

“Secondary School Pupils’ Conceptions about the Behavior of Air Enclosed in an Inflatable Container under two Temperature Conditions”

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Abstract

The study investigated secondary school pupils’ views on the action of heat on air enclosed in an inflatable ball placed first in a hot, and then a cold environment. The study involved 86 form one and 64 form four students studying physics in four Nairobi province schools during term two in 2010. Both groups comprised boys and girls. A diagnostic test of reliability index 0.87 enabled the respondents to provide explanations for the gas behaviour. The scientific conceptions of the pupils who were just joining secondary school were compared with those of the pupils who were about to leave secondary school. The study detailed the quality of conceptions held by both the form one and form four students. Two broad categories of conceptions were detected: True Conceptions (TC) and Misconceptions (MC). Both descriptive (means, frequencies, graphs) and inferential statistics (chi-square, t-test) were used in interpreting the results. The results showed that there was no clear significant difference in the quality of alternative conceptions held by the form one and the form fours. Gender considerations showed a marked differential in favour of the boys at the two levels. The gender difference was also detectable at each of the form one and four levels. These results indicate that there is generally a low value addition to students’ conceptual development by the end of secondary schooling concerning behaviour of gases under the temperature conditions indicated. In addition boys were found to outperform the girls in this content area. Specific recommendations concerning the confrontation of the many unscientific ideas held by the students were suggested.

Key terms: alternative conceptions, diagnostic tests, gender differential, heat environments, quality of conceptions

Introduction

Learning of physics inexorably places Energy Matters as the central concern in most curricula (Trumper, et al, 2000). The various forms of energy, their transformations and subsequent conservation, utilisation and degradation form major constituents in these curricula at all levels (Fensham, 2002; Driver and Warrington, 1985). Besides, energy is the prime mover of industry, technology, and all production processes known to mankind (Wernet, et al, 2011; Mathuriya, 2010). It is useful in homes and indeed in all facets of life. Every person has direct concerns about energy matters all their life. It is only fair that this topic be given due attention in the school system. The various forms of energy studied in the secondary school curriculum include: Electricity and Magnetism, Light, Sound, Mechanics, Atomic and Nuclear energy, Heat and Thermodynamics. This study concentrated on a heat event derived from everyday experience.

Even before coming to school the pupils have had manifest encounters with the concept of heat energy. From the time they wake in the morning up to when they retire to bed heat energy will have impinged on their life styles (Driver & Millar, 1985). It is usual to study “Energy” in combination with “Properties of matter”. These topics are usually taught in a spiral curriculum implementation approach (Bunch, 2009; Trumper, 1996, Bybee, 1995). Thus, both the form one and form four pupils who participated in the study had been exposed to various extents to the content under investigation both in school and at home.

Yet studies on pupils’ understanding of events involving heat are replete with often unanticipated results. The pupils’ explanations are noteworthy in the novelty of expression, signifying a different theoretical paradigm for interpretation of concerned physical phenomena. Studies have coined many terms to label these pupil conceptions. They are often referred to as pre-conceptions, pupils’ naive ideas, alternative conceptions, misconceptions (Taber, 2000; Trumper, et al, 2000; Hammer, 1996), or pupils’ phenomenological primitives or p-prims (Di-Sessa, 2002; Ueno, 1993).

The main point of concern is that these pupils' ideas are stable and tenaciously held. They differ from experts' views on the same physical phenomena, and they affect how the pupils understand and interpret world phenomena involving the interaction of heat and matter. Clearly, the main aim of teaching secondary school physics is to ensure that these pupil ideas are confronted, modified or eliminated all together so that there is a gradual move to interpreting the physical world using scientifically accepted frameworks. By the time the pupils are leaving secondary school, it is expected that they have made significant progress in the shift towards embracing scientifically accepted explanatory frameworks for physical phenomena. Yet, the end of secondary school cycle national examinations usually tells a completely different story. Often physics is the worst performed subject. As a result the subject attracts the smallest number of candidates (KNEC, 2006-2010). In addition to diagnosing pupil performance at the two levels, this study sought to shed light on the kind of views predominant in the pupils thinking at these levels.

