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Two-tier Multiple-choice Questionnaires to Detect the Students' Misconceptions about Heat and Temperature

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Abstract: This study aimed to develop a two-tiers diagnostic test to assess the high school, junior high school, and elementary pre-service teachers about the heat and the temperature concepts in a general physics course. There are two tiers in this test: The first tier composed of six items consisting of multiple-choice questions related to the heat and the temperature, including the correct answer. The second tier of each item contains reasons for students choosing their answer to the first tier. The second tier included four or five responses, one of which is a correct conceptual understanding. The wrong answers, also called distractors, were based on students' misconceptions. To this end, 128 pre-service teachers from Quebec in Canada completed a pencil-paper questionnaire of sixty minutes duration composing of six questions (four open-ended questions and two multiple choice questions with justifications). As illustrations, the following conceptual understandings have been identified in our qualitative analysis of the data collected: 1. The change of state of the matter does not require a constant temperature; 2. The temperature is a measure in degrees to indicate the level of heat of an object or person; 3. The mercury contained in a thermometer expands when it is heated so that the particles which constitute it expand; and 4. The sensation of cold (or warm) is related to the difference in temperature.

Keywords: *Conceptual understanding, first tier test, pre-service teachers, second tier multiple-choice questionnaires.*

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Introduction

Research conducted with students at elementary and secondary schools demonstrated that most have false conceptions regarding heat and temperature (Alwan, 2011; Anderson, 1980; Bar & Travis, 1991; Erickson, 1980; Harrison et al., 1999; Reiner et al., 2000; Romer, 2001). According to these studies, students regarded heat as a substance that has properties attributed to material objects; hot and cold are distinct and opposite phenomena that are not part of the same scale; 5. The temperature is the measure of heat; 6. Metal can absorb heat and cold; and 7. Matter contains heat.

Several studies have highlighted the poor conceptual understanding of students' heat and temperature concepts even after instruction (Chu et al., 2012; Clough & Driver, 1985 Duit, 2006; Sözbilir, 2003). How to explain the persistence of false conceptions built before teaching despite teaching over several years? Most works in science education underline that the educators should consider, in their teaching, the initial conceptions of their students that are erroneous and that constitute an obstacle to the acquisition of scientific notions.

However, one must note that most teachers do not consider the initial conceptions of their students systematically (Tiberghien, 2003). They do not consider them because of their insufficient expertise in science education research and didactics (Coppens et al., 2009; Tüysüz, 2009). To remedy this gap, one should develop more and more software that considers students' misconceptions, and that could be used by the educators to bridge the gaps as highlighted by Tüysüz (2009):

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"The two-tier test could help teachers teach and students learn better. Therefore, instead of multiple-choice tests, two-tier tests can be easily used by teachers to increase students' knowledge level and prevent students' alternative conceptions. Thus, two-tier tests help to improve teaching and learning." (p. 630)

To this end, various misconception diagnostic methods were constructing in science education research (Chandrasegaran et al., 2007; Métioui & Trudel, 2020; Peşman & Eryilmaz, 2010; Urban, 2017; Yeo & Zadnik 2001). According to Gurel et al. (2015), the methods commonly employed are 1. Sample items of misconception diagnostic methods; 2. Individual demonstration interview item; 3. Open-ended test item; 4. Ordinary multiple-choice test item; 5. Two-tier multiple-choice test item. Note that other detections methods are used as Venn Diagrams and Concept maps.

About these different methods, more researchers resorted to the two-tier method to detect the students' misconceptions as underlined by Gurel et al. (2015, p. 995) "Two-tier tests were considered a great improvement over the previous approaches in that these tests consider students' reasoning or interpretation behind their selected response and link their choices to misconceptions of the target concept". In the present research, we developed a two-tier multiple-choice questionnaire to evaluate the students' conceptual understanding of the heat and the temperature concepts.

Methodology

In the present research, we developed a two-tier multiple-choice test item to diagnose rapidly elementary pre-service teachers, junior high school students and high school students, about the temperature and the heat concepts. Methodologically, the development of the two-tier test will take place in two tiers.

