A Report on a Preliminary Diagnostic for Identifying Thermal Physics Conceptions of Tertiary Students

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Abstract

A solid understanding of students' conceptions in thermal physics is absolutely necessary for successful development of instruction and for promoting understanding of and enthusiasm for the subject. This study reports on student understanding for a range of thermal topics. The sample included first and second year university students studying physics and the tool was a short, 15 question, concept inventory-like 'Diagnostic Survey' administered at the beginning of first semester 2009 at the University of Sydney. The results indicate that some thermal physics misconceptions exist for a large proportion of tertiary level students. More specifically, basic concepts, such as heat transfer, appear to be systematically misunderstood by the more novice student. For Australian tertiary instructors, our preliminary diagnostic could provide information about student's abilities in thermal physics and, consequently, why they experience difficulty understanding similarly structured fundamental processes in other physics topics. The subjects covered in our diagnostic are considered a foundation of any thermal physics course and are present in many further science related courses. Thermal topics such as atmospheric thermodynamics and climate change thermodynamics have lately appeared the popular headlines, strengthening the justification for at least a basic understanding of such topics from students studying physics at university.

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Introduction

Although it may appear that there is plentiful literature on students' conceptions and that there are many diagnostic tests developed, administered and ultimately reported on in published papers, the number of reports decreases tremendously when considering work in an Australian context, and work at a tertiary level (Meltzer, 2004). The importance of gauging student understanding has been established over almost three decades of relevant and influential work. However, there are substantial sections of physics content that continue to remain troublesome for students for reasons that are not yet fully understood (Duit, 2002). Thermal physics is an area that has not attracted as much work as other topics, yet it covers what some consider to be the most fundamental, common physical processes (Hurley, 2005); processes that, through mastery, lead to a fuller understanding of science in general (Linn, 1993). Linn and Songer's study reports successful realisation of sophisticated beliefs in science through examples exclusively from the subject area of thermal physics. It has also been reported that thermal physics concepts are amongst the most challenging across most levels of expertise (Lewis & Linn, 1994). Finally, thermal physics also appears in many university courses, from medicine to engineering and applied science, making knowledge of thermal physics (at least formally) necessary for a wide range of careers.

This study presents the findings of a survey probing students' conceptions of basic thermal physics principles and, in doing so, begins to reveal some of the unknowns in this familiar story.
The specific research objectives are as follows:

- To pinpoint which thermal physics concepts are proving most difficult for university students from a large range of thermal concepts
- To identify which of these recognised thermal physics concepts are basic and/or fundamental enough to be of interest for further investigation.
- To compare novices and experts with regards to these topics to help identify the ease or difficulty of progress by assessing the state of student conceptions at different levels of expertise.

Theoretical background

The motivation for the current study lies with the familiar and significant research on misconceptions, conceptual change and is also within research on novice-expert comparisons. 'Misconceptions' was the term initially given to 'incorrect ideas' students presented whilst learning science. There are now a number of various terms in use, including 'alternative conceptions', which was introduced to avoid labelling conceptions as necessarily wrong. For clarity, and without judgement, the term misconception is used throughout this paper.

Nussbaum and Novak (1976) succinctly state the most defining and important observations from misconceptions research. First, similar misconceptions seem to be prevalent even among students of different cultures, ages and abilities. Next, some views are persistent and difficult to change or replace. Lastly, existing conceptions affect subsequent learning.

Most of the research based on misconceptions in thermal physics has focused on younger (primary and middle school) children. Results from those studies are relevant to the present study since many of the conceptions of young children are articulated by older children and even by students who have some formal physics instruction (Engel Clough, Driver, & Wood-Robinson, 1987). Table 1 summarises the main thermal physics misconceptions for a range of student ages.

The Force Concept Inventory was the first reliable tool that exposed the widespread existence of misconceptions in motion and force topics and so it became clear that such misconceptions needed to be addressed (Mazur, 2001). Conceptual change is the area of research which looks to encourage and facilitate learning through encouraging a change in perspective. Often, this involves overcoming misconceptions. Research on conceptual change has been based on two fundamentally different perspectives. The theory-like perspective (Vosniadou, 1994) assumes that conceptions are manufactured from a coherent theoretical framework. The fragment-like perspective (diSessa, Gillespie, & Esterly, 2004) assumes no higher order structure to conceptions and treats them more or less as independent. Underlying both views is the theoretical stance that conceptual change and meaningful learning are synonymous (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Conceptual change research is also theoretically aligned with constructivism, and a summary of the pair's relationship is neatly presented in Smith, diSessa and Rochelle (1993).

In order to help the reader appreciate the significance of the results presented in this paper, I offer a simple model of thinking from Sabella and Redish's (2007) summary of findings from cognitive science, neuroscience and behavioural science (Sabella & Redish, 2007). The first and smallest entity considered in Sabella and Redish's summary is the neuron. The authors identify two important observations regarding neurons; that activated neurons can in turn activate other neurons and that knowledge seems to be associated with an increase in associations or synaptic connections