Problem of Research

The form one and form four pupils were provided with a written task concerning an inflatable ball. The task was modeled on Epstein's (1987) "Thinking Physics is Gedanken Physics". Essentially the task was a thought experiment. In the task, a pupil was charged with monitoring the experiment. The ball had been inflated with air and placed in the hot sun at noon. When the pupil pressed on the ball, it felt hard. The ball was then left in the open field until evening when the temperatures had dropped significantly. To the pupil's surprise the ball was now soft to the touch. The respondents were requested to provide explanations for the varying hardness of the ball, given that there had been no leakage of air from the ball after the initial inflation.

Research Objectives

The study sought:

1. To determine whether there was a class level difference in performance on the tasks concerning the ball placed in the two temperature conditions.
2. To detail the quality of conceptions held by the form one and the form four pupils concerning the behaviour of the ball in the two different temperature conditions.

In built in each of the objective was the need to detect whether the performance and the quality of the conceptions had a gender preferential.

The procedure

An integrated concept formation criteria (Amadalo, 1998) was used to determine the presence of True Concepts (TC) and Misconceptions (MC). An appropriate mark was assigned for each pupil's response. The scores ranged from 15 to 42 out of a maximum of 50 marks. The pupil explanations enabled the various shades of conceptions to be gleaned. Thus data was generated from pupils' individual responses and organised according to the objectives.

Results of Research

The respondent performances as evaluated from the concept formation criteria and the quality of conceptions held are presented below.

(i) Performance on the task according to class level findings

The raw performance data was transformed into mean group performances. Standard deviations and further inferential statistics were determined. The statistical analysis on performance data involved the determination of the t-test for unequal samples of unequal variance and is shown in the Table 1 below:

Table 1: t-test for performance comparison based on class level

Class level	Number, N	Mean performance, \bar{X}	Standard Deviation, s	t-test
Form 1	86	34.52	12.25	3.152*
Form 4	64	39.47	6.74	

* indicates the comparison is significant.

The t-test shows that there is a significant difference between the performances of the form fours relative to that of the form ones.

The form fours' and form ones' performance on this task was compared to reveal the direction of gender bias of the groups. Step-wise determination of the t-test was according to the groups as indicated below:

Table 2: t-test comparison based on gender

Groups compared	n	\bar{X}	s	dF	t-test
F1 Boys	48	38.69	7.89	84	31.47*
F1 Girls	38	29.25	9.04		
F1 Boys	48	38.69	7.89	92	8.08*
F4 Boys	46	44.01	4.32		
F1 Boys	48	38.69	7.89	64	18.37*
F4 Girls	18	27.85	10.12		
F1 Girls	38	29.25	9.04	54	0.5
F4 Girls	18	27.85	10.12		
F4 Boys	46	44.01	4.32	62	19.01*
F4 Girls	18	27.85	10.12		

* indicates the comparison is significant.

The results summarised in Table 2 above shows that performance is significant for all the groups compared except the F1 and F4 girls groups.

(ii) Quality of conceptions held by the respondents

The quality of conceptions held were determined by analysing the respondents' written responses. Out of all the responses made the True Conceptions were 12.5 %. The rest i.e. 87.5 % of the responses were classified as Misconceptions. Five general misconceptions categories emerged. They included:

- A: Heat expands and cold contracts the individual sizes of the air molecules.
- B: Heat makes the air molecules heavier, massive.
- C: Heat multiplies the number of air molecules, cold makes some to disappear.
- D: Molecules are closer during the day when it is hot, and more mobile during the evening when it is cold.
- E: As temperature goes down, pressure goes up.

Figure 1 below depicts the occurrence of the misconceptions among the analysed responses for each of the categories detected.