Survey instrument: first tier

In the first tier, we constructed a paper and pencil questionnaire consisting of five questions on the concepts of heat and temperature (see Table 1). Note that the selected questions considered the following elements: (1) the research done worldwide on elementary and secondary students' misconceptions about heat and temperature as synthesized in the introduction; (2) the notions prescribed in the curriculum and (3) the student's everyday contexts.

Table 1: Paper-pencil questionnaire

Question # 1	How can you explain that sometimes, when you come out of a swimming pool, you shiver and have goosebumps?
Question # 2	Using a thermometer, we note 100°C when the water is boiling. The thermometer will indicate which temperature if we increase the amount of heat while the water is boiling? Explain your answer.
Question # 3	When we touch objects in an evenly heated room, they are hot or cold to the touch. Are these objects at the same temperature in touch? Explain your answer.
Question # 4	Is there a difference between heat and temperature? Explain your answer.
Question # 5	Put a cross in the box that corresponds to your choice of the answer: ❒ Sweat would tend to warm us up. ❒ Sweat would tend to cool us. Explain your choice:

For each question, respondents had to explain their answers. At the methodological level, the explanations respondents provided were crucial to identify their conceptual reasonings because students might correctly answer without justifying their reasons for choosing their specific answer (Gurcay & Gulbas, 2015; Hestenes & Halloun, 1995).

Sample

The paper and pencil questionnaire of sixty minutes duration was completed voluntarily by 128 preservice teachers (aged between 19 and 23 years) in teacher education for primary school. To fill it out, they had to refer to their alternative conceptions. Note that they have taken a course on these themes in secondary school.

Analysis of data: Paper and pencil questionnaire (first-tier)

Analysis: Question # 1

The first question aims to identify the teachers' conceptual reasoning on the chills felt when leaving a swimming pool. Let us underline that the cold felt because our body supplied an amount of heat to the water droplets on our skin, which causes their evaporation because of increasing their movement. So, the goosebumps felt are due to the loss of heat. Likewise, if they know that this feeling of cold will be more intense if it was winding.

The analysis of students' answers allowed us to identify three categories of conceptual representations:

1. We shiver because the water on our body evaporates on contact with cold air (16/128-13%).
2. We shiver because of the difference in the temperature between our body (or water on our body) and that of the ambient air (63/128-49%).
3. We shiver because the air outside is colder than in the swimming pool or vice versa (18/128-14%).

For 23% (23/128) of students, we could not identify their reasonings because their explanations are indecipherable or incomplete.

Analysis: Question # 2

The second question had for the object to differentiate the notions of heat and temperature when increasing the heat of boiling water. We know that boiling water occurs at a constant temperature (100°C) by absorbing heat under atmospheric pressure. We also know that the heat supplied to boiling water does not raise its temperature, but keeps it bubbling water: molecules attract quite strongly; when water vaporizes, the molecules, which touched in the liquid phase, must separate. Therefore, it is necessary on the mechanical level to provide the necessary potential energy (the latent heat of vaporization, 2.253 kJ/g). Temperature, which is a measure of molecules' movement, does not increase during this time because thermal energy does not produce any increase in their kinetic energy. Thus, during vaporization, the temperature remains constant even if the amount of heat absorbed by the molecules increases.

The data analysis permitted us to identify two conceptual representations:

1. During a physical transformation, the temperature indicated by the thermometer remains constant (66%).
2. During a physical change, the thermometer's temperature increases with the heat (34%).

Analysis: Question # 3

Question 3 aimed to learn about students' conceptual representations of the hot and cold feeling when touching objects in a uniformly heated room concerning their temperature. In this regard, note that the objects in the room are at the same temperature before they were touched but are no longer at the same temperature in the touched places. For example, a wooden table and a metal chair are at the same temperature before being touched. However, to the touch, the chair appears cooler compared to wood. The cold feeling because our hand's heat was transferring to the metal chair. Note that the metal is an excellent thermal conductor, unlike wood, which is a poor conductor. Thus, if the hand gives heat to the metal, it is because the metal is colder than the hand. After all, the heat always goes from the hot body to the cold body. This phenomenon does not happen with wood because the wood is a thermal insulator and that no heat, or only a small quantity, is transferred from the hand to the wood; thus, a wood surface appears to be hot to the touch.

