An Exploration of Tertiary students’ Conceptions of Familiar Thermodynamic Processes

Helen Georgiou

The University of Sydney
Acknowledgements

I returned to university this year after three years of experience in the ‘real world’. The experience I received throughout the honours year has been invaluable and for this, I have many people to thank. First and foremost thank you to the SUPER group, who helped in many aspects of the administration and progress of the project. I am grateful to my supervisor Manju Sharma for truly doing everything a supervisor should, and then some. To my secondary supervisors, Brian McInnes, Ian Sefton and John O’Byrne, thank you for your suggestions, support and mentoring. John, your constructive criticism is some of the most helpful I have received throughout my education and training. To Alex Hugman and Ian Johnston of the SUPER group, I had immediate respect and admiration for you both and valued the opportunity to work with you. To my fellow SUPER students, Nigel Kuan, George Pinniger and especially Christine Lindstrom, I have rarely had so many people around me are so in tune with my own attitudes, beliefs and interests. Thankyou to Ian Cooper for entering all of the exam data and thankyou to Thomas Hubble, Kevin Varvell, Richard Tarrant and all of the Lab supervisors and tutors for helping administer the tests. Of course, a big thanks to all of the students who voluntarily participated in the project.

Finally, I must express eternal gratitude to my ever patient family, who have provided unconditional support and encouragement and have sacrificed a great deal over the years for my education and ambitions. To my husband David Fergusson, thank you for your cooperation and confidence in my venture and for murdering all of my comma’s and teaching me the secrets about how to write good.

Statement of Student Contribution

The original idea for this particular project stemmed from a suggestion from my supervisor Manju Sharma. The topic of thermodynamics was of particular interest for me, and I wanted to investigate aspects of the topic that were basic and familiar because of their general relevance. These particular interests were developed through the experience I had with teaching physics at high school.

The decision to use two tests was my own. The Diagnostic test was compiled from other sources and the data entered by Ian Cooper. The Test-question was designed by me and I completed all of the data entry for this test. I researched and evaluated a number of methodologies and decided to use a combination of these to strengthen the study. Mixing methods is not a common approach in educational studies but I concluded that the use of only one method of analysis would be limiting and reduce validity. Researching and understanding each of these methods was fairly involved and there is still much that I would be interested to learn.

The decision to use NVivo (program) was also my own. There was no experience with NVivo in the SUPER group so I received training during the year to help familiarise myself with the program. The way the data was analysed within the program was my own. This included the development of a coding scheme, the coding of responses, and the types of analyses performed on the data.

I certify that this report contains work carried out by myself except where otherwise acknowledged
Abstract

Although there are various ways of assessing the performance of students or the outcomes of a tertiary physics course, there are very few opportunities to gauge the details of students’ conceptions, especially for content that is assumed knowledge or not explicitly assessed. The current study explores tertiary students’ conceptions of familiar thermodynamic processes and was novel in its approach, the mixing of methods, and in its focus on tertiary students. Two different paper and pen surveys (tests) were administered to a large sample of students enrolled in both science and humanities based degrees. The first test revealed that students sustain a number of alternative conceptions in a range of thermal concepts. The analysis of the second test was facilitated by a computer program designed for flexible coding and provided further details about conceptions on one selected topic. The main findings indicate that students who are able to sufficiently explain a concept in one context may fail to do so in another. It was also found that certain conceptions were common to groups of students with similar degrees of formal physics instruction. Further qualitative-based analysis may help unearth and therefore address student difficulties not obvious within typical university assessments.
Introduction

1.1 Personal rationale

Lillian McDermott, a world leader in physics education research, once explained that the nature of a paper is strongly influenced by the background and orientation of the author (McDermott, 1990). The rationale for this study originated with my wonder at physics, developed with my desire to share this wonder, and was fortified with my first hand experience of teaching physics and engaging in educational research. My aims for this project go beyond this particular study. I hope to join and support like-minded academics in their quest to further progress in physics, and to help develop the communication of this discipline to future generations.

1.2 Overview of study

The aim of this research project is to investigate university students’ conceptions about basic and familiar thermodynamic processes in detail. Traditionally, such topics have posed a challenge for students. To understand why this is so, or how it can be addressed, a systematic and comprehensive exploration of student’s conceptions is necessary. Research is strong in some aspects of this objective, including the probing of conceptions of children, and in the identification of certain misconceptions. However, much less work exists at the tertiary level, where ironically, the communication of the subject is particularly important.

Conceptions were gauged primarily via analysis of a brief written response to a two part question (the ‘Test Question’) based on the concept of thermal equilibrium and presented in two different contexts. The Test Question was administered to 598 first year university students taking the first year physics units and 63 taking the first year primary education course. The chosen topic of thermal equilibrium and the other particulars of the Test Question were based on the results from a Diagnostic Test which was itself based on a wider range of thermal topics informed by the literature and administered earlier in the year. As well as informing the Test Question, the Diagnostic Test provided some support and validation of the final results. These combined results revealed evidence for the existence of considerable conceptual difficulty in topics such as heat, heat transfer, thermal equilibrium and conductivity. Some of these difficulties were only identified through extensive analysis of the Test Question, indicating that it may possible for students to appear to have a solid understanding of a topic whilst still retaining incomplete or faulty conceptions. The comparison of the different groups revealed certain patterns which could contribute to the understanding of concept development and conceptual change. The mechanics of the study had several novel features, including the use of mixed methods which ranged from basic quantitative analysis to tailored computer facilitated qualitative approaches. This approach captured details of particular elements of conceptions that could have been missed with current diagnostic tools such as multiple choice inventories. A coherent understanding of basic thermodynamic concepts such as thermal equilibrium is undoubtedly important for science graduates. The topic is also more generally important due to its everyday relevance and familiarity and therefore provides a distinctive means for promoting scientific sophistication of students.

1.3 Overview of thesis

This thesis addresses the research aims in the following way: First, a summary of the literature will be presented. Much of this section will have relevance to subsequent sections in the thesis and some parts will be extended after the results are presented. A brief overview of general quantitative and qualitative analytical methods is also included in this section to clarify the orientation of the research. Because there were two different tests administered, these will be presented in the sections 4 and 5 following the literature review under the headings Diagnostic Test and Test Question. The development of these tests along with the methods, results and discussion of each will be presented separately in these respective sections. Following these sections, a general comment on the strengths and weaknesses of the study, suggestions for further work and implications will be discussed. A conclusion at the very end will integrate the findings of the study as a whole, addressing to what extent the research aims had been fulfilled.
2 Background and summary of literature

2.1 What makes Physics Education Research unique

Physics education research (PER) is a relatively new specialty that is gaining prominence in educational research, and in the discipline of physics. Even though physics has been enthusiastically communicated for centuries, the quality of this communication cannot be judged and maintained without consistent and substantial commitment:

‘During the World Year of Physics, much effort is being made to celebrate the unprecedented advances in our understanding of the physical world made during the past century. However, we have not yet seen comparable advances in our understanding of student learning of our discipline.’ (Heron & Meltzer, 2005)

Fortunately, this commitment is now more vigilantly addressed through research efforts focused on physics education. PER is a specialty within the broader field of educational research in which there exists a group of researchers with an overarching philosophy, goal and ethic which uniquely identifies and distinguishes them. Physics attracts more educational research than in any other scientific discipline, and justifies the specialist status through extensive practical and theoretical advances (McDermott, 1990).

Physics education researchers and authors are unique in the sense that they often have an established expertise in an area of physics, or remain within physics departments at university. Thus their influences and attitudes are infused by their discipline, leading to slightly different perspectives and approaches compared to specialists in general education research. As individuals, PER authors embrace a variety of viewpoints and stances. Collectively, a common ethos, methodological approach and objective are identifiable. While this is inherently a beneficial product, it is also often at odds with other groups within the field of educational research. For example, when reflecting on their own intentions, PER authors often admit their primary motivation is to better understand what students find difficult in their learning of physics and use this information to improve instruction:

‘(the goals of PER are) the research-based development of tools and processes for practitioners’
(Burkhardt & Schoenfeld, 2003, p. 3).

