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Exploring the Prevalence of Misconceptions Regarding Heat and Temperature among Grade Nine Natural Science Learners

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Abstract

Learners bring various misconceptions to class. The study explored learners' misconception prevalence about heat and temperature among Grade nine Natural Sciences learners. A single case study design with 30 Grade nine learners from one secondary school in Magatle Circuit. The Heat and Temperature Concept Questionnaire (HTCQ) was used to elicit learners' misconceptions. For each questionnaire item, percentage frequencies of incorrect, correct, and unanswered responses were calculated. The overall prevalence of misconceptions regarding heat and temperature among learners ranged from 40 to 93% (Mean 68.0% SD = 6.3), with the highest prevalence in thermal dynamic questions. The correct responses ranged from 0 to 57% (Mean = 25.1, SD = 7.1) where most learners scored between 20-30%, while unanswered questions ranged from 0 to 13% (Mean = 6.9, SD = 1.3). These results show a high prevalence of misconceptions. They could not explain how heat travels within molecules of different objects because of the lack of a link between every knowledge and school science. The findings of this study have several implications for classroom planning, teaching, and the designing of learning materials.

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INTRODUCTION

Learners deal with heat and temperature in their everyday life and their experiences of the world change as they get old (Alwan, 2011). Their understanding of nature sometimes controverts scientific concepts. It is important when teachers plan teaching and learning materials to know how these naïve conceptions differ from the scientific explanations and why learners construct such ideas. Physics education research shows that learners' understanding and epistemological beliefs (Sharma & Ahluwalia, 2012 strongly influenced new concepts). Wenning (2008) explicates that learners do not come to school as clean slates, meaning they come to school with prior knowledge. Learners come to school with their scientific knowledge, which is correct or incorrect. Pre-existing knowledge can lead to gaps between what learners learn and what the teacher expects them to learn (Sharma & Ahluwalia, 2012). Teachers do not understand why learners do not science concepts. Learners' failure be from several factors, such as improper teaching or a clash between pre-existing knowledge and scientific knowledge, especially where teachers cannot resolve the difference. Learners come from different socio-cultural contexts, and their experiences affect how they grasp scientific concepts.

The Constructivists' approach underscores that learners interact with the nature to learn (Kural & Kocakulah, 2010). It suggests that learners bring to class ideas about their environment, which differ from school science (Kural & Kocakulah, 2010). Wenning (2008) refers to learners' improper interpretations of the physical world as alternative conceptions, while Yalcin et al. (2009) refer to them as preconceptions. Preconceptions that conflict with the scientific views are called misconceptions. Pathare and Pradhan (2010) assert that a misconception is more than having a fact to memorise. Misconceptions may arise from daily language and metaphors, learners' presumed ideas, and other teacher-driven misconceptions (Pathare and Pradhan, 2010). Students' misconceptions of heat and temperature emanate from their experiences in early years of schooling (Schnittka, 2009). Schnittka (2009) further explains that children experience the temperature changes and consider it as heat. Heat and temperature are important concepts in all science and learners' day-to-day lives.

Heat and temperature constitute secondary school and university levels. Previous study found that students have difficulties discriminating between heat and temperature (Alwan, 2011). Extensive studies have dealt with misconceptions of heat and temperature. Researchers like Kartal et al. (2011), Kulkarni and Tambade (2013), Tanahoung et al. (2010) identified students' misconceptions of heat and temperature at the university level using diagnostic multiple-choice tests. Other studies identified learners' misconceptions at secondary and primary levels using multiple-choice tests (Akbaş, 2012; Gönen & Kocakaya, 2010; Turgut & Gürbüz, 2011). There has been no study conducted in Magatle Circuit on Grade nine learners' misconceptions regarding heat and temperature to the researchers' knowledge. Therefore, the present study focused on exploring the prevalence of misconceptions for Grade nine learners about heat and temperature in the Magatle Circuit. Exploring the prevalence of misconceptions is important because it leads to teachers searching for new ideas for teaching physics in secondary schools.