For 58% (74/128), objects in the room are not at the same temperature to the touch. As pointed out above, this answer is correct. On the other hand, by analyzing the explanations put forward, we found that most were incomplete, indecipherable, or false. Note that most of them advanced response elements scientifically correct, such as 1. The temperature depends on the degree of agitation of matter; 2. Some objects conduct heat, and others do not; 3. Heat measures the amount of energy in the material; and 4. Heat depends on the temperature and amount of material.

Analysis: Question # 4

The goal of the question was to identify their conceptual representations of heat and temperature. On this subject, let us underline that these are two concepts that maintain a complicated relationship that depends on the material's nature. In other words, adding one joule to one gram of water does not have the same effect on the temperature as adding one joule to one gram of iron. It is important to note that there is an essential difference between the two concepts. For example, if we place two subsystems in thermal contact, it is not the amount of heat that determines which way heat is exchanged between them; it is each's temperature. Thus, it is the temperature that determines the direction of heat exchange and not the heat. As well, the amount of heat is an additive property, and it is not the same with temperature.

All students said that there is a difference between heat and temperature. It is the right affirmation. However, the analysis of their explanations put forward enabled us to identify their conceptual difficulties in distinguishing the difference between heat and temperature. Three conceptual representations were identified:

1. Temperature is the measure of the degree of heat (31/128 - 24%).
2. The temperature may be hot or cold. On the other hand, heat only represents hotness (e.g., heat is part of the temperature; heat is high) (48/128 – 38 %).
3. Heat is a sensation (e.g., a state, a phenomenon, a situation) that cannot be measured. On the other hand, the temperature is a quantifiable quantity measured with a thermometer (30/128 - 23 %).

For 15% (19/128) of students, we could not identify their reasonings because their explanations were indecipherable or incomplete.

Analysis: Question # 5

The objective is to identify the students' representations of the phenomenon of the formation of sweat linked to the notions of heat and temperature. 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 environment. Thus, the evaporation of sweat by a windy day will provide us with more freshness.

Most students [122/128 - 95%] chose the correct answer, namely that sweat would tend to cool us (representation 1). The analysis of the explanations can be categorized into four sub-representations:

1. The evaporation of sweat cools our body (11/122 - 9%).

2. The hot sweats in contact with ambient colder air become colder and cool us (27/122 - 22%).

3. The evacuation of sweat brings out the surplus of heat (23/122 – 19%).

4. Sweat is a body's reaction to stabilize the body temperature when it is sweltering or during physical activities (32/122 - 26%).

For 24% (29/122), their explanations were incomplete, undecipherable, or unknown explanations.

Survey instrument: second tier

The second tier includes the Multiple-Choice questions developed in the first tier and their responses, including the correct answer and several wrong conceptual students' reasoning identified in the first-tier data analysis. Many researchers use the term distractor to designate these incorrect answers:

> "Distractors are intended to distinguish between students who have not yet acquired the knowledge necessary to answer the item correctly from those who understand the content. Therefore, distractors in a multiple choice item are designed to contain plausible but incorrect answers based on students' common errors or misconceptions so that the option can measure students' level of mastery in a specific content area." (Shin et al., 2019; p. 3)

The Two-tier test: Question 1

As pointed out above, we shiver because of the loss of part of our body heat. From the first-tier data analyses, we constructed three wrong conceptual understandings among both students who gave the correct and false answers with wrong explanations. The fourth conceptual understanding retained is a correct conceptual understanding. The two-tier design is presenting below in Frame 1.

Note that the student who does not agree with any of the explanations given can reformulate his own.

Frame 1: Two-tier/Question 1

Put a cross in the box that corresponds to your answer:

- ❒ When we come out of a swimming pool, we shiver and have goosebumps because we lose our body heat.
- ❒ When we come out of a swimming pool, we shiver and have goosebumps because the cold air outside cools us down.

Which one of the following is the reason for your answer to the previous question?