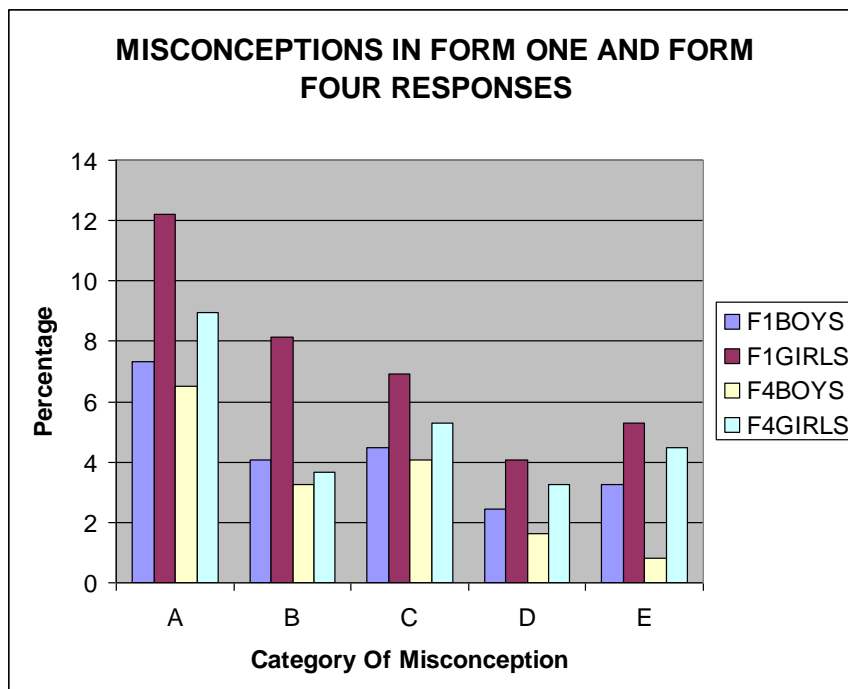


Figure 1: Occurrence of Misconceptions in the responses

The five categories are the secondary school pupils' way of explaining the air behaviour under the task conditions. These views are contrary to the foundations and explanations of scientifically accepted general gas behaviour.

Category A misconceptions were the most prevalent in all the responses analysed (34.96%). This was followed by categories C (20.73%), B (19.11), E (13.82%), and D (11.38%) in that order. Similarly, Form 1 Girls had the most number of misconceptions on all the categories considered (36.59%). This was followed by Form 4 Girls (25.60%). Form 1 Boys (21.55%) had fewer misconceptions than each of the Form 1 and Form 4 Girls. The grade level with the smallest number of misconceptions was the Form 4 Boys (16.24%).

The chi-square statistic yielded a calculated value of 6.242 at a confidence level, $\alpha = 0.05$. This value is much less than the tabulated value of 21.026 at the same confidence level. So, the responses are not significantly different despite their striking patterns.

Discussion

(i) The performance on the tasks

Since the form four mean performance is higher than that of the form ones it is clear that the direction of preference is in favour of the form fours. The form fours' performance shows a much smaller spread on the average indicating that this could be a deliberate result from instruction. On the other hand the form ones' performance shows a much higher spread indicating that at the time the form ones join secondary school they have a more diversified understanding of the behaviour of gases. Still, the comparison of the performance averages does not show a difference commensurate with the fact that the form fours have had four years of instruction whilst the form ones have hardly had one year. This result is in line with the findings of Ehrenberg, et al, (2001) as well as Jorgenson & Hyde (1974), who showed that pupils tend to improve in academic and reading ability as they progress up the academic ladder. The findings also agree with Ruthven (2010) who found a slight improvement in mathematics and science due to increased grade level among secondary school pupils who had participated in an international survey.

The comparison of the form one boys and girls shows that even at this level the boys already have an edge compared to the girls. This is contrary to the findings of the 2003 "Trends in International Mathematics and Science Study (TIMSS)", which detected no overall gender related difference in science and mathematics achievement. This TIMSS study found that girls significantly outperformed boys in 7 nations (Sanders, 2008; Gonzales, et al, 2004; Martin, et al, 2004). Hyde, et al, (2008) found that despite apparent parity in performance between boys and girls, the stereotype persists that girls struggle with math and science at secondary school and higher levels. Contrarily, Kost-Smith (2010) determined that boys always out-perform girls in physics tasks and tests. This current study tends to support the stereotype views.

