item 1
Thermal equilibrium	Ice and freezer temperature is not in thermal equilibrium	75
	Ice and freezer temperature is in thermal equilibrium at 5°C because ice cannot be at 0°C	15
Other categories	No choice and no explanation	3
	Question/choice reiteration	4
	The answer cannot be understood	3

6. Conclusion and Implication

The primary goal of this research was to investigate first-year college students' understanding of thermal concepts associated with their everyday life experiences. To categorize alternative conceptions that were believed by the students established on a questionnaire (the TCQ) that was developed by the author [16] and related research conducted by the authors [4].

Nevertheless, a different approach was used in the design of the questionnaire and the data analysis in this study; initially, students' open-ended explanations for their answers to 19 multiple-choice items were categorized into four conceptual groups. Alternative conceptions from the open-ended reasons were next identified to determine the factors that hindered students' conceptual understanding and their capability to apply the same thermal physics concepts in not the same contexts.

Most university students had alternative conceptions of basic thermal concepts such as boiling, heat transfer during cooling, and freezing. Students mentioned scientific concepts with theoretical explanations in their open-ended reasons, but learners could not make associations with the everyday contexts of the items. For example, learners knew that evaporation resulted in a cooling process, but students could not justify the energy (heat) transferred from the skin to the sweat. Similarly, students knew that the boiling point of water is measured under standard conditions (1-atmosphere pressure at sea level). Still, students could not use this scientific concept in an everyday context.

The results of this study have some implications for classroom instruction and future research. Chances for students to make connections between their knowledge have to be provided. Also, this implies that teachers must elicit students' alternative conceptions before teaching a particular concept. In this sense, they will be able to address students' alternative conceptions during instruction. Furthermore, the metacognitive process to make students think about what they know, what they don't know, and why they don't know should be provided through these kinds of everyday-based test items.

Suppose the students are not made aware that whatever they learned in the past will have some relevance. In that case, they will have difficulty integrating new knowledge and an existing alternative conception. Furthermore, the patterns of understanding show that students' alternative conceptions and the degree to which conceptual change occurs are essential aspects in assessing the endpoints of instruction. If addressing the students' alternative conceptions is to be used by teachers in assessing students' understanding, it is the quality of the change in scientific conceptions that should matter.

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