Such an assertion is not one that is typical of all educational research perspectives. Opposition to this statement is embedded within accusations of reductionism and positivism. Authors from a variety of backgrounds may consider the systemic or scientific orientation towards educational research inappropriate. This is often guided by a somewhat injudicious interpretation of the ‘scientific’ approach:

‘(scientific) educational research… (is)… simply a “technology”, a set of methods, skill and procedures to be implemented’ (Usher, 1996, p. 9). (Instead, research)... ‘should be a social practice…(that involves)… looking at traditional epistemological questions to do with what constitutes knowledge, models of explanation, theory-justification and acceptance, the nature of objectivity, probability and causality, and different traditions such as empiricism, rationalism and realism.’ (Usher, 1996, p. 2).

While this sentiment is echoed only diffusely throughout the educational and social research fields, it remains robust and influential. Some authors, for example, have contested the policy reforms that physics and science education research has evoked:

‘Some researchers have worried, with good reason, given the current political climate, that important ways of knowing, sometimes referred to as “non-scientific,” (e.g., philosophical, historical, cultural, affective, postmodern, and practice-oriented), will be forgotten in the rush to achieve scientifically based research’. (Eisenhart & Towne, 2003, p. 31).

Developments in physics educational research have been significant and beneficial and it is important that progress continue. The teaching of physics (and this is true for all sciences) cannot be reduced to content and definable objectives. It is a complicated communication of scientific methods, beliefs, arguments and history that comes from integration into the scientific language and community (Heron & Meltzer, 2005). Understandably, an appropriate episteme of science is accepted to be a major factor for the successful learning of science (D. Hammer, 1994) and the motivation for it (Nussbaum, Sinatra & Poliquin, 2009). Pre-service teacher training courses therefore assess teachers beliefs in science as well as their content knowledge (Irez, 2006) and it is clear that similar aspects would play an important role in educational research. That is, research about physics teaching and learning is benefitted by being a part of a physics community and should invariably continue to be supported and developed in this way (Beichner, 2009).
2.2 Situating the study within the literature

The objective of this section is to provide a coherent summary of the literature within PER and educational research in general that is associated with this study. This includes a review of research regarding theories of learning, descriptions of scientific reasoning, models of concept development and details of conceptions in thermodynamics. Although the study is focused on identifying conceptions of students at university, the scope of this study is multidisciplinary and involves a number of research areas and fields. The word ‘conception’ may be used in various capacities, but the current use of the word simply refers to the tangible information we receive that is related to the way students think, learn and know:

Conceptions (or ideas) identify and relate factors that students use to explain intriguing or problematic phenomena. They also represent the knowledge, expressed in terms of solution strategies and their rationale, that constitutes the core solution to specific problems (Smith, A.A. & Roschelle, 1993, p. 119).

2.2.1 Constructivism

Constructivism is arguably the most significant theory to have influenced science education. It is based on the notion that knowledge is not ‘transmitted but constructed by the mental activity of learners’ (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 5). This theory was so influential because it was able to, for the first time, explain many previously unexplained observations about how students think and learn. It was especially significant to the study of conceptions because there was now a mechanism to explain why students held certain wrong ideas or ‘misconceptions’. Constructing knowledge clearly implies that some transformation or alteration had occurred and in science education and this can therefore explain the existence and development of ideas that are at odds with scientifically accepted ones. This issue will be addressed in more detail in the sections conceptual change and misconceptions.

In addition to the focus on discrete (mis)conceptions, constructivist theorists also embraced more dynamic concerns, those which involved the attempt to qualitatively describe changes in ideas and development of reasoning of students. Known as the ‘developmentalists’, researchers in this particular field would investigate similar characteristics of learners at various ages and attempt to uncover trends in the evolution of these characteristics. In this context ‘characteristics’ refer to the different ways in which children think, reason and perceive the world, and are known collectively as ‘cognition’. Studies associated with children’s cognition were heavily observation based, and either initiated or motivated by Jean Piaget. As such, a brief summary of his work in this area will be presented for clarity.

Piaget’s subtle and yet significant observation that children’s cognition differed from adults’ led him to investigate how this change manifested itself in the behaviours and actions of children. Numerous investigations identified that younger children exhibited what he called ‘concrete’ ways of thinking, which progressed to ‘formal’ ways of thinking sometime during adolescence. Concrete and formal represent real characteristics of cognition that have been documented in a number of different areas, from opinions of dreams, to explanations about physical processes (Piaget, 1929). Think of the example of a four-year old shown two identical glasses filled with the same amount of juice. After the juice from one glass has been poured into a taller, thinner glass, the child who is asked which glass has more juice points to the taller glass. In physics education, this translates to the presence (or absence) of certain conceptions, because these inherently imply a level of concreteness/formalness. For example, the conception of a scale of hotness is generally acquired at or after the age of nine, as children younger than this can only prescribe ‘hot’ or ‘cold’ to objects (Erickson, 1980). The general implication was that certain knowledge structures may only develop once a child has reached a certain age (Koplowitz, 1979).

This was a very powerful hypothesis, and empirical evidence continued to accrue in defence of the notion that cognition developed with age. Typically, empirical investigations involved either assigning conceptions to each of the stages of Piagetian development1 and comparing to responses from children (Liu & McKeough, 2005), or simply stating at which age specific concepts are attainable, as in the example with hotness mentioned above.

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1 In order: Sensory motor stage (0-2), Pre-operational stage (2-7), Concrete operational stage (7-11), Formal operational stage (11-16)
A study by Shayer and Wylam coordinated the development of heat concepts in children between the age of 9 and 12 with the associated Piagetian stages (Shayer & Wylam, 1981). Effectively, this study revealed that there was a non random way in which heat concepts develop and suggests this would have implications for order of concept introduction and for other curriculum design. Table 2.1 provides descriptions of the levels (I, II and III) which correspond to three differentiated levels regarding heat concepts. These descriptions were developed from actual student responses on written tests and interviews. The study hypothesised and confirmed that there was a correlation between these levels and student age and/or Piagetian developmental stage.

<table>
<thead>
<tr>
<th>Level</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Heat is associated with its effects, e.g. Burning, Heating, Melting, but is not modelled at all. “Why does the small piece of ice melt first?” “Because it is smaller.”</td>
</tr>
<tr>
<td>II</td>
<td>Heat associated semi-quantitatively with its effects, i.e. the more the heat the more the effect, and more substance requires more heat for a given effect. But no modelling of heat as an extensive property because the variables of mass and quantity of heat are not differentiated.</td>
</tr>
<tr>
<td>III</td>
<td>Heat differentiated from amount of substance and sensation of hotness. Have an implied calorific-liquid model of heat flow, and can take mass and temperature as independent variables in simple calculations on heat exchange. Yet the more complex kinetic theory model is still out of range except in its simplest applications such as in explaining the expansion of solids.</td>
</tr>
</tbody>
</table>

Table 2.1 Descriptions of differentiated levels for conceptions of heat (Shayer & Wylam, 1981 p.428)

The study goes on to conclude that certain concepts appear sequentially as a student progresses from one year to another, and also, that certain concepts are only attainable at certain developmental stages.