The difference between form one and form four boys performance shows a slight advantage for the form four boys. Boughton (2000) found a similar trend when profiling performance among Canadian science and mathematics students' achievement. However, the mean performance for each group is not far apart, indicating that the impact of instruction was essentially minimal. Stinebrickner & Stinebrickner (2011) found out that in general, secondary school students do not perform to the level that is expected of them. As a consequence many opt out of high intensive science and mathematics after school courses. The overall gain at the secondary school exit point relative to their performance on entering secondary school is not that high to give them enough confidence of doing well at the more demanding post secondary courses in science and mathematics.

Comparison of the form one (boys and girls) and form four girls performances brings up results that are confounding. The form one boys outperformed the form four girls. The boys obtained a higher mean mark and the spread of the marks was much smaller compared to the girls. Similarly, the form one girls' performance was better than the average form four girls' performance. The form four girls' range of responses shows a lower mean and a bigger spread, indicating that they still contain many unresolved issues about gaseous behaviour under the task specified conditions. Taken to the extreme it would appear that the four secondary school years served the purpose of unlearning whatever knowledge the girls came with in form one. Again, when the form groups' responses were compared, the boys' average performance was significantly better than that of the girls. Many studies suggest that the girls lag behind the boys in science performance at all levels (Fiske, et al, 2009; Hyde, et al, 2008; Halpern, et al, 2007).

These current findings compare performance on the same test across different class levels and are in agreement Hamilton, et al (1995) who traced sex related performance across several grades. Like in the Hamilton study, the girls' performance in this study could be attributed to factors that have their roots in none school persuasions. Such differences in performance have been attributed to factors derived from psychology, endocrinology, sociology, economics, and general educational orientations (Ceci & Williams, 2010). These factors suggest that male–female mathematical and spatial ability gaps, sex discrimination, sex differences in career preferences, and lifestyle choices are pre-defined by the gender differential in mathematics and science performance.

(ii) The quality of conceptions held by the respondents

Sakpakornkan & Harries (2003) found ranges of between 2.2-31.2% and 20.4-59.2% for Thai and English secondary school students' responses on a mathematics diagnostic test belonging to the True Conceptions category. Nunes & Bryant (2008) found that the fraction of correct student responses when studying two year groups was 31-35%. This study was concerned with challenges and insights to pupils' implicit knowledge concerning rational numbers and other intensive properties. The Correct Responses in the current study have a range of 8-19%, much lower than the Nunes and Bryant (2008) findings.

Category A misconceptions were held by a significant number of respondents. This category of pupils' conceptions could have arisen because of misapplication of the general effect of heat on bulk solids, liquids and gases. It common experience that when matter is heated in bulk, it expands (Hinwood,1992). However, the hardness to the touch of the ball left in the hot sun is due to increased pressure of the air. This is explained by considering the air particles as miniaturist and in-expandable. Increased pressure is a result of heightened impingement of the individual particles on the inner surface of the ball. The more often the particles hit that surface the more the pressure increases. In the case of air, heat will not increase individual air molecule sizes. These twin misconceptions find some traction and rapport in the work of Peat, et al, (1963) who reported that after heating a Cobalt (II) complex, the molecule increased in size. Walker & Trinick (1986) also reported that there was shortening of the tail of the myosin molecule when heated in the range 25° - 42 °C. However, the two molecules which have been reported to be temperature sensitive are giant biological molecules whose behaviour may be significantly different from that of the basic gas molecules the current study was involved in.

Category B misconceptions implied that heat makes the air molecules heavier, massive. The heat contains a substance which gets deposited into the material that is heated. The reasoning here could have been from the commonly held view that the more massive a substance is, the more it would press on the surface it is resting upon. In solids and liquids, this scenario could be sustained since both states of matter assume definite shapes in an enclosure. Gas shape is indefinite, depending only on the shape of the container. Heat does not add any matter to the individual gas particles. It only agitates the gas particles, making them more frantic, more energetic. The increased energy makes the air molecules to slam into the ball wall more frequently causing the noticed pressure. In the evening, when the temperatures are colder, the air particles are slower, less agitated. They impinge less frequently onto the ball wall resulting in the reduced ball pressure. Literature indicates a relationship between heat and mass per unit volume for a gas (Kennan, 1999-2011; Gayathri & Bagchi, 1999; Aleksandrov & Bazelyan, 1996). These studies have reported consistently that the higher the temperature, the smaller the mass per unit volume (density) of the gas. In any case the relationship between heat and mass per unit volume is reciprocal, not proportional. And this cannot be confused with the absolute mass that the responses in this category allude to.