Learners have misconceptions regarding their physical world (Wenning, 2008). Learners come up with various impressions and concepts about their own lives (Kartal et al., 2011). According to Kulkarni and Tambade (2013) and ElKababi et al. (2020), learners have challenges understanding heat and thermodynamics. Several researchers have studied learners' misconceptions regarding heat and temperature at the university level using diagnostic tests and questionnaires (Kartal et al., 2011; Kulkarni & Tambade 2013; Nottis et al., 2010; Alwan, 2011). Other researchers like Gönen & Kocakaya (2010) used primary school learners as respondents in the study. Most studies identified learners' misconceptions regarding heat with little regard to their prevalence. It is a gap in the literature which this study sought to narrow. Thus, this paper contributes to the understanding of the prevalence of learners' misconceptions on thermodynamics topics so that teachers can aim at methods that minimize them. Therefore, this study explored the prevalence of misconceptions concerning heat and temperature among Grade nine learners in the Magatle Circuit. The findings are important to teachers and textbook publishers to suggest feasible solutions to minimise the misconceptions. Kavsut (2010) contends that minimising learners' misconceptions improves the quality of learning.

The purpose of the study was to explore the prevalence of misconceptions regarding heat and temperature among Grade nine Natural Sciences learners in Magatle Circuit, South Africa. The research question that guided the research was: what is the prevalence of misconceptions regarding heat and temperature among Grade nine

Natural Science learners in Magatle Circuit?

Misconceptions on any topic can be problematic to both educators and learners (Hlatshwayo, 2006). Misconceptions on heat and temperature have been widely studied. Presented in the literature are some of the findings from different studies. According to psychology, an individual prior knowledge is very important in learning (Seçken, 2010). So, identifying misconceptions and using the correct teaching methodologies could improve the quality of teaching (Seçken, 2010). Alwan (2011) explains the importance teacher knowledge concerning the use effective methods to minimize misconceptions.

Also, Alwan (2011) studied students' misconceptions about heat and temperature among 53 students at Alfateh University in Tripoli. Data were collected using a questionnaire. The findings revealed many students confused heat and temperature concepts and did not know how to distinguish the two. It was also revealed that some students regarded heat and temperature as alternative expressions. Alwan (2011) revealed that while students could solve mathematical problems in the questionnaire, many did not understand the formulae's concepts. Kartal et al. (2011) used a diagnostic test to identify science teacher candidates' misconceptions regarding heat and temperature. Their findings revealed that students' misconceptions were the reasons for choosing the incorrect answers, and they did not seem to understand heat and temperature concepts. Therefore, students used the two concepts interchangeably.

Although several studies have identified high school learners' misconceptions about heat and temperature. Other studies suggest that learners at all levels have challenges to distinguish between heat energy and temperature (Nottis et al., 2010). A study conducted by Kulkarni et al. (2013) showed that students had serious difficulties understanding heat and thermodynamics in physics in general when taught using the traditional teaching method. The researchers used the Thermodynamic Concept Test (TCT) to assess students' conceptual understanding of heat and thermodynamics at the undergraduate level.

Also, a study by Tanahoung et al. (2010) to investigate misconceptions among Thai first-year science students identified specific common misconceptions among students' written responses. The study found that most students could not offer valid reasons for their answers. It could result from poor teaching approaches that did not address misconceptions. Anwar et al. (2019) used the ARIAS model to improve learners' conceptual understanding and minimised misconceptions. Akbaş (2012) found that students did not adequately understand the concept of temperature and its factors.

In Turkey Gönen & Kocakaya (2010) conducted a study on grade six to eight learners' cognition of heat and temperature that learners had challenges to connect between science knowledge and everyday life practices. For example, students thought skin or touch could determine the temperature of a material. Turgut et al. (2011) study found that eighth-grade learners had misconceptions on thermodynamics.

METHODS

A non-experimental quantitative case study (Yin, 2009, Creswell, 2007) was used. The design was suitable for the study since the data were collected using a questionnaire. A case study is characterized by probing the characteristics of a unit (Cohen, Manion & Morrison, 2007; Maree, 2007). In this study, the researchers probed misconceptions prevalence about heat and temperature amongst Grade nine learners in the Magatle Circuit. According to Macmillan (2010) a case can be an individual, group, activity, event, or process. In this study, the case was Grade nine learners in Magatle Circuit. Yin (2009) contended that a survey study uses statistical generalisation, while a case study depends on analytical generalisation. Thus, this study aimed to generalize the results to some broader theory. A case study design characteristics were met: specificity, boundaries, inductive, descriptive, and voluntary participation. Marshall and Rossman (2006, p. 164) allude that specificity refers to "specific organization, program or process", and in our case it is the misconceptions. For boundaries, Stake (1995) stated a case study must always have boundaries and in this study the boundary is one grade, nine learners.

The population of the study was learners from Magatle Circuit. Thirty Grade, nine learners from one high school in Magatle Circuit served as the sample for the study. Magatle Circuit has eight senior secondary schools. Grade nine learners were selected because the scheme of work had heat and temperature topic at that time.