However, as resourceful as this approach came to be, concept development and constructivist theories diverted from the causality between age and cognition implied by initial Piagetian research to attempt to more fully explain how cognition developed and why. The two most obvious irreconcilable facets to Piaget’s theory were:

- Instructional methods were developed to, and succeeded in, encouraging concept acquisition or conceptual development outside of the prescribed age group (Stavy & Berkovitz, 1980)

- Evidence confirmed the existence of formal thinking in younger children and the retention of concrete ways of thinking in older children or even adults (Smith, et al., 1993)

The proliferation of observation based (empirical) investigations and the existence of abundant theoretical perspectives led to great developments in the area of research concerning conceptions and their development. However, the question of ‘what develops’ is still very much an active issue. Arguably the most influential (and largest) body of recent work is associated with the field of cognitive science, which attempts to relate observations of learning and development to physical quantities. Working memory (a certain, immediate form of memory) was a construct developed from cognitive psychology and was useful in predicting and facilitating certain behaviours.

However, measurements of memory alone are insufficient in explaining development. Chi describes ‘what develops’ as a combination of changes in memory capacity, changes in strategies and changes in knowledge (in Siegler, 1978). Chi’s study reported a situation where children with background knowledge in chess were shown to perform better than adults with little or no knowledge, despite confirmation that the adults’ memory capacity is larger than the child’s.

Large bodies of literature exist on theories of knowledge and development. Two areas of this research that are relevant to this study are treated in more detail in the following sections; Novice-Expert Literature and Socio-Cultural Theories.
2.2.2 Novice-Expert Literature

Traditionally, this area of research has effectively worked on constructing a catalogue of characteristics associated with each stratum of expertise. Expertise is a woolly term but is generally considered to be the collection of advanced capabilities in a field as the result of continuous and relevant efforts in that field. A comparison of characteristics of experts and novices provides insights into the conceptions of each and therefore the development of expertise.

Research has focused primarily on problem solving and has been both in specific subject areas (eg., for a summary of chess and mathematics see Voss, 1989) and on a more general level, since many characteristics were found to be largely independent of context. Methods range from direct observation, such as watching chess moves, to analysing approaches to set problems. Studies regarding problem solving in physics indicate that there are some patterns in the development of expertise.

Results indicate that generally, experts tend to: Excel primarily in their domains, 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 problem solving (Feldon, 2007). Cognitive science has also determined that different parts of the brain are active in novices and experts when approaching a problem, strengthening these observations (Bjorklund, 2007).

Observations of novices and experts in various physics subject areas have confirmed many of these general characteristics, Table 2.2 summarises some of these observations.

<table>
<thead>
<tr>
<th>Novice</th>
<th>Expert</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sort problems by superficial similarity</td>
<td>Sorts problems according to underlying physics and solution principles</td>
<td>(Chi, Feltovich, &amp; Glaser, 1981)</td>
</tr>
<tr>
<td>Tend to solve problems based on manipulation of formulas</td>
<td>Refer to theory primarily, and employ formulae more appropriately</td>
<td>(Larkin, 1983) ; (J. Larkin, McDermott, Simon, &amp; Simon, 1980)</td>
</tr>
<tr>
<td>Intuitive knowledge is more fragmented and to the context it was encountered in</td>
<td>Knowledge is more suitably linked and transferred</td>
<td>(A. diSessa, 1993)</td>
</tr>
<tr>
<td>‘Work backward’ and set subgoals to achieve a ‘means end’ analysis</td>
<td>‘Work forward’ towards a known goal by finding unknowns</td>
<td>(J. Larkin, et al., 1980)</td>
</tr>
<tr>
<td>Tend to talk in terms of equations</td>
<td>Can more aptly describe the actual physical situation</td>
<td>(Gick, 1986)</td>
</tr>
<tr>
<td>‘Search based’ and ‘means end’</td>
<td>working forward by schemata (knowledge structure) that also have solution procedures</td>
<td>overall summary</td>
</tr>
</tbody>
</table>

Table 2.2. Characteristics of experts and novices in physics

More current studies of expertise consider additional issues regarding development and the characteristics of novices and experts (Hammer, 1991).

2.2.3 Socio-Cultural Theory

Within the framework of Socio-cultural theory, the mechanism for human development is based on the process of social interaction. Vygotsky was the dominant proponent of the theory, which asserts that social and individual processes are interdependent and development is mediated by social factors; especially symbols (language):

‘all higher functions originate as actual relationships between individuals’ (Vygotsky, 1978, p. 57)

‘Vygotsky conceptualized development as the transformation of socially shared activities into internalised processes’ (John-Steiner & Muhn, 1996, p. 192).
This approach is different from the Piagetian view of development in that Vygotsky believed that Piaget-like stages would be fundamentally driven by the social context and not the age of the person. Vygotsky implied that *learning resulted in development*, instead of the reverse. This presents a novel view of a familiar set of observations. He described higher mental processes as *mediated* and therefore required mediators to occur. Mediation in this framework is facilitated by tools language, art, numbers and other culturally derived symbols and social interactions. It stipulates that development will plateau without social interaction; left with their innate abilities, humans could not develop higher mental functioning. It is only when they acquire social symbols (eg language) through their innate abilities (reflexes) that they then engage in higher order human capacities.

A socio-cultural perspective on developing expertise describes a process whereby learners depend on experts (either relative or absolute) to mediate development. The cusp of this expansion at any one time is known as the ‘zone of proximal development’. The zone of proximal development was initially described by Vygotsky in *Mind in Society* (1978) and is closely linked with mediation of progress by an adult or more capable peer.

There is not much observational or experimental research directly grounded in socio-cultural theory, but there have been a number of studies concerning the issues related to language in thermodynamics- which strongly implicate social factors in the learning of the topic. The word heat for example, has had various meanings throughout history and is therefore used differently in different contexts. This has sparked discussion and debate relating to how the term heat should be approached when teaching thermodynamic topics at school (Zemansky, 1970)

One particularly relevant study poses the question of whether of not certain conceptions of heat are a function of their intellectual (cultural) environment, or whether a concept is formed more or less naturally (for example, as Piaget’s developmentalist approach would suggest). Comparing western and African (Sotho) cultures, the study notes that the two cultures have different perceptions of heat. In western cultures, the heat flow or caloric model dominates when describing heat, while the Sotho people have meaning associated with their physical environment. In fact, their associations are sometimes negative, with drought, sickness, and even death considered as metaphorically ‘hot’. Such a difference in meaning could have significant effects on the understanding of associated thermal processes. For example, the study concludes that the Sotho people are likely to be at an advantage when learning about the kinetic theory of heat because they do not have to ‘unlearn’ the caloric model (Hewson & Hamlyn, 1984). Accepting the significance of cultural symbols and contexts allows us to recognise the effect they may subsequently have on learning.

### 2.2.4 Conceptual Change

This section is associated with describing the process and conditions for conceptual development or change. A concise and faithful summary of conceptual change is almost impossible given the vast amount of literature on the topic. For more expansive summaries see (P. W. Hewson, 1981; Posner, Strike, Hewson, & Gertzog, 1982b; Tyson, Venille, Harrison, & Treagust, 1997; Vosniadou, 1994; Özdemir & Clark, 2007). For the purpose of this paper, I summarise only the relevant points and introduce those points with the following statement:

‘...Empirical studies of many different domains indicate that students begin their study of science with strongly held conceptions about some phenomena, conflicting ideas about similar phenomena, and little knowledge of other phenomena’(Eylon & Linn, 1988, p. 253)

Despite its sprawling coverage, conceptual change literature represents the drastic reorganisation of certain concepts, which are in conflict with other, more widely established concepts to develop and improve ones understanding (Posner, et al., 1982b). The result of the change is significant for many reasons, but is most fascinating because it seems to represent a type of knowledge that is identifiable, meaningful and associated with the broadest objectives of education. Conceptual change soon became a focus for science researchers and educators and attitudes began to convey the idea that conceptual change and meaningful learning were synonymous (Driver, et al., 1994). Research flourished during the 1980s and ‘90s, with efforts focused on how to encourage conceptual change and how to best capture a description of the process theoretically (Wandersee, Mintzes, & Novak, 1994).