Table 1: Misconceptions of young children and university students

Young Children		University Students (Meltzer, 2004)
Assuming a caloric theory of heat transfer (Erickson, 1979)		Trouble distinguishing between the concepts of heat, temperature, internal energy, and thermal conductivity
Confusion regarding the terms 'heat' and 'temperature' (Erickson, 1979, 1980)		
Assigning 'hot' and 'cold' to objects as discrete characteristics rather than two ends of a continuum (Erickson, 1979, 1980)		Misinterpreting heat as a mass-independent property of an object
Uncertainties about boiling, including erroneous interpretations of the constituents of the 'bubbles' and why the water level decreases (Bar & Gallili, 1994)		Interpreting temperature as a measure of intensity with reference to the object
Ignorance related to the conservation of energy (First Law of Thermodynamics) (Kesidou & Duit, 1993)		Thinking of temperature and heat as the same concept
Incorrect or incomplete associations and interpretations of energy and thermodynamic processes (Sila & Olgun, 2008)		Believing that objects made of materials that are good thermal conductors are hotter or colder than other (poorer thermal conductors) objects at the same temperature due to sensations experienced when they are touched

between neurons. This implicitly presents learning as a *physically verified neural associative process*. The authors then move on to larger units, describing the learners whole knowledge structures (schemata). Schemata are unique to individuals as well as to particular situations and are crudely characterised by a set of connections between concepts. They are often used to describe a student's approach to problem solving because they can identify which concepts the student has recalled and how that student is linking these concepts together to arrive at a solution. The more expert a student becomes, the more concepts become activated (where necessary) and the more numerous and appropriate their inter-schema associations are. See Figure 1 below.

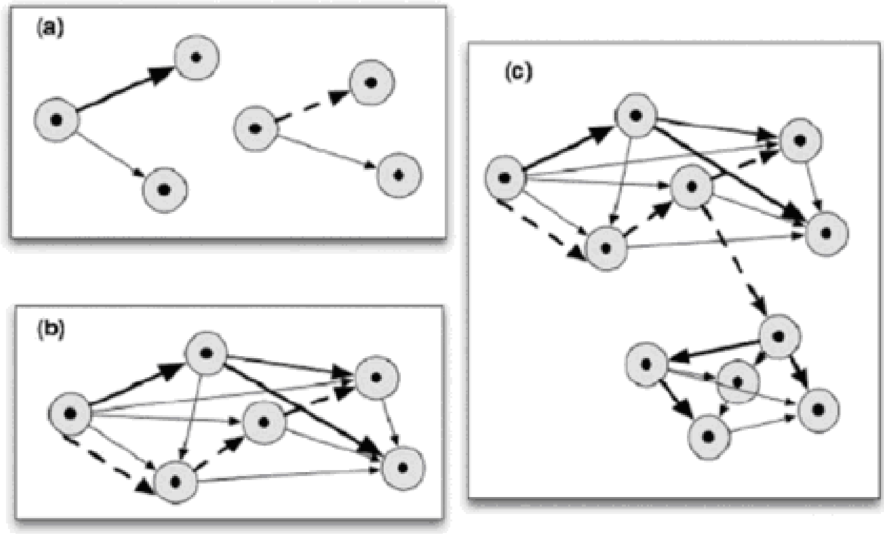


Figure 1: Representation of knowledge structures from Sabella and Redish (2007, p1019). The nodes represent declarative knowledge and procedural rules. The lines represent relations between different nodes.

This neuro-scientifically based model therefore represents experts as having more nodes, or ‘knowledge’, and a greater ability to make appropriate connections between them. In educational literature, expertise is expanded on more fully. Broadly defined as the collection of advanced capabilities as the result of continuous and relevant efforts in a particular field (Ertmer & Newby, 1996), results from this body of work indicate that generally, experts excel primarily in their fields; they recognise significant patterns, work faster and more efficiently than novices, have superior memory, perceive problems differently and spend more time thinking about problems. Another important characteristic of experts is that they have superior meta-cognitive skills and are therefore better at monitoring themselves, especially when solving problems (Feldon, 2007). Cognitive science legitimises these differences by presenting evidence which shows that for novices and experts, different parts of the brain are active whilst problem solving (Bjorklund, 2007).

To identify conceptions of students is to reveal information about the structure of their knowledge in physics, their ideas, beliefs and ability to reason within the subject, about the subject. Clearly a desirable outcome and unsurprisingly, a difficult task. Multiple-choice diagnostic tests have been a useful and informative tool in revealing conceptions. They can be used for large samples, can be objectively graded and statistically analysed. Although there are inherent limitations, they prove efficient in providing overviews of data. When a more in depth analysis is intended, qualitative approaches dominate. Interviews offer a richness that is unparalleled amongst research methods but introduce the risk of researcher bias and usually require a lot of time (Otero & Harlow, 2009). Free response questions are a compromise, balancing detail, timing and reliability of analysis.

Development of the Diagnostic Survey

The Diagnostic Survey consisted of 12 multiple choice questions and three longer response questions (see Appendix A). The 12 multiple choice questions were selected from a variety of sources to represent basic thermal physics concepts. Questions 1-6 were sourced from a thermal concept inventory (Yeo & Zadnik, 2001), Questions 7,8 & 11-12 came from a research project which probed a range of thermodynamics conceptions amongst university students (Gray, 1998) and Q9 and Q10 were adapted from a first year university topic test on thermodynamics

Table 2: Topics covered in the Diagnostic Survey

Specific Topic	Question
Phase change and latent heat	4,5,6,8
Thermal equilibrium	1,2,3
Temperature	1,2,5
Thermal contact	1,3,5,7
Temperature as a measure of hotness	2,5,7,8
Specific heat	4,11
Rate of cooling	9,10
Heat transfer	3,12

Of the three extended response questions, Q13 was adapted from a study conducted by Henderson (1994) and both Q14 and Q15 were sourced from Gray (1998). The style and length of the survey and the particular collection of questions was verified by a panel of experienced physics education researchers to ensure the suitability for the intended purpose. Table 2 shows a basic classification of the concepts represented by multiple-choice section of the Diagnostic Survey.

The Sample

The participants were first and second year university physics students at the University of Sydney in 2009. The project was conducted in compliance with guidelines set by the human research ethics committee of the University of Sydney.