- ❒ The water that remains on the surface is like sweat. In contact with air, the water's heat decreases because it evaporates, and it cools down our skin.
- ❒ The goosebumps felt due to the evaporation of water droplets on our skin through part of our body heat. We feel chills because of this heat loss.
- ❒ The outside air is colder than the pool water. Therefore, we feel the coldness that manifests itself by having goosebumps.
- ❒ 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.
- ❒ Other. Please write: _____

The two-tier test: Question # 2

As pointed out above, the temperature indicated by the thermometer remains constant during the water ebullition. We constructed two wrong conceptual understandings from the first-tier data analyses among students who gave the correct and false answers with wrong explanations. The third conceptual retained is scientifically correct. The two-tier design is presenting below in Frame 2.

Frame 2: Two-tier/Question 2

Put a cross in the box that corresponds to your answer:

- ❒ If the amount of heat increased while the water is boiling, the temperature indicated by the thermometer will be equal to 100°C.
- ❒ If the amount of heat increased while the water is boiling, the temperature indicated by the thermometer will be higher than 100°C.
- ❒ If the amount of heat increased while the water is boiling, the temperature indicated by the thermometer will be less than 100°C.

Which one of the following is the reason for your answer to the previous question?

- ❒ As the quantity of liquid water decreases, the temperature will increase faster and faster.
- ❒ The thermometer does not need to indicate more than 100°C because 100°C corresponds to the amount of heat required to put water to ebullition. So long as the water is not entirely evaporating, it will indicate 100°C because less than 100°C, boiling is not ultimately reached.
- ❒ Higher than 100°C, the water evaporates more and more because of higher heat.
- ❒ Other. Please write: _____

The two-tier test: Question # 3

As pointed out above, when we touch objects in an evenly heated room, they are not at the same temperature to the touch. From the first-tier data analyses, we identified three conceptual understandings among both students who gave the correct and false answers with wrong explanations. The fourth conceptual retained is scientifically correct. The two-tier development is presenting below in Frame 3.

Frame 3: Two-tier/Question 3

Put a cross in the box that corresponds to your answer:

❒ When we touch objects in an evenly heated room, they are at the same temperature in touch.

❒ When we touch objects in an evenly heated room, they are not at the same temperature in touch.

Which one of the following is the reason for your answer to the previous question?

❒ Objects in the room are not at the same temperature in the touched because different materials do not all have the same physical transformation temperatures. For example, metal heats up much slower than wood, so metal objects seem to be always cooler than wood objects. The two materials do not react in the same way at the same temperature.

❒ Objects in the room are at the same temperature before they were touched but are no longer at the same temperature in the touched places. Indeed, the cold felt results from the fact that an amount of our hand's heat was transferring to the metal chair, an excellent thermal conductor, unlike wood, a poor conductor. Thus, if the hand gives heat to the metal, it is because the metal is colder than the hand. After all, the heat always goes from the hot matter to the cold matter. This phenomenon does not happen with wood because to touch its temperature, and that of our hand is balanced.

❒ Objects in the room are at the same temperature in the touched places because some objects conduct heat while others do not. Besides, the level of agitation of atoms in objects (temperature) is not the same. At a temperature of 36°C, our body carries out heat transfer with an object with a temperature below 36°C. Hence the feeling of coldness. The opposite happens when we touch an object that has a temperature above 36°C.

❒ Objects in the room are at the same temperature in the touched places because the temperature depends on the matter composition. Some objects are conductive, and others are insulating. In contact with our hands, we will feel the differences between conductive objects because of heat transfer. That said, their temperature (agitation of molecules or atoms of different materials) will differ all the same.

❒ Other. Please write: _____

The two-tier test: Question # 4

From the first-tier data analyses, we identified five wrong conceptual understandings. The fifth conceptual retained is scientifically correct. The two-tier developed is presented below in Frame 4.

Frame 4: Two-tier/Question 4

Put a cross in the box that corresponds to your answer:

❒ There is a difference between heat and temperature

❒ There is not a difference between heat and temperature

Which one of the following is the reason for your answer to the previous question?