The most influential (over 3000 citations in published articles) and aptly summative model of conceptual change is that of Posner, Strike, Hewson and Gertzog (1982a). It highlights the importance of conflict as a means of facilitating conceptual change in science through the impact and acceptance of new ideas or information. This fundamentally involves the restructuring of knowledge elements in the knowledge structure of a student, which the authors call their ‘conceptual ecologies’. Restructuring is the act of making more productive connections.
between knowledge elements. For example, if a student who has developed the idea that motion is caused by a force observes a contradiction in this notion (perhaps through instruction), they may begin to construct new links which are more associated with Newtonian mechanics. As these links become strengthened, the student is now able to generalise and predict the behaviour of similar objects in a more systematic and accurate way. The acts of strengthening and weakening links are effectively the path towards a development of an integrated and coherent structure of elements, or conceptions. The flow chart below indicates the main elements of the Posner and Strike model.

One of the major branches of the conceptual change movement was the investigation of conceptions of natural phenomena. Historically, authors called these misconceptions because they represented unsound or non-scientific conceptions. This was a dominant field of research with regards to physics education and some considerations are mentioned below, to capture the essence of the work of misconceptions authors:

- Why are some misconceptions more robust than others? (Chi, 2005)
- Is the nature of conceptual change domain specific or more general? (Chi, 2005)
- Is conceptual change dependant on the individual’s age? (Tyson, et al., 1997)
- Is the nature of the content important? (Tyson, et al., 1997)
- Can conceptual change be thought of independently of social and cultural influences? (Guzzetti & Hynd, 1998)
- Does a change occur in steps, or more gradually? (Vosniadou, 1994)
- Must a new theory exclusively replace the old one? (Driver, et al., 1994)

Any further discussion of conceptual change and misconceptions will be presented within the specific context of thermodynamics.

2.2.5 Thermodynamics

The topic of thermodynamics was chosen intentionally. Thermodynamics is a unique selection for research within physics for many reasons. First, it not as emphasised as other topics (Hurley, 2005). Second, many thermal processes are very familiar, and grounded in interesting fundamental concepts. Third, these fundamental concepts continue to cause conceptual difficulties, even for relative experts (Lewis & Linn, 1994).

It is also a topic that is reported to be closely linked with broader science education goals. Given the wide discrepancies within the topic between naïve understanding and scientific understanding, this topic provides an excellent context in which to encourage conceptual change. This particular link has been confirmed through a study which reports that developing an integrated understanding in thermal concepts has proven to increase scientific literacy and is associated generally with sophisticated beliefs in science (Linn, 1993). This is not surprising when one considers that the existence and validity of different viewpoints is the basis of a scientific epistemology (Wiser & Amin, 2001).

This thesis will focus on the basic concepts such as heat, temperature, thermal equilibrium and heat transfer. Specific misconceptions related to these topics are presented in the following section.
2.2.6 Misconceptions in thermodynamics

The nature of the material presented in a physics course causes distinctive difficulties amongst students of different ages, cultures and abilities. These distinctive difficulties were initially referred to as ‘misconceptions’ but now go by various names (alternative conceptions, alternative frameworks and naïve beliefs or conceptions) in an effort to accurately and fairly represent them. Many recent authors in this field are accepting that misconceptions or alternative conceptions cannot be treated in isolation, and in identifying the ‘wrong’ conceptions, one must also consider the ‘right’ ones that are essentially linked. Unfortunately, there are also particular names for conceptions as a whole, for example, calls them ‘facets’ (Minstrell, 2001).

Two theoretical perspectives on misconceptions dominate the literature, and present opposing views: that knowledge is theory-like and that it is piece-like.

The knowledge-as-theory view can be seen to fix knowledge within a web-like theory. Specifically, it claims that knowledge is organized by students, and this framework is in a sense theory-like; and thus can be likened to theories of scientists (eg., Carey, 1985). Misconceptions manifest themselves within these personal theories.

The piece-like theory categorizes students’ understanding in terms of elements. diSessa describes a piece-like knowledge element known as the ‘phenomenological primitives’ or p-prims (A. A. diSessa, 1996; A. A. diSessa, Gillespie, & Esterly, 2004). A p-prim is a knowledge element that involves no further explanation (eg. Motion requires a force). Common p-prims have been recorded for various topics they are often found to be fairly robust. Although they may exist in a group of related p-prims, they are inherently discrete. They are related to the notion of a misconception because they explain that certain concepts are acquired and retained because they do not require further investigation or query. This study is more naturally grounded within this approach as it is revealing conceptions, which are elements of knowledge.

Despite different perspectives, there still exists a common theme or rationale for misconceptions investigations that can be summarised by noting that:

- Children’s views seem to be widespread even among students of different cultures, ages, abilities and appear in many science domains (biology/chemistry etc)
- They are very persistent and difficult to change or replace
- They affect subsequent learning
  (J. Nussbaum & Novak, 1976)

Studies within the topic of motion are the most abundant, especially after the development of the diagnostic tool the Force Concept Inventory (FCI) (Hestenes & Halloun, 1995). Thermodynamics has been explored to a lesser extent. The reasons for attention in these two topics can be attributed to their underlying similarities: Their inherent familiarity, their relevance to everyday life, and paradoxically, their inherent difficulty in comprehension. It is also these characteristics that provide the unique opportunity to engender meaningful and relevant learning.

Below is a discussion of the specific thermodynamic misconceptions that exist amongst students of different ages. The use of the word ‘misconception’ will be used here for historical accuracy.
**Misconceptions of children**

Most of the research based on misconceptions in thermodynamics has focused on younger children. Results from these studies are relevant to the present study since many of the conceptual difficulties of young children are also present in older children and even students with formal physics instruction (Engel Clough, Driver, & Wood-Robinson, 1987). The following difficulties are amongst the most significant:

- Assuming a caloric theory of heat transfer (Erickson, 1979)
- 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)
- Uncertainties about boiling, including erroneous interpretations of the constituents of the ‘bubbles’ and why the water level decreases (Bar & Gallili, 1994)
- Ignorance related to the conservation of energy (2nd Law of Thermodynamics) (Kesidou & Duit, 1993)
- Incorrect or incomplete associations and interpretations of energy and thermodynamic processes (Sila & Olgun, 2008)

**Misconceptions of University students**

Universities have attracted by far the least amount of research on misconceptions (Meltzer, 2004a). In NSW, university is often the first substantial introduction to the field of thermodynamics, with a sparse covering in high schools in (Board of Studies, 2002). Thermodynamic concepts are encountered in many courses and degrees including chemistry, biology, medicine, engineering, agricultural studies, some education courses (eg. Human movement and primary), nursing, health sciences and other applied sciences. It has been noted that basic conceptual misunderstanding in such subjects translates to difficulties in further studies:

‘..it is not just that a few facts have been taught wrongly. The pattern of thought which is inculcated is quite often lacking in logical structure. It thus becomes extremely difficult to remedy these errors by later teaching. As the student meets more advanced developments of thermodynamics he becomes increasingly confused and the subject becomes progressively more difficult’ (Warren, 1972, p. 41)

Evidence also suggests that basic concepts are often assumed knowledge, and are therefore not explicitly assessed at university, possibly missing the indications of a lack of fundamental understanding. A study by Meltzer demonstrates that certain fundamental concepts and idealisations often taken for granted by instructors are still proving very troublesome for many students (for example the relation between temperature and kinetic energy) (Meltzer, 2005). Another study conducted at university level revealed that although the ‘correct’ answer was initially given (in a multiple choice test), subsequent and deeper questioning caused contradictions in students answers in different contexts (Niaz, 2000).