The Fundamental, Regular and Advanced students were all first year physics students while the second year group is the second year physics cohort. Generally, in accordance with course specifications, the Regular and Advanced groups are required to have completed high school physics with the latter containing high achievers. The Fundamentals group is made up of students who have not completed senior high school physics or have underperformed in it. Although demographics were not collected for the Diagnostic survey, the researcher had access to information on both the degrees enrolled and the highest formal physics education attained by the first year group (Figure 2).

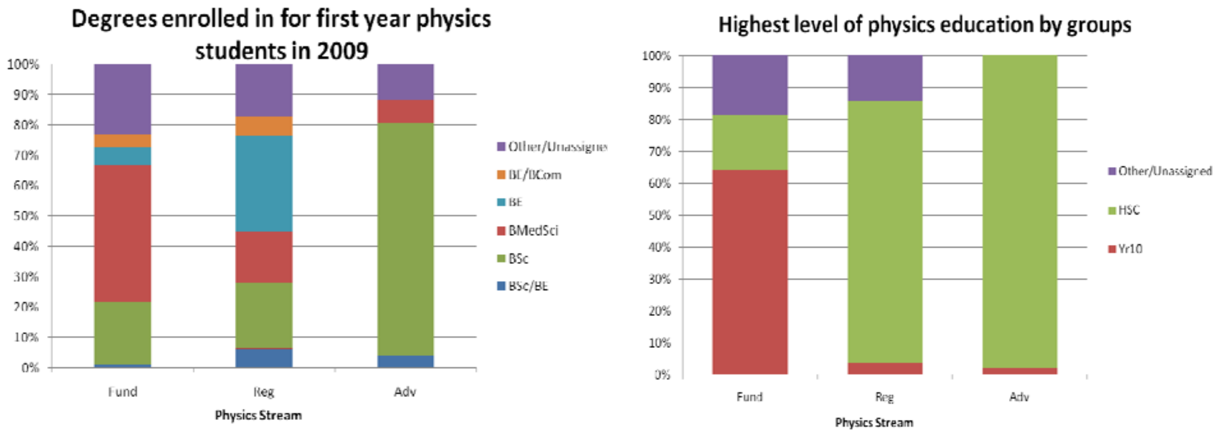


Figure 2. Degrees enrolled and highest physics instruction recorded for first year physics students in 2009

Most of the students attempted the multiple choice sections (Table 3) however there was a small number of questions unanswered in this section and the numbers decreased steadily for consecutive longer response questions, hence the lower number of responses for Q15. This may have indicated that the 15-20 minutes allowed for the completion of the survey was not really sufficient.

Table 3: Number of students attempting each question of the Diagnostic Survey

	Multiple Choice		Longer Response	
	Q1-12	Q13	Q14	Q15
Fundamental	248	171	142	146
Regular	479	329	286	275
Advanced	131	100	92	88
2nd Year	80	43	45	40

Results and discussion

The results from the multiple choice sections and extended response sections are presented separately. For the multiple choice section, the results are presented first, followed by a discussion. For the extended response section Q12-15, the analysis and discussion are presented within one account.

Results: multiple choice section

Two tests for ‘quality’ were undertaken on the multiple choice section using techniques within classical test theory. These are **discrimination index** and **facility**. The facility indicates the proportion of students answering the question correctly. Acceptable values for a summative multiple choice test are reported to lie within the range 0.2-0.8. The discrimination index is a measure of the relationship between performing well on one particular question and performing well overall. Values for this index should ideally be positive and high to ensure the question is able to discriminate between high and low performing students. A negative index for one test item is concerning, and indicates that students who performed poorly on the test overall tended to answer the item question extraordinarily well. None of the questions of this test had a negative discrimination index (Figure 3).