Category C respondent views implied that when it is hot, the number of gas molecules increases, and this number reduces when it is cold. The foundations of the kinetic theory of gases postulate that the individual gas particles are indivisible. Individual molecules cannot be broken to form more numbers. Besides, in the task, gas molecules were not allowed to leak into or out of the ball. This alternative conception could be due to the view that the more the molecules, the more they lie against the surface of the ball. The confusion is in the source of extra molecules necessary for the pupils to layer the surface of the ball. Then, like in solids, more gas could have been invoked to cause an increase in pressure. This type of misconception could find some similarity in the work of Volland (2010). In the report about determination of percentage of water in popcorn, Volland reported that higher temperatures produce more gas molecules from the popcorn seed. This means more water molecules impact on the kernel wall increasing pressure and making the popcorn to fluff out. Yet it should be realized that in this particular case what the heat does is simply to release captive water molecules which already existed in the popcorn seed. Category D conceptions suggested that molecules are closer at hotter times and further apart when it gets colder.

Given the known proportional relationship between temperature and agitation of air molecules, the above view would be untenable. Palkanis (2006) states that as temperature of a gas increases, the molecules move faster and further apart. If anything, the pupils should have indicated that heat causes the molecules to be further apart. Also category E responses suggested that as the temperature goes down the pressure will go down. Though not so many respondents held this view, it is nevertheless a misconception. The etymology of gas laws indicates that the relationship between temperature and pressure has always been of direct proportionality. This view is augmented by the kinetic theory of gases which also emphasize the contribution of increased temperature to agitation and therefore increased pressure.

Conclusions

The study investigated two main objectives concerning the behaviour of a gas enclosed in an inflatable container at two different temperatures. The first objective involved determining the performance of form four pupils and comparing this to that of form ones. In this way it is possible to judge the value addition of the four years of secondary science schooling. The results showed that there was a small but significant difference in the performance means of the two groups favouring the form fours. When gender considerations were brought to bear on the results, the boys outperformed the girls at all levels. The form four boys had better results compared to the form four girls as well as form one girls and boys. On this objective the form four girls fared worse than every other group. Not only were they outperformed by the form four boys but also by the form one boys and girls. It would appear that this group did not benefit much from secondary science schooling concerning gas behaviour.

The second objective was concerned with determining the quality of conceptions held by the different groups of form one and form four respondents. The total percentage of the True Conceptions held by all the respondents was an average of 12.5%. The portion is below the percentage determined from similar studies. Five categories of misconceptions were identified. The most prevalent Misconception in all the responses was the one identified as Category A in which pupils suggested that heat actually makes individual molecules to expand. The least prevalent misconception was category D whereby the pupils put forward the view that during the day when conditions are hot the molecules coalesce together but get far apart in the evening when it is cold. A substantial number of responses suggested that heat makes the air molecules heavier, heat multiplies the number of air molecules, and that as temperature fell the pressure in the container increased. For each category of responses the form one girls contributed the greatest percentage, whereas the form four boys contributed the smallest percentage.

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Appendix A: The Integrated Concept Formation Criteria

Level	Description of responses	Conception Equivalent	Scores allocated
1	Lack of response, or response clearly unacceptable	No Conception, NC	0
2	Response indicated verbatim definitions, but further explanations were hazy, fuzzy, unclear	Misconception MC	1-2
3	Response indicated reasonable explanations involving limited related concepts, or explanations were not in a conventional form, but appeared plausible	Misconception MC	2-4
4	Response was accurate and involved linking particular concept properly with related relevant key concepts	True Conception TC	5

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