Below is an outline of the reported thermodynamic misconceptions at the university level, as summarised by Meltzer (2004a):

- Trouble distinguishing between the concepts of heat, temperature, internal energy, and thermal conductivity
- Misinterpreting heat as a mass-independent property of an object
- Interpreting temperature as a measure of intensity with reference to the object
- Thinking of temperature and heat as the same concept
- 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
- Having problems grasping the relationship between laws of thermodynamics and the concept of entropy.

Meltzer has focused on addressing and overcoming these misconceptions for almost a decade with success in both the identification of student conceptions and the development of effective instructional techniques.
2.3 Review of Methods of Analysis

2.3.1 Quantitative vs. Qualitative research methods

Any educational research, physics included, is a form of social research. Consequently, research methods are varied, including both quantitative and qualitative types. For a brief overview of each, see Table 2.3. These two kinds of research seem to be emphasised differently depending on the background of the researcher. Traditionally, quantitative type research has been more dominant in physics education research. A fair amount of conflict still exists between the two approaches as purists of each camp sometimes find it difficult to understand each others orientation and intellectual clashes often result in heated and defensive debate. Ironically, the conflict is fuelled more by the communities of these two fields, rather than the ‘science’ behind them².

<table>
<thead>
<tr>
<th>Quantitative Research</th>
<th>Qualitative Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deductive</td>
<td>Inductive</td>
</tr>
<tr>
<td>Objective/outsider-centered</td>
<td>Subjective/insider-centered</td>
</tr>
<tr>
<td>Natural science worldview</td>
<td>Anthropological worldview</td>
</tr>
<tr>
<td>Attempt to control variables</td>
<td>Relative lack of control</td>
</tr>
<tr>
<td>Goal: to find facts and causes</td>
<td>Goal: to understand the actor’s view</td>
</tr>
<tr>
<td>Static reality assumed: relative</td>
<td>Dynamic reality assumed: “slice of life”</td>
</tr>
<tr>
<td>constancy in life</td>
<td></td>
</tr>
<tr>
<td>Confirmatory</td>
<td>Explanatory</td>
</tr>
</tbody>
</table>

Table 2.3 Summary of the main characteristics of quantitative and qualitative research (Otero & Harlow, 2009, p. 4)

Unfortunately, the cultures of these two research methods sometimes affect how efficiently research is conducted. Some believe the two methods are fundamentally grounded in such different approaches as to make them incompatible. This limits the opportunity to mix methods, which is ultimately a beneficial enterprise.

Although it may seem unusual to use many different methods and approaches- in reality it is necessary for approaches to be so diverse, especially given the social and highly contextual nature of educational research.

Quantitative methods are the more transparent and definite, consisting mainly of statistical analysis that are generally widely recognised (Neuman, 2003). Qualitative methods are less easy to summarise, since both the ‘types’ of methodologies and ‘characteristics’ of these methodologies are not widely established. Some widely accepted traditions include discourse analysis, phenomenology, grounded theory, narrative analysis, and ethnography (Otero & Harlow, 2009).

Specific qualitative methodologies such as written tests, interviews, concept mapping (or combinations of these) are methods that are now considered reliable and highly effective in gauging conceptions and performance. However, the inherent difficulties with analysis of tests regarding conceptions still remain. There is a compromise between objectivity and illumination since to extract more meaning, we must move away from strictly quantitative analysis and yet by doing so, we lose the comfort of statistics and numbers.

Although comparing conclusions resulting from different methodologies introduces added complications, researchers are much more willing to work towards a way of synthesising diverse research rather than finding a ‘one size fits all’ approach (Liu, 2001). Improvements to educational theory and instructional design are more likely if individual studies are long term, or if many different studies are integrated instead of existing in isolation (J. Nussbaum & Novak, 1976).

Distilling useable methods from this mountain of approaches is not an easy task, yet there are certain techniques which are firmly established amongst physics education researchers. For this study, the methods of Phenomenography, SOLO taxonomy and coding were used and will be outlined in more detail below.

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2 In Miles and Huberman (1994, p. 40) Kerlinger, a quantitative researcher, is quoted as saying ‘there is no such thing as qualitative data. Everything is either 1 or 0’. Campbell, who is a qualitative researcher, is also reported as saying ‘All research ultimately has a qualitative grounding’
2.3.2 Phenomenography

Phenomenography represented a turning point in educational research and now forms the basis of a major strand of qualitative methods regarding the analysis of conceptions. Phenomenography can be described most crudely as a categorisation method, and more eloquently as:

‘finding and systemizing of forms of thought in terms of which people interpret significant aspects of reality’ (Marton, 1981, p. 177)

In its original form, phenomenographic analysis consisted of first-order and second-order considerations:

‘These two ways of formulating questions represent two different perspectives. In the first and by far the most commonly adopted perspective we orient ourselves towards the world and make statements about it. In the second perspective we orient ourselves towards people’s ideas about the world (or their experience of it) and we make statements about people’s ideas about the world (or about their experience of it). Let us call the former a first order and the latter a second-order perspective.’ (Marton, 1981, p. 178)

The second-order is considered to be more relevant in educational studies and is aimed at describing the conceptions of students regarding various topics. Phenomenographic studies have been performed in various topics (for an example in computer assisted learning see Jones & Asensio, 2001) and have had their supporters as well their critics (Richardson, 1999). Generally, supporters assert that it is beneficial to qualitatively summarise conception with some structure and consistency, whilst its critics object to the vagueness of the method (Ashworth & Lucas, 1998). However, the appropriate application is the responsibility of the researcher and subsequently its effectiveness and usefulness can vary.

2.3.3 SOLO-taxonomy

The Structure Of Learning Outcomes (SOLO) taxonomy is another form of categorisation. Instead of describing particular conceptions, it imposes a hierarchical structure which represents certain levels of learning outcomes. Each ‘level’ has similar characteristics with respect to these learning outcomes but may contain a number of different conceptions. This method is useful when you wish to summarise findings from large data sets but do not necessarily want to focus on details. It has been used in various science contexts, for example numeracy in biology (Lake, 1999), and organic chemistry (Hodges & Harvey, 2003). At the time of writing, no studies on thermodynamic concepts have used the SOLO method. Below in Table 2.4, the five hierarchical levels are presented alongside the description of the general learning outcomes as constructed by the designers (Biggs and Collins) as well as a more recent author using the technique. This is included to highlight that adopting a SOLO taxonomy requires the use of a common structure, but the specific learning outcomes or descriptions of levels may be different for each study.

<table>
<thead>
<tr>
<th>SOLO description</th>
<th>Description from Biggs and Collins (1982)</th>
<th>Description from Boulton-Lewis (1994)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestructural</td>
<td>Tautology, denial, transduction, bound to specifics</td>
<td>There is no evidence of any knowledge of the processes involved in learning</td>
</tr>
<tr>
<td>Unistructural</td>
<td>Can ‘generalise’ only in terms of one aspect</td>
<td>One relevant aspect of learning is understood and focused on</td>
</tr>
<tr>
<td>Multistructural</td>
<td>Can ‘generalise’ only in terms of a few limited and independent aspects</td>
<td>Several relevant independent aspects of learning are presented, these are not integrated into an overall structure</td>
</tr>
<tr>
<td>Relational</td>
<td>Induction. Can generalize within given or experienced context using related aspects</td>
<td>Relevant aspects of learning are integrated into an overall structure</td>
</tr>
<tr>
<td>Extended abstract</td>
<td>Deduction and Induction. Can generalise to situations not experienced.</td>
<td>The integrated knowledge of learning is generalised to a new domain</td>
</tr>
</tbody>
</table>

Table 2.4 SOLO taxonomy levels and descriptions.
2.3.4 Coding: Computer software in qualitative research and NVivo

Coding is the name given to the act of assigning meaning to a section of text (or transcript, diagram, graph etc) and is used in some capacity for most qualitative based research. The analysis of the Test Question explicitly used coding as a primary source of analysis although by definition, phenomenography and SOLO analysis are effectively coding techniques also. The following excerpt offers a formal definition of coding:

‘Coding transcripts or other text-based data is the process of going through a transcript in detail in hopes of finding words, statements, or events that can be sorted and labeled using a cover term (code). Ultimately, the researcher will use these codes to find patterns and meaning in the data’ (Otero & Harlow, 2009, p. 31).