A class of 30 Grade nine learners was conveniently selected as the sample for the study. These Grade nine learners were selected because they were near the second researcher's workplace, and hence he had easy access to them. A convenience sample encompasses selecting the nearest individuals to serve as respondents to avoid high travelling expenses and time-wasting.

A diagnostic test, Heat and Temperature Concept Questionnaire (HTCQ), was deployed to collect information from a Natural science class. Heat and temperature Concept Questionnaire (HTCQ) is online material available for thermal physics knowledge testing. According to Neuman (2006), validity means truth, and authenticity is providing an honest description of one's social life. In this study, three teachers teaching Natural Science validated the questions in the questionnaire, and a few changes were made to naming some items to fit the South African context. A pilot study was conducted using twelve (n = 12) learners not included in the study for reliability. The overall Cronbach Alpha was 0.77, suggesting the instrument was suitable for the study. The Heat and Thermal Concept questionnaire (HTCQ) test had 30 multiple-choice questions to explore learners' understanding of the basic concepts of thermal physics. The items of the HTCQ test comprised four conceptual sections: heat, temperature, heat transfer and temperature change, as well as thermal properties of materials. The questions in the various sections enabled the researchers to identify the misconceptions that learners held. HTCQ was applied once during this diagnostic study of learners 'conceptual knowledge of thermal physics.

Data were collected using the HTCQ questionnaire. The second author distributed the questionnaire to 30 learners. All learners answered the questions by selecting the best choices that best described their understanding of the concepts. After one hour, the second author collected the completed questionnaire.

Descriptive statistics: percentages, means and standard deviations were employed to determine the misconceptions prevalences regarding heat and temperature among Grade nine learners. For every concept, learners' responses to items in the questionnaire were coded as incorrect, correct, unanswered, and presented as percentages in tables. The frequency of the incorrect responses over the total number of leaner times 100% constituted the prevalence of learners' misconceptions.

RESULTS AND DISCUSSION

The prevalence of Grade nine learners' misconceptions was calculated using percentages. Results show that learners' misconceptions were prevalent in all the four major heat and temperature concepts ranging from 40 to 93.3% with an overall mean of 68.0%, SD = 6.3 (Table 1). The correct answers ranged from 0 to 57%, Mean = 25.1, SD = 7.1 where most learners scored between 20-30%. Also, there are some questions learners did not answer ranging from 0 to 13%. (Mean = 6.9%, SD = 1.3) (Tables1-5). The overall percentage means of learners' responses from the questionnaire were calculated and are presented in Table 1.

The items from the questionnaire and the respective learners' responses on heat were collated using percentages for incorrect responses, correct responses and unanswered items. The percentage of incorrect responses depicts the prevalence of misconceptions (Tables 2-5).

Table 2 shows a high percentage of incorrect responses regarding heat with prevalence ranging from 50% to 77%, Mean = 66.4, SD = 8.3. Learners' correct responses ranged from 20% to 37%, while un-answered items ranged from 3% to 13%. Also, 67 to 73 % of learners responded incorrectly, showing that Heat and temperature are the same in items 13, 18, 23, and 24. The percentage of correct responses was very low, ranging from 20 to 37%, while unanswered responses ranged from 3 to 13%.

Table 3 shows that learners' incorrect conceptions of temperature ranged between 60% and 90%, Mean = 74.4%, SD = 10.2. Learners' correct conceptions of temperature ranged from 3% to 30%. Unanswered items constituted 0-13% for items 1 and 21. 80% to 90 % of the learners responded incorrectly that an object's temperature is directly proportional to its size. This high percentage was from items 1, 19, and 14 of the tests. Although 7% did not respond to items 1, 19 and 14 of the tests, a very low percentage of 3 to 17% responded correctly.

Table 4 shows that the percentage of learners' incorrect responses about heat and temperature change ranged from 40% to 70%, with Mean = 58.4%, SD = 10.2. The correct responses ranged from 20 to 57%, while the unanswered responses ranged from 0% to 13%. Sixty percent of the learners responded incorrectly that hot objects cool down and cold objects warm-up naturally in item 3 of the test. 40% of the learners responded correctly to item 3 and no unanswered item.

Table 5 shows that the percentage of incorrect responses ranged from 40% to 93%, with an overall Mean = 72.9%, SD = 13.6. That "metal can attract, hold, intensify or absorb heat and cold" had the highest number of incorrect responses, thus had the most prevalent misconception. The correct responses ranged from 0% to 30%. On item 29, 60% of the learners did not respond.