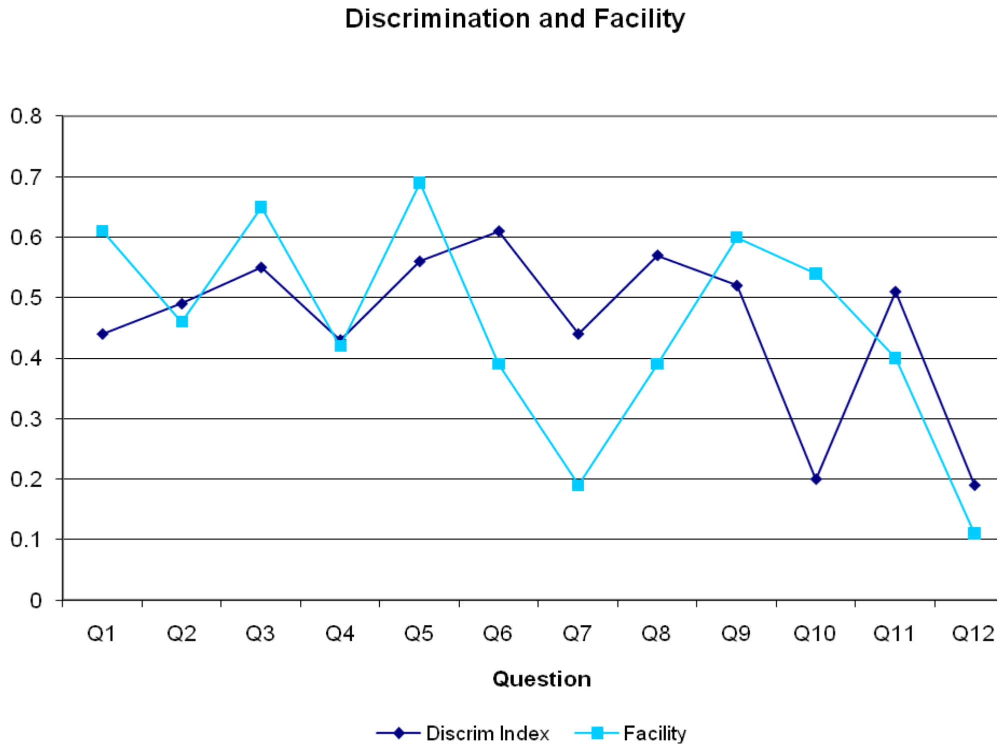


Figure 3: Discrimination and Facility for 12 multiple choice questions

For an item that is highly discriminating, the students who responded to the item correctly also did well on the test. A discrimination index above 0.3 is acceptable. Figure 3 shows that the values outside of normal range for either discrimination or facility occur at Q7, Q10 and Q12. Although there are many factors affecting these indices, it can be assumed that, although these indices are used out of context in this application, values outside the normal range of either index do highlight questions causing particular difficulty. The formulae for discrimination and facility are presented and explained in Appendix B.

The full question, multiple choice alternatives, and histograms for questions 2, 7, 10 and 12 are presented in Table 4. Note that Q2 and Q7 are two questions with the same underlying concept.

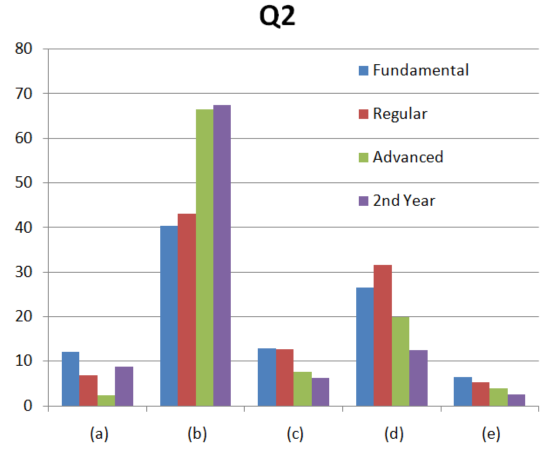
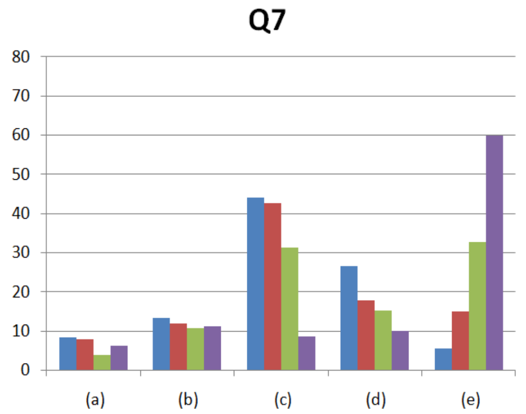
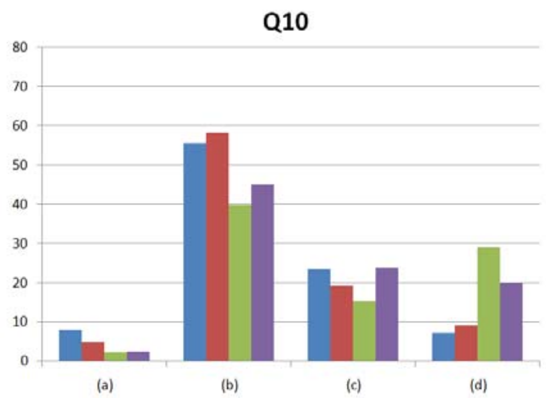
Table 5 provides a summary of the full twelve questions in the multiple choice section. This table summarises the questions for convenience and reports the proportion of students answering these questions correctly for each of the groups in the sample (Fundamental, Regular, Advanced and 2nd year). The table also indicates which distractor (incorrect alternative) was dominant amongst the groups and highlights the instances where this varied depending on which group was considered.

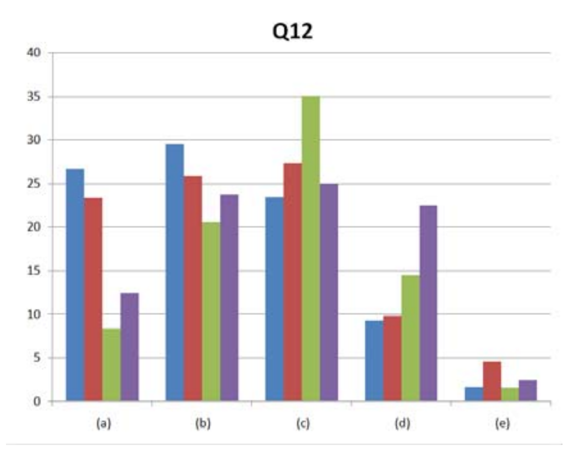
Discussion: multiple choice section

The multiple choice section primarily addressed the first research objective, the identification of troublesome concepts in thermal physics. Below is a list which summarises the main misconceptions of students from Table 5.

Main misconceptions: That ice cubes in a freezer could be 0°C instead of below zero, that water and ice at 0°C ‘contain’ the same amount of heat, that ice can have a temperature above zero, that water boils at the same temperature, that objects in thermal contact in conditions of assumed thermal equilibrium could be at different temperatures, that energy added will

Table 4: Data from a selection of questions from the multiple choice section of the Diagnostic Survey. Histograms illustrate the range of responses for each group. Correct answer is in bold.