The coding may be used to analyse qualitative data as follows:

‘The codes and patterns observed in the codes can be used to develop a descriptive model of the phenomenon being investigated. Taxonomic domains, concept maps, and componential analyses all represent descriptive models. On the other hand, a researcher may use the frequencies of the codes themselves to make descriptive statements such as, “Students spend 10% of their discussion time in sense-making during laboratory activities that use equipment and 40% of their discussion time sense-making in activities which use a computer simulator.” A descriptive model does just that - it describes the phenomenon in terms of characteristics appropriate for the research question.’ (Otero & Harlow, 2009, p. 39)

NVivo is a computer program that can facilitate qualitative analysis and therefore coding. Although computer programs are not extensively used in qualitative research, there are still a number of programs to choose from if this is your preference. NVivo was selected on information from a general qualitative data analysis sourcebook (Miles & Huberman, 1994), and a handbook with detailed information on NVivo (Bazeley, 2007). In hindsight, the selection was appropriate, and the program was a useful tool in the analysis of the Test Question. It is interesting to note that NVivo is a particular favourite of ‘positivist’ or quantitatively minded researchers, as it inherently provides a comfortable level of objectivity or transparency (Johnston, 2006). Understandably, many PER researches in the US have begun to use the program to facilitate qualitative research, and NVivo has been specifically mentioned described as a useful tool in a handbook designed to introduce students beginning research in PER (Otero & Harlow, 2009). Below is a justification for engaging in exploratory research as facilitated by the program:

‘Researchers engage in projects (with NVivo) involving interpretation of unstructured or semi structured data for a variety of reasons… exploration, description, comparison, pattern analysis, theory testing, theory building or evaluation’ (Bazeley, 2007, p. 2)

Also, a summary of the capacity of the software program:

‘It (NVivo) is designed to remove rigid divisions between “data” and “interpretation”…It offers many ways of connecting the parts of a project, integrating reflection and recorded data’ (Richards, 1999, p. 3)

Specifically, NVivo is designed to help: manage data, manage ideas, query data and graphically model and report data (Bazeley, 2007). The computer program (and indeed computer programs for qualitative analysis in general) has been subject to intense scrutiny by those who believe the ‘nature’ of qualitative analysis is threatened (Kelle, 1995). The main concern is that the analysis will become too methodical and researchers alienated from their data, losing sight of the ‘bigger picture’. These criticisms are satisfactorily answered in the literature but their prevalence still appears to be significant. Given the fact that the program improves transparency and recording, and that it merely facilitates already existing analytical methods, these criticisms seem to exist more out of a concern for the programs misuse, or the tendency to mistrust change or technology. The program can be misused as much as any other technique in research, and if this is the case, the advanced functioning of the software merely clarifies the existing problems associated in qualitative research by enhancing them (Johnston, 2006).

In saying this, it is universally acknowledged that researchers need to be meticulous with regards to their methods for the use of the program if it is to prove beneficial for rigorous analysis. Coding in the software must be carefully monitored and checked to avoid superficial coding or automated coding without external reference to literature or discourse.

‘(Computers) cannot resolve essential dilemmas of inquiry, nor eliminate the important role of creativity... and will not ultimately make the work less challenging’ (Cousins & McIntosh, 2005 p.597).
The mechanics of the program

A screen shot of the coding process is presented in Figure 2.1 to help clarify the mechanics of the program. The screen shot depicts the work space where the researcher would code their data. The large window in the middle contains the responses from the current study, and the window to the right depicts the ‘coding stripes’ which track which sections of the text the researcher has coded. Each colour represents a different code. This window may also record who has performed the coding in the case of collaboration.

![Figure 2.1. Screen shot of coding window in NVivo](image)

2.4 Summary of methods and techniques used

Table 2.5 summarises the methods used in this study and their advantages and disadvantages. The first three methods were used in the Diagnostic Test and the last was used in the Test Question. Further details regarding these methods are provided in the corresponding sections.

<table>
<thead>
<tr>
<th>Method of analysis</th>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Where used</th>
<th>Computer Facilitated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility and discrimination</td>
<td>Quantitative-statistical analysis</td>
<td>Objective, confirmatory, convenient (time and effort), transparent and easy to report</td>
<td>limited, not descriptive, may over-estimate understanding, affected by guessing</td>
<td>Diagnostic Test (Multiple choice)</td>
<td>Excel, SPSS</td>
</tr>
<tr>
<td>Phenomenography</td>
<td>Qualitative-Categorisation into like responses</td>
<td>Able to categorise and describe conceptions of large groups of students</td>
<td>Difficult to unanimously and objectively determine categories. Responses can belong to one category only</td>
<td>Diagnostic Test (Q13)</td>
<td>No</td>
</tr>
<tr>
<td>SOLO taxonomy</td>
<td>Qualitative-Categorisation according to sophistication of responses</td>
<td>Firm structure allows differentiation of different ‘levels’ of sophistication of responses and assessment of learning outcomes</td>
<td>Responses can belong to one category only, inhibiting multiple descriptions</td>
<td>Diagnostic Test (Q14 and Q15)</td>
<td>No</td>
</tr>
<tr>
<td>Coding</td>
<td>Qualitative-inductive approach</td>
<td>Flexible, specific, versatile</td>
<td>Issues with valid and reliable coding</td>
<td>Test Question</td>
<td>NVivo</td>
</tr>
</tbody>
</table>

Table 2.5 Comparisons of methods and techniques used in current study
3 Outline of research project

3.1 The approach to the research aims

The aims of this research study were broad. There is no prescribed way to probe student conceptions. The present study therefore approaches the aims using a triangulation method. The Diagnostic Test, which was administered in semester one at the outset of this study, was effective in outlining conceptions of students and also helped focus these aims by providing an appropriate subsequent Test Question. The Test Question provided information about the details and specific nature of some of these conceptions, and both approaches were supported by the literature.

3.2 A note on the different ‘groups’

Much of this thesis is focused on comparisons between different ‘groups’. The use of groups was a necessary condition since one of the study’s aims was to compare the conceptions of relative ‘experts’ and ‘novices’. The groups in this study represent levels of expertise in the sense that students belonging to each group have common and identified levels of prior experience with formal physics instruction. Less experience with formal physics instruction corresponds to a more novice-type learner, while more experience with formal physics instruction implies a relatively more expert-type learner. The groups considered in the analysis of the two different tests were as follows. The Diagnostic Test compares the Fundamental, Regular, Advanced and 2nd year groups, where we can assume an increase in expertise as defined by the previous statement (Fundamentals have two years less high school instruction on average than Regular and Advanced and the 2nd year group has one year additional tertiary physics instruction). In the Test Question, the Fundamental, Regular and Advanced groups were used again, but the 2nd year group was not. Instead, a Primary Education group was included, and this group fit in before the Fundamentals on the scale. This was because although they had the same high school instruction, the Fundamentals had one extra semester of tertiary physics instruction and were therefore less ‘novice-type’ with regards to our definition. This definition will stand throughout the thesis.