❒ The temperature is the unit of measure of heat.

❒ The temperature can be cold or hot while the heat is hot.

❒ The heat is a sensation that one feels, and the temperature is in degrees (precise measure).

❒ The temperature can be measured objectively with a thermometer and can be positive or negative. Heat is not measured objectively.

❒ 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.

❒ The temperature can vary below or above 0°C while the heat is above 0°C.

❒ Other. Please write: _____

The two-tier test: Question # 5

From the first-tier data analyses, we identified four wrong conceptual understandings. The fifth conceptual is scientifically correct. The two-tier developed is presenting below in Frame 5.

Frame 5: Two-tier/Question 5

Put a cross in the box that corresponds to your answer:

❒ Sweat would tend to warm us up.

❒ Sweat would tend to cool us.

Which one of the following is the reason for your answer to the previous question?

❒ Sweat is secreted through the skin pores to allow our body to lower its temperature when it is too hot.

❒ 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.

❒ When our body becomes too hot, it evacuates this excess of heat by sweating, which reduces our body heat.

❒ 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.

❒ Sweat appears when we are hot. The water in our body evaporates, and our body heat will decrease.

❒ Other. Please write: _____

Discution

The paper and pencil questionnaire analyses revealed that the students' conceptual representations about the heat and the temperature concepts appear to be irreconcilable regarding scientific explanations illustrated in Table 2. The

identified categories are relevant and allowed the design of the double questionnaire to quickly know the representations of the students before and after teaching the concepts of heat and temperature.

Table 2. Summary of students' conceptual representation and of their corresponding scientifically accepted counterpart

Students' representation	Scientific representation
Coming out of a swimming pool, we shiver because the water on our body evaporates in contact with cold air.	Coming out of a swimming pool, we shiver because our body heat evaporates water droplets on our body.
Coming out of a swimming pool, we shiver because of the difference in the temperature between our body and that of the ambient air.	
Coming out of a swimming pool, we shiver because the air outside is colder than in the swimming pool or vice versa.	
During a physical change, the thermometer's temperature increases with the heat.	During a physical transformation, the thermometer's temperature indicated remains constant.
A wooden table and a metal chair placed in an isolated room for several days are not at the same temperature because, to the touch, the chair feels cold.	A wooden table and a metal chair placed in an isolated room for several days are at the same temperature because temperatures of the metal and the wood equalized after a reasonably long time. The chair, to the touch, appears cold because of the heat given up by the hand.
In a room with a temperature of 20^0C, a wooden table is at the same temperature as our body when we touch it because the wood is not cool to the touch.	In a room with a temperature of 20^0C, a wooden table is at the same temperature as that of our body when we touch it because hand and wood temperatures immediately equilibrate at the point of contact. After all, wood is a good insulator.
Temperature is the measure of the degree of heat.	Temperature is related to the random motion of the atoms and molecules in a substance.
The temperature may be hot or cold.	The temperature may be higher or lower: the temperature is a quantifiable quantity measured with a thermometer.
Heat is a sensation that cannot be measured.	Heat is a form of energy and can be measured in joules or calories (1 calorie = 4,184 joules).
Matters contains heat.	Matters contains thermal energy, not heat.
After running, the hot sweat formed in contact with ambient colder air becomes colder and cools us.	After running, the evacuation of sweat brings out the surplus of heat; hence the freshness felt. Sweat is a body's reaction to stabilize the body temperature when it is sweltering or during physical activities thanks to the sweat glands.

Many students have conflicting conceptual representations of the concepts of heat and temperature to solve the same problem related to different situations. The two-tier development must confront the student with multiple contradictory explanations, which some researchers qualify as distractors related to the same problem.