Question	Multiple choice Alternatives	Histogram (Y-axis represents percentage)
2. 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?	a) They are both less than 7°C **b) They are both equal to 7°C** c) They are both greater than 7°C d) The cola is at 7° C but the bottle is greater than 7°C e) It depends on the amount of cola and/or the size of the bottle	
7. In a bathroom, not exposed to direct sunlight, what can you say about the temperature of the ceramic tiles on the floor compared to the temperature of a bath mat made of a thick towel-like material?	a) The mat is at a lower temperature as it does not absorb energy well. b) The tiles are at a lower temperature as they conduct energy well. c) The tiles are at a lower temperature as they do not store energy well. d) The tiles are at a lower temperature as they do not conduct energy well. **e) They are both at the same temperature as they are in contact with each other.**	
10. Two identical cups each contain 100g of water. The cups are in a room where the temperature is 25°C. The water in cup A is initially at 55°C degrees while that in B is initially at 40°C. Select the statement that best reflects the situation when approaching thermal equilibrium (when a final temperature is reached);	a) Cup A reaches this final temperature first. **b) Cup B reaches this final temperature first.** c) Both will take the same time. d) They will never reach a final temperature.	

12. Clear nights are cooler than cloudy ones. What is the best explanation for this?	a) The clouds act like a blanket and prevent the air in the atmosphere from escaping. b) The clouds absorb the energy so it does not escape into space, keeping the earth's atmosphere warm. c) The clouds reflect the energy back to earth. **d) The clouds absorb the energy and release it in all directions.** e) Clouds only appear when the weather is warm or humid.	

always increase temperature (ignoring latent heat), that objects cool in a manner other than Newton's law of cooling and do so independently of starting temperature.

Of particular interest is the apparent lack of the concept that heat is a form of energy. The notion of heat as a substance is dominant across all groups of expertise (Q3,8,9,10 and 11 see Yeo & Zadnik, 2001)). There were still a number of students who appear to believe that heat and cold are different entities (Q3), and many were uncertain about the specific nature of heat transfer (Q3,4,9,10).

The second research objective concerned the identification of the conceptions of particular interest. This was achieved by selecting the misconceptions which would be considered most familiar to everyday experience, most fundamental and therefore most important for progress in the learning of thermal physics. Table 4 highlights the main questions of interest (as identified by the researcher and verified by higher or lower than normal values for discrimination and facility). Question 2 is an example of a question for which there seemed to be no abnormal trends in responses from groups. That is, there was an increase in the proportion of students answering correctly as we consider the groups spanning from the Fundamentals to the 2nd year group. There is also one dominant alternative (incorrect answer) chosen by all groups which indicates the existence of a conception that a vessel and a liquid in contact for a significant amount of time are not at thermal equilibrium. In terms of the underlying physical processes, Question 7 is almost identical to Question 2 and yet students have approached Question 7 very differently and indeed (excepting the 2nd year group) more unsuccessfully. The dominant alternative that was chosen in Question 2 has become the dominant distractor chosen in Question 7. The ways in which these questions are different are in their embellishments, Question 2 includes a liquid and a solid whilst asking to compare the *same kinds* of objects, while question 7 compares 2 solid objects that are *different*. Another interesting detail is in the distractors. Question 2 has a selection of quantitative answers while question 7's distractors are descriptive and contain no values or units. In both questions, the objects that are compared have been in contact either with each other, or with a common third environment so that an assumption of thermal equilibrium was necessary to answer correctly.
Question 10 had an interestingly low value for discrimination, which indicates that students who did well (or badly) on this questions would not necessarily do well (or badly) on the test overall. There seemed to be confusion relating to the rates of cooling based on a complication involving thermal equilibrium. The more expert groups selected the option which explains that two objects cooling down from different temperatures will 'never reach a final temperature' (option d). This alternative seems to be an artefact of proficiency. Something

Table 5. Summary of results. Proportion of students selecting the correct response is presented in the second column. The proportion of students choosing the most popular incorrect response is presented in the fourth column. The shaded rows correspond to alternatives which had two dominant distractors choices. The preference for each distractor depending on groups is represented by the bold percentage value

Summary of question in Multiple choice section	% correct				Dominant Alternative Conception	% answered			
	Fund	Reg	Adv	2nd		Fund	Reg	Adv	2nd
1. Likely temperature of ice cubes in a freezer	54	58	80	81	a) Ice in a freezer is 0°C	42	39	17	19
2. Likely temperature of can of cola and plastic bottle of cola	40	43	66	68	d) Liquid (cola) inside a bottle is at a different temperature to the bottle itself	27	32	20	13
3. Reason counter under cola can feels colder than rest of counter	45	67	93	91	a) Cold is transferred from the cola to the counter	39	21	3	6
4. Equal volumes of water and ice in freezer, which loses greatest amount of heat?	42	39	56	61	c) Water and ice at 0°C contain the same amount of heat	15	**25**	**31**	18
					e) Water can't have a temperature of 0°C	**32**	**25**	10	18
5. Likely temperature of ice cubes in puddle of water	58	72	77	88	c) Ice is at 5 °C	29	17	17	5
6. Reason behind water boiling and effect of high altitude	21	40	73	66	b) Water always boils at the same temperature	**44**	**34**	10	8
					c) Water can increase temperature after boiling	2	**19**	**10**	**25**
7. Explanation of bathroom tiles feeling colder than bathroom mat	6	15	33	60	c) Tiles are at a lower temperature because they do not store energy well	44	43	41	9
8. Effect on temperature of an object from the addition of energy	32	35	48	71	a) Adding energy to an object always increases that objects temperature	30	48	42	20
9. Objects of different temperature, which cools fastest initially?	49	57	77	76	c) Objects at different temperatures cool at the same rate initially	32	29	8	10
10. Objects of different temperature, which eventually reaches equilibrium first?	56	58	40	45	c) Objects at different temperatures cool at the same rate eventually	**23**	**19**	15	**24**
					d) Objects cooling down will never reach a final temperature	7	9	**29**	**20**
11. Different materials at the same temperature. Why do they transfer different amounts of heat?	36	37	47	56	No Dominant alternative conceptions See for example, the histogram for Q12				
12. Reason why clear nights are cooler than cloudy ones.	9	10	15	23					

about the students more ‘expert’ knowledge or thinking has encouraged them to either (d) consider option the correct, or perhaps safe, option.