The study explored the prevalence of

Table 1. Summary of learners' responses from the questionnaire.

Conception Category	Incorrect response %	Correct response %	Unanswered item %
Heat	66.4	27.9	5.8
Temperature	74.4	18.9	6.3
Heat transfer and temperature change	58.4	35.5	6.1
Thermal properties of materials	72.9	18.1	8.9
Overall Mean %	68.0	25.1	6.9
SD	6.3	7.1	1.3

Table 2. Learners' conceptions of heat.

Conceptions of heat	Item Number	Incorrect response %	Correct response %	Unanswered item %
Heat is a substance Heat travels	10	77	20	3
Heat is not energy, Heat and temperature can be transferred.	22	50	37	13
Heat and cold are different, rather than opposite ends of a continuum	13	70	27	3
	18	73	20	7
	23	67	26	7
	24	67	30	3
Temperature and heat are the same thing.	27	60	37	3
	30	67	26	7
Mean %		66.4	27.9	5.8
SD		8.3	6.6	3.5

Table 3. Learners' conceptions of temperature

Conception of temperature	Item number	Incorrect response (%)	Correct response (%)	Unanswered item (%)
Temperature is the "intensity" of heat.	15	83	10	7
Perceptions of hot and cold are unrelated to energy transfer	21	67	20	13
When temperature at boiling remains constant, something is "wrong."	5	60	30	10
Boiling point is the maximum temperature a substance can reach.	19	73	24	3
A cold body contains no heat.	26	67	23	10
An object's temperature depends on its size.	1	83	17	0
	9	90	3	7
	14	80	13	7
No limit on the lowest temperature.	25	67	30	3
Mean %		74.4	18.9	6.3
SD		10.2	8.6	4.3

misconceptions regarding heat and temperature among Grade 9 Natural Sciences learners in Magatle Circuit, Capricorn District. The results show a high (68.0%) overall prevalence of misconceptions among learners in all four concepts. The most prevalent (93%) misconception was that metal could absorb attract, hold or intensify heat and cold (Table 5). It implies that the vast majority of learners did not clearly understand the properties of energy transfer among objects,

Table 4. Learners' conceptions about heat transfer and temperature change.

Conception about heat transfer and temperature change	Item number	Incorrect response	Correct response	Unanswered response
Heating always results in an increase in temperature.	5	60	30	10
Heat only travels upward.	20	53	40	7
Heat rises.				
Heat and cold flow like liquids.	13	70	27	3
Temperature can be transferred.	7	50	47	3
Objects of different temperature that are in contact with each other or in contact with air at different temperature do not necessarily move toward the same temperature. (Thermal equilibrium is not a concept.)	2 6	40 67	57 23	3 10
Hot objects naturally cool down, cold objects naturally warm up.	3	60	40	0
The kinetic theory does not really explain heat transfer. (Explanations are recited but not believed)	21	67	20	13
Mean %		58.4	35.5	6.1
SD		10.2	12.7	4.5

Table 5. Learners' conceptions about thermal properties of materials.

Learners' conception about thermal properties of materials	Item no	Incorrect response (%)	Correct response (%)	Unanswered response (%)
Temperature is a property of a particular material or object.	24	67	30	3
Metal has the ability to attract, hold, intensify or absorb heat and cold.	9 16	89 93	4 7	7 0
Objects that readily become warm do not readily become cold.	25	67	30	3
The boiling point of water is 100°C (only).	4 8	73 57	27 30	0 13
Ice is at 0°C and/or cannot change temperature.	1	83	17	0
Water cannot be at 0°C.	11	74	19	7
Steam is more than 100°C.	6 19	67 73	23 24	10 3
Materials like wool have the ability to warm things up.	17	76	17	7
Bubbles mean boiling. The bubbles in boiling water contain "air", oxygen or nothing.	12	66	27	7
It starts to melt at 420°C	29	40	0	60
Mean %		72.9	18.1	8.9
SD		13.6	10.4	14.6

yet the concepts in that item refer to everyday life issues. It suggests learners could not distinguish between heat and temperature. This finding is comparable to Kartal et al. (2011) and Gönen et al. (2010), who found that learners had difficulties describing heat and temperature.