Figure 3.1 Outline of project and illustration of triangulation method

Figure 3.2 Representation of level of expertise of groups used in the two sections of the project. Throughout the project, abbreviations may be used to represent these groups. ‘Primary’ for Primary Education, ‘Fund’ for Fundamentals, ‘Reg’ for Regular, ‘Adv’ for Advanced and 2nd or 2nd Yr for Second year group.
4 The Diagnostic Test

The Diagnostic Test was designed to provide an initial impression of tertiary student’s conceptions. These initial impressions would both inform the development of the subsequent Test Question and help support the ultimate conclusions of the study. The main objectives were to ensure the right topics were targeted, and to give an indication of the expected style and length of responses. As part of the analysis, there was an additional focus on

1. The identification and description of alternative conceptions of students

2. The comparisons between novice-type and expert-type groups

4.1 Development of the Diagnostic Test

The Diagnostic Test was administered in week two of semester one and consisted of 12 multiple choice questions and 3 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 was adapted from a first year university topic test on thermodynamics intended for revision (Sharma, 1995).

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 test and the particular collection of questions was verified by a panel of physics education researchers to ensure the suitability for the intended purpose. As the test was intended to act as a probe only, many of the stylistic concerns that are usually considered for formal tests were not strictly adhered to. These included consistency of question types, number of distractors and the length of the test. Table 4.1 shows a basic classification of the concepts represented by multiple choice section of the Diagnostic Test.

<table>
<thead>
<tr>
<th>Thermodynamic Concepts</th>
<th>Specific Topic</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theromodynamic Processes</td>
<td>Phase change and latent heat</td>
<td>4,5,6,8</td>
</tr>
<tr>
<td></td>
<td>Thermal equilibrium</td>
<td>1,2,3</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>1,2,5</td>
</tr>
<tr>
<td></td>
<td>Thermal contact</td>
<td>1,3,5,7</td>
</tr>
<tr>
<td></td>
<td>Temperature as a measure of hotness</td>
<td>2,5,7,8</td>
</tr>
<tr>
<td>Zeroth law</td>
<td>Specific heat</td>
<td>11</td>
</tr>
<tr>
<td>Cooling and heating rate</td>
<td>Rate of cooling</td>
<td>9,10</td>
</tr>
<tr>
<td>Heat transfer</td>
<td>Heat transfer</td>
<td>3,12</td>
</tr>
</tbody>
</table>

Table 4.1 Classification of concepts in the Diagnostic Test

4.2 The Sample

The participants were first and second year university physics students at the University of Sydney. The Fundamental, Regular and Advanced students were all first year physics students while the 2nd year group is the second year physics cohort. Generally, due to course specifications, the Regular and Advanced groups are required to have 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. Most of the students attempted the multiple choice sections (Table 4.2) however there were 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 test was not sufficient.
4.3 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.

4.3.1 Results: Multiple choice section

Two tests for ‘quality’ were undertaken on the multiple choice section using techniques within classical test theory. These are facility and discrimination index. The facility indicates the proportion of students answering the question correctly. Acceptable values for a multiple choice test 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 abnormally well. None of the questions of this test had a negative discrimination index (Figure 4.1). 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 4.1 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 in this application, values outside the normal range of either index will highlight questions causing particular conceptual difficulty. The equations 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 4.3. Note that Q2 and Q7 are two questions with the same underlying concept.

Table 4.4 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.
Histograms for selected questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Multiple choice Alternatives</th>
<th>Histogram</th>
</tr>
</thead>
</table>
| 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 | ![Histogram Q2](image) |
| 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. | ![Histogram Q7](image) |
| 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. | ![Histogram Q10](image) |
| 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. | ![Histogram Q12](image) |

Table 4.3. Data from a selection of questions from the multiple choice section of the Diagnostic Test. Histograms illustrate the range of responses for each group. Correct answer is in bold.
<table>
<thead>
<tr>
<th>Summary of question in Multiple choice section</th>
<th>% correct</th>
<th>Dominant Alternative Conception</th>
<th>% answered</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Likely temperature of ice cubes in a freezer</td>
<td>Fund: 54</td>
<td>a) Ice in a freezer is 0ºC</td>
<td>Fund: 42</td>
</tr>
<tr>
<td></td>
<td>Reg: 58</td>
<td></td>
<td>Reg: 39</td>
</tr>
<tr>
<td></td>
<td>Adv: 80</td>
<td></td>
<td>Adv: 17</td>
</tr>
<tr>
<td></td>
<td>2nd: 81</td>
<td></td>
<td>2nd: 19</td>
</tr>
<tr>
<td>2. Likely temperature of can of cola and plastic</td>
<td>Fund: 40</td>
<td>d) Liquid (cola) inside a bottle</td>
<td>Fund: 27</td>
</tr>
<tr>
<td>bottle of cola</td>
<td>Reg: 43</td>
<td>is at a different temperature</td>
<td>Reg: 32</td>
</tr>
<tr>
<td></td>
<td>Adv: 66</td>
<td>to the bottle itself</td>
<td>Adv: 20</td>
</tr>
<tr>
<td></td>
<td>2nd: 68</td>
<td></td>
<td>2nd: 13</td>
</tr>
<tr>
<td>3. Reason counter under cola can feels colder</td>
<td>Fund: 45</td>
<td>a) Cold is transferred from the</td>
<td>Fund: 39</td>
</tr>
<tr>
<td>than rest of counter</td>
<td>Reg: 67</td>
<td>cola to the counter</td>
<td>Reg: 21</td>
</tr>
<tr>
<td></td>
<td>Adv: 93</td>
<td></td>
<td>Adv: 17</td>
</tr>
<tr>
<td></td>
<td>2nd: 91</td>
<td></td>
<td>2nd: 6</td>
</tr>
<tr>
<td>4. Equal volumes of water and ice in freezer,</td>
<td>Fund: 42</td>
<td>c) Water and ice at 0ºC contain</td>
<td>Fund: 15</td>
</tr>
<tr>
<td>which loses greatest amount of heat?</td>
<td>Reg: 39</td>
<td>the same amount of heat</td>
<td>Reg: 25</td>
</tr>
<tr>
<td></td>
<td>Adv: 56</td>
<td>e) Water can’t have a temperature</td>
<td>Adv: 31</td>
</tr>
<tr>
<td></td>
<td>2nd: 61</td>
<td>of 0ºC</td>
<td>2nd: 18</td>
</tr>
<tr>
<td>5. Likely temperature of ice cubes in puddle</td>
<td>Fund: 58</td>
<td>c) Ice is at 5 ºC</td>
<td>Fund: 44</td>
</tr>
<tr>
<td>of water</td>
<td>Reg: 72</td>
<td></td>
<td>Reg: 34</td>
</tr>
<tr>
<td></td>
<td>Adv: 77</td>
<td></td>
<td>Adv: 10</td>
</tr>
<tr>
<td></td>
<td>2nd: 88</td>
<td></td>
<td>2nd: 8</td>
</tr>
<tr>
<td>high altitude</td>
<td>Reg: 40</td>
<td>same temperature</td>
<td>Reg: 43</td>
</tr>
<tr>
<td></td>
<td>Adv: 73</td>
<td>c) Water can increase temperature</td>
<td>Adv: 41</td>
</tr>
<tr>
<td></td>
<td>2nd: 66</td>
<td>after boiling</td>
<td>2nd: 9</td>
</tr>
<tr>
<td>7. Explanation of bathroom tiles feeling</td>
<td>Fund: 6</td>
<td>c) Tiles are at a lower</td>
<td>Fund: 44</td>
</tr>
<tr>
<td>colder than bathroom mat</td>
<td>Reg: 15</td>
<td>temperature because they do not</td>
<td>Reg: 43</td>
</tr>
<tr>
<td></td>
<td>Adv: 33</td>
<td>store energy well</td>
<td>Adv: 41</td>
</tr>
<tr>
<td></td>
<td>2nd: 60</td>
<td></td>
<td>2nd: 9</td>
</tr>
<tr>
<td>8. Effect on temperature of an object from</td>
<td>Fund: 32</td>
<td>a) Adding energy to an object</td>
<td>Fund: 30</td>
</tr>
<tr>
<td>the addition of energy</td>
<td>Reg: 35</td>
<td>always increases that objects</td>
<td>Reg: 48</td>
</tr>
<tr>
<td></td>
<td>Adv: 48</td>
<td>temperature</td>
<td>Adv: 42</td>
</tr>
<tr>
<td></td>
<td>2nd: 71</td>
<td></td>
<td>2nd: 20</td>
</tr>
<tr>
<td>9. Objects of different temperature, which</td>
<td>Fund: 49</td>
<td>c) Objects at different</td>
<td>Fund: 32</td>
</tr>
<tr>
<td>cools fastest initially?</td>
<td>Reg: 57</td>
<td>temperatures cool at the same</td>
<td>Reg: 29</td>
</tr>
<tr>
<td></td>
<td>Adv: 77</td>
<td>rate initially</td>
<td>Adv: 8</td>
</tr>
<tr>
<td></td>
<td>2nd: 76</td>
<td></td>
<td>2nd: 10</td>
</tr>
<tr>
<td>10. Objects of different temperature, which</td>
<td>Fund: 56</td>
<td>c) Objects at different</td>
<td>Fund: 23</td>
</tr>
<tr>
<td>eventually reaches equilibrium first?</td>
<td>Reg: 58</td>
<td>temperatures cool at the same</td>
<td>Reg: 19</td>
</tr>
<tr>
<td></td>
<td>Adv: 40</td>
<td>rate eventually</td>
<td>Adv: 15</td>
</tr>
<tr>
<td></td>
<td>2nd: 45</td>
<td>d) Objects cooling down will</td>
<td>2nd: 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>never reach a final temperature</td>
<td></td>
</tr>
<tr>
<td>11. Different materials at the same temperature.</td>
<td>Fund: 36</td>
<td>No Dominant alternative</td>
<td>Fund: 7</td>
</tr>
<tr>
<td>Why do they transfer different amounts of heat?</td>
<td>Reg: 37</td>
<td>conceptions</td>
<td>Reg: 9</td>
</tr>
<tr>
<td></td>
<td>Adv: 47</td>
<td>See for example, the histogram</td>
<td>2nd: 29</td>
</tr>
<tr>
<td></td>
<td>2nd: 56</td>
<td>for Q12</td>
<td>2nd: 20</td>
</tr>
<tr>
<td>12. Reason why clear nights are cooler than</td>
<td>Fund: 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cloudy ones.</td>
<td>Reg: 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adv: 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2nd: 23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.4. 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.
4.3.2 Discussion: Multiple choice section