Conclusion

A brief review of the literature related to students' conceptual reasoning about heat temperature and thermal energy revealed the great difficulty in distinguishing the difference between heat and temperature concepts. Likewise, elementary pre-service teachers have serious conceptual problems to establish the relationship between heat and temperature. Note that many renowned researchers encountered these difficulties before the advent of thermodynamics. The paper-pencil data revealed that a tiny percentage of elementary pre-service teachers answered correctly, based on scientific reasoning. The majority hold erroneous beliefs as temperature measure the amount of heat containing inside an object. As well, they have considerable conceptual difficulties to consider hot and cold part of the same phenomenon. Studies worldwide demonstrate the ineffectiveness of traditional interventions to enhance students' scientific literacy (see Duit & Treagust, 2003; Gregg et al., 2001; Hewson & Hewson, 1988; Masson, 2001; Posner et al., 1982, for examples). For that, we must consider the students' conceptual reasoning before teaching. The two-tier test developed will allow educators to rapidly identify their students' reasoning (Rodriguez, 2016).

Recommendation

The following recommendations are made based on the findings of the study:

1. The teachers must identify their students' alternative conceptions before and after teaching about the concepts of heat and temperature.

2. To diagnose the students' alternative conceptions rapidly, the two-tier test developed could help the teacher.

3. Students have difficulty conceptually distinguishing between heat and temperature; teachers must develop strategy teaching confronting scientific and student misconceptions summarized upper.

Limitation

The two-tier test requests to be assessing by at least two experienced high-school physics teachers to vet each item to the student's level and the suitability of the language.

References

Alwan, A. A. (2011). Misconception of heat and temperature among physics students. *Procedia Social and Behavioral Sciences*, *12*, 600–614. https://doi.org/10.1016/j.sbspro.2011.02.074

Anderson, A. (1980). Some aspects of children's understanding of boiling point. In W. F. Archenhold, R. Driver, A. Orton, & C. Wood-Robinson (Eds.), *Cognitive Development in Science and Mathematics: Proceedings of an international Seminar* (pp. 17-21). Center for Studies in Science Education, University of Leeds.

Bar, V., & Travis, A. S. (1991). Children's views concerning phase changes. *Journal of Research in Science Teaching*, *28*(4), 363-382. https://doi.org/10.1002/tea.3660280409

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice*, *8*(3), 293-307. https://doi.org/10.1039/B7RP90006F

Carlton, A. (2000). Teaching about heat and temperature. *Physics Education*, *35*(2), 101-105. https://doi.org/10.1088/0031-9120/35/2/304

Chu, H. E., Treagust, D. F., Yeo, S., & Zadnik, M. (2012). Evaluation of students' understanding of thermal concepts in everyday contexts. *International Journal of Science Education*, *34*(10), 1509-1534. https://doi.org/10.1080/09500693.2012.657714

Coppens, N., Rebmann, G., & Munier, V. (2009). Suivre l'évolution des conceptions des élèves en mécanique: développement et évaluation d'exercises informatisés [Follow the evolution of students' conceptions of mechanics: Development and evaluation of computerized exercises]. *Teaching/ Didaskalia*, (35), 37-58. https://doi.org/10.4267/2042/31136

Clough, E., & Driver, R. (1985). Secondary student's conceptions of the conduction of heat; bringing together scientific and personal views. *Physics Education*, *20*(4), 176-182. https://doi.org/10.1088/0031-9120/20/4/309

Chu, H. E., Treagust, D. F., Yeo, S., & Zadnik, M. (2012). Evaluation of Students' Understanding of Thermal Concepts in Everyday Contexts. *International Journal of Science Education*, *34*(10), 1509-1534. https://doi.org/10.1080/09500693.2012.657714

Duit, R. (2006). *Bibliography: Students' and teachers' conceptions and science education, Kiel, Germany*. Institute for Science Education. http://www.ipn.uni-iel.de/aktuell/stcse/stcse.html

Duit, R., & Treagust, D. (2003). Conceptual change: A powerful framework for improving science teaching learning. *International Journal of Science Education*, *25*(6), 671-688. https://doi.org/10.1080/09500690305016

Erickson, G. (1980). Children's viewpoints of heat: A second look. *Science Education*, *64*(3), 323-336. https://doi.org/10.1002/sce.3730640307

Gregg, V. R., Winer, G. A., Cottrell, J. E., Hedman, K. E., & Fournier, J. S. (2001). The persistence of a misconception about vision after educational interventions. *Psychonomic Bulletin & Review*, *8*(3), 622-626. https://doi.org/10.3758/bf03196199

Gurcay, D., & Gulbas, E. (2015). Development of three-tier heat, temperature, and internal energy diagnostic test. *Research in Science & Technological Education*, *33*(2), 197-217.