Lastly, Question 12 is an example of a question which was generally answered incorrectly. In this case, it is clear that there was a lack of content knowledge and insufficient ability to transfer any previous knowledge to the more abstract context of atmospheric temperature and clouds. This question was an example of a subject which would not be suitable for further, in depth, study.

With reference to the model of learning described above, these observations can be roughly described in terms of nodes and connective lines. Firstly, in some cases, concepts such as thermal equilibrium, or knowledge about atmospheric dynamics (Q12), did not exist at all as a concept and therefore as a node in the model. Students were thus not able to make relevant associations in order to select the correct answer. Heat transfer may have existed as a concept in most responses (Q2) and yet the associations proved tenuous, relying on the information presented in the question. More expert students revealed more associations being made to relevant concepts and remaining fixed despite contextual changes (Q7).

To address the third research question, we consider if there are any patterns across the groups of expertise. First, the selection of multiple choice options across groups presented an interesting pattern. For some questions the correct response was selected by the majority of students, followed by an obvious dominant distractor. This dominant distractor was common to all groups for most questions, apart from questions 4, 6, and 10 which are highlighted in Table 5 and Q11 and Q12 for which there was no dominant distractor choice overall. In questions 4, 6 and 10, one of two distractors was favoured by the different groups. For example, in Q6, the incorrect option that explained that water always boiled at the same temperature was favoured by the Fundamental and Regular groups, while the option that stated that water continued to increase in temperature to 100ºC after boiling at higher altitude was favoured by the Advanced and 2nd year groups (indicated in bold). This result suggests that expert- and novice-types sometimes favour different conceptions, and may imply there is a trend towards sophistication of thermodynamic concepts.

Analysis and results: extended response section

The three extended longer response questions are shown below. Because of their related nature, Q14 and Q15 were analysed using the same method and therefore will be presented together after a discussion of Q13 for which a different method was used.

Question 13

Question 13 is presented below:

13. Three Styrofoam cups were filled with 200ml of water at 22°C. To each of the cups, an equal amount (50g) of a material at a temperature 80°C was added. In cup A, Copper was added. In cup B Aluminium was added, and in cup C, water was added. Assume no heat is transferred to the surroundings at any time. Do you expect the final (equilibrium) temperatures to be similar, or different? Explain.

The responses were analysed using a phenomonographic approach where the researcher collaborated with a thermodynamics lecturer to sort groups of responses with similar characteristics. Initial classification was undertaken on a sample of 160 from the Regular group to produce 10 categories. A more correct response would recognise that different objects with the same mass (at the same temperature) would transfer different amounts of energy to the water in the vessel according to their different specific heat capacity. A correct answer should be that the final temperatures are all different and the order from highest temperature to lowest would be: water, aluminium and copper. Note that the question does not request that the materials be ranked in that way.

A brief summary from the preliminary analysis presented in Table 6.

Table 6: Summary of main findings from Q13

Results	**Examples of responses**
When the process heat transfer is recognised as dependant on the materials properties, specific heat was explained correctly using one of three words. 'Absorb' 'transfer' or 'store'. In some cases the order of the materials' specific heat was incorrectly assumed.	"Different, because the ability of the added materials to absorb energy as heat is different (specific heat capacity) therefore the final temperature of the materials will be different" "Different, as each material has a different specific heat capacity; each will transfer a different amount of themal energy on the water" "different, as each material stores a different amount of heat within itself. Metals such as copper & Aumunium can store a lot more heat than water and will therefore heat the cup more"
Analysis indicated that there were difficulties in explaining specific heat	Almost half of responses were incorrect, stating that the final temperatures would be the same or that they would be different due to conductivitis of the materials
Conductivity was linked to specific heat as a direct relationship	"No. 'A' would warm the most as copper is the best conductor. Followed by Aluminium, followed by water"
Responses ranged from one word to quite lengthy	"no", "yes" or " because of specific heat capacity"

This analysis was not extended to the entire sample as responses had stabilised. That is, due to the unfamiliarity and therefore difficulty of the questions subject matter (specific heat capacity), there was not a very wide or useful range of responses to facilitate addressing the research questions beyond the conclusion that specific heat was not a 'fundamental' or 'familiar' concept. If examined more comprehensively, it is predicted that there would be a large number of students providing vague and superficial responses.

Question 14 and 15

Questions 14 and 15were:

14. Explain why we are comfortable in 15°C air but find swimming in 15°C water unpleasant.
15. Explain why it is suggested that blowing over hot tea may make it cool faster.

These two questions were more thoroughly analysed than Q13. The responses to both questions displayed certain shared characteristics in terms of levels of sophistication, where the responses themselves were quite varied, but the level of sophistication of a group of varied responses seemed fairly uniform. The (usually four of five) tiered sorting of responses due to sophistication is a familiar one in conceptions analysis, and although there are many different approaches, the use of the established SOLO taxonomy (Biggs & Collis, 1982) guided this particular analysis.