This study shows more than 66% of the learners held misconceptions about the heat concept (Table 2). A high percentage of learners' incorrect responses suggest a high prevalence of misconceptions. Also, it implies that learners' understanding of heat was shallow because learners regarded heat and cold as two different concepts. It is no wonder their correct responses constituted only 27.8%, with the vast majority scoring between 20 and 30% (Table2). These findings are not surprising because ElKababi et al. (2020) reported learners' difficulties understanding heat among student teachers in Morocco. ElKababi et al. (2020) suggest the decline in learners' understanding of the heat concept may be because of the lack of a clear vision in curricula, textbooks and other instructional materials. Also, teachers unknowingly discourage learners from daring to study science, limiting the number of high school learners studying science subjects (Fortus & Daphna, 2020).

Learners had difficulties understanding the concept of temperature, with misconception prevalence ranging between 60% and 90% (Table 3). Many believed that by touching, one could determine an object's temperature, suggesting temperature is influenced by the nature material. In this way, they may think that temperature or heat and cold can flow. These views are similar to Fenditasari and Istiyono (2020), who contend that concepts of heat and cold are confusing to learners.

Learners had misconceptions regarding the boiling point of water. Item 5 asked about what was likely to be the temperature of water in the kettle left to boil rapidly on a stove. 60% responded incorrectly that the temperature of the water would increase to 110°C because water would still be boiling. According to learners' responses, when water boils, the temperature increase until the water evaporates. This finding agrees with Costu et al. (2007), who found that learners believed the temperature of boiling of water increased to more than 100ºC.

Learners' conceptions of heat transfer and temperature change revealed misconception prevalence ranging from 40 to 70% (Table 4). Learners' understanding of heat energy transfer was that heat can be transferred in one direction, and heat is transferred from hot to cold and not vice versa. These results point out that learners have a misunderstanding of heat flow. Learners thought that diverse temperatures do not move toward an equilibrium when objects of different temperature are in contact. This observation is in line with Fenditasari and Istiyono (2020), who observed learners' challenges in understanding heat transfer between objects at different temperature values.

Learners' conceptions of thermodynamics revealed the biggest range of 40 to 90% of misconceptions (Table 4). The highest prevalence of misconceptions was exhibited on item 16, which stated metals could attract, hold, intensify, or absorb heat and cold. The misconception on this item was high because of thermodynamic challenges for learners. They cannot explain how heat travels within the molecules of different objects because of the lack of a link between every knowledge and school science. This observation agrees with Kulkarni et al. (2013), who contend that learners have learning difficulties understanding thermodynamics. Tanahoung et al. (2010) contend that the teaching style in Thai high schools could be one of the causes of misconceptions. Learners tend to get a superficial understanding of heat and other topics like Newtonian Physics (Handhika et al., 2017) and Impulse and Momentum (Adianto & Rusli, 2021). In everyday life, "heat" is linked to temperature, which confuses learners in science lessons (Gönen & Kocakaya, 2010). Their experiences have no distinction between heat as the energy that can be transferred and temperature, which measures the kinetic energy of atoms in an object. There are other issues regarding heat and temperature that were not explored in this study.

Finally, there were unanswered questions that ranged from 0 to 13%. Although this study did not determine why learners did not answer some of the questions, it is assumed that they had no apparent answer. Some learners may have had no clue what the questions demanded, and some may have missed responding due to the limited time allocated. No clear answer to why some numbers were not answered. Therefore, more studies are needed to address such issues in physics and other subjects. Also, the use of a mixed approach would add new insights to the topic.

The study recommends teaching styles that can improve learning by minimising misconceptions (Supriana et al., 2020). The findings of this study have several implications for classroom planning, teaching, and designing of learning materials and future research. Also, teachers should provide opportunities for learners to make connections between their prior knowledge and science concepts. This study was limited to 30 learners and may not be used for statistical generalisation for surveys. Also, the study was limited to identifying the prevalence of misconceptions. The researchers did not find out other misconceptions that learners had outside the HTCQ questionnaire. The study did not address how the prevalent misconceptions can be minimised. The researchers recommend more studies with larger samples to identify methods to minimise these prevalent misconceptions.

CONCLUSION

This study showed that the majority (68%) of learners had misconceptions regarding heat and temperature, and 6.9% were unanswered, which implies that the correct answers were very low. Thus, learners have little understanding regarding the heat transfer between the two systems. Learners' misconceptions of heat and temperature were highly prevalent among grade nine learners. Most learners had misconceptions about basic thermal concepts such as heat and temperature concepts, heat transfer and energy change and thermal properties of materials. The high prevalence of misconceptions has far-reaching implication in Science, Technology, Engineering and Mathematics because many learners get discouraged by the low attainments and opt for other non-STEM subjects.

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