Gurel, D. K., Eryılmaz, A., & McDermott, L. C. (2015). A review and comparison of diagnostic instruments to identify students' misconceptions in science. *Eurasia Journal of Mathematics, Science & Technology Education*, *11*(5), 989-1008. https://doi.org/10.12973/eurasia.2015.1369a

Harrison, A. G., Grayson, D. J., & Treagust, D. F. (1999). Investigating a grade 11 student's evolving conceptions of heat and temperature. *Journal of Research in Science Teaching*, *36*(1), 55-87. https://doi.org/10.1002/(SICI)1098-2736(199901)36:1<55::AID-TEA5>3.0.CO;2-P

Hestenes, D., & Halloun, I. (1995). Interpreting the force concept inventory. *The Physics Teacher*, *33*(8), 502–506. https://doi.org/10.1119/1.2344278

Hewson, P. W., & Hewson, M. G. (1988). An appropriate conception of teaching science: A view from studies of science learning. *Science Education*, *72*(5), 597-614. https://doi.org/10.1002/sce.3730720506

Masson, L. (2001). Instructional practices for conceptual change in science domains. *Learning and Instruction*, *11*(4-5), 259-263. https://doi.org/10.1016/S0959-4752(00)00032-3

Métioui, A., & Trudel, L. (2020). Unipolar reasoning in electricity: Developing a digital two-tier diagnostic test. *WSEAS Transactions on Electronics*, *11*, 85-92. https://doi.org/10.37394/232017.2020.11.11

Peşman, H., & Eryilmaz, A. (2010). Development of a three-tier test to assess misconceptions about simple electric circuits. *The Journal of Educational Research*, *103*(3), 208-222. https://doi.org/10.1080/00220670903383002

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: Toward a Theory of Conceptual change. *Science Education*, *66*(2), 211-227. https://doi.org/10.1002/sce.3730660207

Reiner, M., Slotta, J. D., Chi, M. T. H., & Resnick, L. B. (2000). Naive Physics Reasoning: A Commitment to Substance-based Conceptions. *Cognition and Instruction*, *18*(1), 1–34. https://doi.org/10.1207/S1532690XCI1801_01

Rodriguez, M. C. (2016). Selected-response item development. In S. Lane, M. Raymond, & T. Haladyna (Eds.), *Handbook of Test Development* (2nd ed., pp. 259-271). Routledge.

Romer, R. H. (2001). Heat is not noun. *American Journal of Physics*, *69*(2), 107-109. https://doi.org/10.1119/1.1341254

Sözbilir, M. (2003). A review of selected literature on students' misconceptions of heat and temperature. *Boğaziçi University Journal of Education*, *20*(1), 25-41.

Shin, J., Guo, Q., & Gierl, M. J. (2019). Multiple-choice item distractor development using topic modeling approaches. *Frontiers in Psychology*, *10*, 825. https://doi.org/10.3389/fpsyg.2019.00825

Tiberghien, A. (2003). Des connaissances naïves au savoir scientifique [From naive knowledge to scientific knowledge]. In M. Kail (Ed.), *Les sciences cognitives et l'école* [Cognitive science and school] (pp. 353-413). Presses Universitaires de France (PUF).

Tüysüz, C. (2009). Development of two-tier diagnostic instrument and assess students' understanding in chemistry. *Scientific Research and Essay*, *4*(6), 626-631.

Urban, H. (2017). Sequential reasoning in electricity: Developing and using a three-tier multiple choice test. *Science in Education/ Scientia in Educatione*, *8*(Special Issue), 285-292. https://doi.org/10.14712/18047106.755

Yeo, S., & Zadnik, M. (2001). Introductory thermal concept evaluation: Assessing students' understanding. *The PhysicsTeacher*, *39*(8), 496–504. https://doi.org/10.1119/1.1424603