A sample of 160 responses from the Regular group was initially analysed and sorted into broad categories. Researchers usually do this in one of two ways. They may either use an already established scheme, such as the Biggs and Collis SOLO taxonomy (1982), or they may independently construct their own categories based on the data at hand. This study used a combination of both approaches beginning with a description of each category based on this particular data, and refined by comparisons with the SOLO criteria. Both approaches were validated through discussions with physics experts and physics education researchers. The final descriptions and results from classifying the full sample are illustrated in Table 7. Column one notes the SOLO levels, column two explains the data specific characteristics as developed by the researcher and further columns show the proportion of students populating each level across the four groups of students. Examples of typical responses are presented in Table 8. The Relational and Extended Abstract level of the SOLO taxonomy was collapsed to one for this purpose, as a full response was attainable at the Relational level and it was not necessary for further differentiation between Relational and Extended abstract responses.

Table 7: Response Classification and SOLO comparisons for Q14 & Q15.
(F=Fundamentals, R=Regular, A=Advanced, 2nd=Second Year)

Level	Characteristics of questions 14 and 15 for each category	Percentage of Reponses in each category							
		Q14				Q15			
		F	R	A	2nd	F	R	A	2nd
Prestructural	Messy, random responses that made little sense.	19	12	1	6	11	7	1	-
Unistructural	Real world links with tendencies of naïve beliefs (some p-prims (diSessa, 1996)). Some mention of unrelated biology or chemistry references.	27	25	6	9	39	19	15	-
Mulitistructural	Use of Physics concepts, but these were either not primarily related to question, or incomplete	26	20	22	4	32	27	40	25
Relational/ Extended Abstract	Understanding of physics behind question. Errors, if any are mainly in use of language or expression.	28	43	71	81	18	47	44	75

Table 8: Examples of typical responses for each level or classification

Level	Q14 response examples	Q15 response examples
Prestructural	*"The water is too cold"*	*"Blowing removes the heat"*
Unistructural	*"Water doesn't allow heat to escape, causing colder conditions"*	*"Cool air from your breath will cool it down because the air is cooler than the liquid"*
Multistructural	*"Air has less density than water molecule which means that each atoms move more freely in air state"*	*"Blowing over hot tea will make the water molecules be blown away thus less heat will be left on the tea"*
Relational/ Extended Abstract	*"Water conducts heat more efficiently than air. As such, our outer body loses heat more quickly in water than in air, This rapid change in temperature is perceived as discomfort. In air, the heat transfer occurs slowly, which is less unpleasant"*	*"Remove hot air from surface of the tea, allowing cooler air to replace. Letting the heat from the tea transfer quicker to the colder air. Cooling tea faster"*

The analysis of these two questions addressed the third research question, the observations of responses of students from different levels of expertise. Unsurprisingly, the sophistication of responses increased in order of expertise across the groups. Looking across the last row in Table 7, we note the increase in the proportion of students at the Relational/Extended Abstract level across the groups. This indicates an understanding of the related concepts and varies from 18% for the Fundamentals to 75% for the 2nd year group for Q15.

Overall, this method has proved useful for quick, large scale assessment of student understanding. The boundary between levels implies an improvement that is identifiable and measurable. For example in Q15, to progress from a multistructural level to the extended level, a student must understand that there are **two** main ideas that need to be integrated: that blowing will remove the hot air above the tea, and that the removal of air will facilitate increased heat transfer, thus cooling the tea. A multistructural response would generally use only one of these ideas or use two that are not as directly related, whereas an extended response will recognise and apply the two integral concepts. It is interesting that this trend is very obvious in this particular question. A large number of responses with similar grounding and similar reasoning are a very useful starting point for understanding and addressing specific conceptual issues.

Diagnostic Survey conclusions

The Diagnostic Survey led to the development of a subsequent instrument. The main contributions to the construction of the instrument were as follows.

- *The topic that was chosen included a variation on the idea presented in Q2 and Q7-* these questions were associated with the perception of temperature, thermal equilibrium, and the concept of conductivity.
- *The question structure would be tailored to maximise administrative convenience and would be pitched at the right level for students-* the question was structured to be completed in approximately 10 minutes to allow for administration in laboratory classes. The question would require a concept choice for each of the two parts to encourage scientifically focused responses because there were a number of responses in Q14 and Q15 that did not attempt a scientific explanation at all.

In the process, some valuable insights into the conceptions of university students were uncovered, not least of which was that misconceptions usually associated with younger children persisted into tertiary level. More interestingly, certain trends and commonalities were revealed. Groupings of conceptions within a level of expertise appeared, and there also appeared to be a detectable but still irregular path from novice to expert. A tool revealing conceptions in thermodynamics is valuable as it may highlight any misunderstanding or ignorance in topics surveyed. This is especially important when such topics either act as assumed knowledge for further studies, or basic knowledge that constitutes a well rounded scientific education.

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Appendix A- Copy of administered test

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Thermal Physics Concept Quiz
March 2009

Instructions:

- This quiz should take about 15 minutes to complete.
- There are two sections. Section 1 consists of 12 multiple choice questions and Section 2 requires three written responses.
- Calculators are not required- where necessary, use approximations.
- There are no mark allocations for the questions.

Important: Participation in this project by completing this survey is completely voluntary.

Information about individual answers or your identity will not be disclosed to course coordinators.

SID: ______________________________

Thermal Physics Concepts Quiz

Section 1: Multiple Choice. *Circle the answer that is most correct.*

1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment?

a) About –10°C
b) About 0°C
c) About 5°C
d) It depends on the size of the ice cubes

2. 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?

a) They are both less than 7°C
b) They are both equal to 7°C
c) They are both greater than 7°C
d) The cola is at 7° C but the bottle is greater than 7°C
e) It depends on the amount of cola and/or the size of the bottle

3. A few minutes later, Ned picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter. Circle the best explanation.

a) Jon says: "The cold has been transferred from the cola to the counter."
b) Rob says: "There is no energy left in the counter beneath the can."
c) Sue says: "Some heat has been transferred from the counter to the cola."
d) Eli says: "The can causes heat beneath the can to move away through the countertop."

4. Pam 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 greatest amount of heat? Circle the statement you agree with most.

a) Cat says: "The 100 grams of ice."
b) Ben says: "The 100 grams of water."
c) Nic says: "Neither because they both contain the same amount of heat."
d) Matt says: "There's no answer, because ice doesn't contain any heat."
e) Jed says: "There's no answer, because you can't get water at 0°C."

5. If a few ice cubes are left on the counter to melt and are lying in a puddle of water, what is the most likely temperature of these smaller ice cubes?

a) About –10°C
b) About 0°C
c) About 5°C
d) About 10°C

6. Jim believes he must use boiling water to make a cup of tea. He tells his friends: "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes." Who would you agree with?

a) Joy says: "Yes it does, but the boiling water is just not as hot as it is here."
b) Tay says: "That's not true. Water always boils at the same temperature."
c) Lou says: "The boiling point of the water decreases but the water itself is still at 100 degrees."
d) Mai says: "I agree with Jim. The water never gets to its boiling point."

7. In a bathroom, not exposed to direct sunlight, what can you say about the temperature of the ceramic tiles on the floor compared to the temperature of a bath mat made of a thick towel-like material?

a) The mat is at a lower temperature as it does not absorb energy well.
b) The tiles are at a lower temperature as they conduct energy well.
c) The tiles are at a lower temperature as they do not store energy well.
d) The tiles are at a lower temperature as they do not conduct energy well.
e) They are both at the same temperature as they are in contact with each other.

8. Which of the following is correct? If you add energy to an object you;

a) Always increase the objects temperature.
b) Sometimes increase the objects temperature.
c) May increase or decrease the objects temperature.
d) Do not have an effect on the objects temperature.

9. Two identical cups each contain 100g of water. The cups are in a room where the temperature is 25°C. The water in cup A is initially at 55°C degrees while that in B is initially at 40°C.

Select the statement that most accurately reflects the initial cooling rates of the cups.

a) A will initially cool faster.
b) B will initially cool faster.
c) They will both cool at the same rate.
d) More information is required to answer this question.

10. Select the statement that best reflects the situation when approaching thermal equilibrium (when a final temperature is reached);

a) Cup A reaches this final temperature first.
b) Cup B reaches this final temperature first.
c) Both will take the same time.
d) They will never reach a final temperature.

11. Two blocks, A and B, of equal mass, which are made of different materials, are each at a temperature of 80°C. Each of the blocks is immersed separately into a bucket, each bucket containing the same amount of water initially at room temperature.

It is observed that the water with block A settles at a temperature of 60°C while the water with block B settles at a temperature of 40°C.

What can you say about the properties of the materials of the blocks?

a) The material of A can store more energy than the material of B.
b) The material of B can store more energy than the material of A.
c) Energy is able to flow faster from block A than from block B.
d) Energy is able to flow faster from block B than from block A.
e) We cannot say anything unless we are given more information.

12. Clear nights are cooler than cloudy ones. What is the best explanation for this?

a) The clouds act like a blanket and prevent the air in the atmosphere from escaping.
b) The clouds absorb the energy so it does not escape into space, keeping the earth's atmosphere warm.
c) The clouds reflect the energy back to earth.
d) The clouds absorb the energy and release it in all directions.
e) Clouds only appear when the weather is warm or humid.

Section 2: Longer response. *Answer the longer answer questions in as much detail as possible, using equations or diagrams if required.*

13. Three Styrofoam cups were filled with 200ml of water at 22°C. To each of the cups, an equal amount (50g) of a material at a temperature 80°C was added. In cup A, Copper was added. In cup B Aluminium was added, and in cup C, water was added. Assume no heat is transferred to the surroundings at any time. Do you expect the final (equilibrium) temperatures to be similar, or different? Explain.

14. Explain why we are comfortable in 15°C air but find swimming in 15°C water unpleasant.

15. Explain why it is suggested that blowing over hot tea may make it cool faster.

Appendix B- Statistical tests

The student's performance on the test as a whole was not a particularly useful measure for the purpose of this study. Instead, statistical treatment of each item was performed. This treatment is titled 'item analyss'. The two indices used in this project from the item analysis were the **facility** and **discrimination**

Facility

The facility of an item is simply given by the number of students answering the item correctly divided by the total number of students. This is sometimes also called the difficulty or p-value. The facility varies between 0 and 1 with an ideal average value of 0.5.

$$\textbf{Facility} = \frac{\textbf{Number answering item } \boldsymbol{i} \textbf{ correctly}}{\textbf{Total number answering test}}$$

Discrimination index

The discrimination index determines the discrimination power of individual test items. The discrimination index applies only to dichotomously scored items, those scored as right or wrong. The discrimination index is calculated by dividing the sample into the upper 27% and the lower 27% and using the following formula

$$\mathbf{D = U - L}$$

Where U is the proportion of students in the upper group who answered the question correctly and L is the proportion of students in the lower group who answered the question correctly. The discrimination index varies between -1 and 1. A negative discrimination index indicates that more students in the low group answered the question correctly while a positive discrimination index indicates that more students in the high group answered the question correctly. Typically, a discrimination index above 0.30 is considered acceptable. The discrimination index is highly affected by the difficulty of the item.

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