The results confirm many of the general findings associated with younger students’ understanding of thermodynamics. Students at university level still have difficulties with a variety of basic thermal concepts that prove troublesome for younger children and their conceptions are highly context-dependent. It is also evident that many alternative conceptions have origins in experiences with daily activities and thermal-related terms in language that have different meaning in scientific and social contexts (Yeo & Zadnik, 2001). Interestingly, the Diagnostic Test began to reveal patterns in responses when comparing across the different ability groups.

Table 4.4 illustrates the main alternative conceptions. 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). There was 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 concept of thermal equilibrium in question 7 presented the most difficulty with no more than 33% answering correctly in any first year group. This concept was much more generally understood in Q2 where it was presented in a different context (66% maximum for first year cohort).

The selection of multiple choice options across groups presented an interesting pattern. Generally, 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 4.4 and Q11 and Q12 which 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, for 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 suggests that expert- and novice-types favour different alternative conceptions, and may tentatively imply there is a sequence towards sophistication of the thermodynamic conceptions.

4.3.3 Analysis and results: Extended response section

The three extended longer response questions are provided 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 where a different method was used.

Question 13

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 purely phenomonographic approach where the researcher collaborated with a thermodynamics lecturer to develop groups of responses with similar characteristics. Initial classification was undertaken on a sample of 160 from the Regular group to produce 10 categories as shown in Appendix C. A correct response would recognise that different materials (at the same temperature) would transfer different amounts of energy to the water in the vessel according to their specific heat capacity. The answer would be ‘different’ and the order from highest temperature to lowest would be: water, aluminium and copper. Note that the question does not request these materials be ranked in this way.

A brief summary from the preliminary analysis presented in Appendix C is presented in Table 4.5.
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.

Examples of responses

“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 thermal 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 (Appendix C)

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”

<table>
<thead>
<tr>
<th>Results</th>
<th>Examples of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>“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”</td>
</tr>
<tr>
<td>“Different, as each material has a different specific heat capacity; each will transfer a different amount of thermal energy on the water”</td>
<td>“different, as each material stores a different amount of heat within itself. Metals such as copper &amp; Aumunium can store a lot more heat than water and will therefore heat the cup more”</td>
</tr>
</tbody>
</table>

Table 4.5 Summary of main findings from Q13

This analysis was not extended to the entire population since this question was not expected to valuably contribute to the design of the Test Question. The focus on specific heat capacity was too narrow and the subject itself too involved. The familiarity with the concept of specific heat would require formal instruction, which much of our sample would not have received.

Question 14 and Question 15

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 since they were more likely to guide the construction of the Test Question. 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 a group of varied responses seemed fairly uniform. This pattern is a familiar one in conceptions analysis, and although there are many different approaches, the use of the established SOLO taxonomy would guide this particular analysis.

A sample of 160 responses from the Regular group was initially analysed and sorted into broad categories. Research usually do this is one of two ways. They may either use an already established taxonomy, such as the SOLO taxonomy, or they may independently construct their own categories based on their specific data. 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 4.6. Column one notes the SOLO levels, column two explains the data specific characteristics as developed by the researcher and further columns illustrate the proportion of students populating each level across the four groups of students. Examples of typical responses are presented in Table 4.7. 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.

Unsurprisingly, the sophistication of responses increased in order of expertise across the groups. Looking across the last row in Table 4.6, 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.
### Table 4.6 Response Classification and SOLO comparisons for Q14 & Q15. (F=Fundamentals, R=Regular, A=Advanced, 2nd=Second Year)

<table>
<thead>
<tr>
<th>Level</th>
<th>Characteristics of questions 14 and 15 for each category</th>
<th>Percentage of Responses in each category</th>
<th>Q14</th>
<th>Q15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>R</td>
</tr>
<tr>
<td>Prestructural</td>
<td>Messy, random responses that made little sense.</td>
<td></td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>Unistructural</td>
<td>Real world links with tendencies of naïve beliefs (some p-prims (A. A. diSessa, 1996)). Some mention of unrelated biology or chemistry references.</td>
<td></td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>Multistructural</td>
<td>Use of Physics concepts, but these were either not primarily related to question, or incomplete.</td>
<td></td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>Relational/Extended Abstract</td>
<td>Understanding of physics behind question. Errors, if any are mainly in use of language or expression.</td>
<td></td>
<td>28</td>
<td>43</td>
</tr>
</tbody>
</table>

Table 4.7 Examples of typical responses for each level or classification

<table>
<thead>
<tr>
<th>Level</th>
<th>Q14 response examples</th>
<th>Q15 response examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestructural</td>
<td>“The water is too cold”</td>
<td>“Blowing removes the heat”</td>
</tr>
<tr>
<td>Unistructural</td>
<td>“Water doesn’t allow heat to escape, causing colder conditions”</td>
<td>“Cool air from your breath will cool it down because the air is cooler than the liquid”</td>
</tr>
<tr>
<td>Multistructural</td>
<td>“Air has less density than water molecule which means that each atoms move more freely in air state”</td>
<td>“Blowing over hot tea will make the water molecules be blown away thus less heat will be left on the tea”</td>
</tr>
<tr>
<td>Relational/Extended Abstract</td>
<td>“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”</td>
<td>“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”</td>
</tr>
</tbody>
</table>

This data is important in assessing the students understanding, and providing a transparent guide for conceptual change. Progression to another level indicates mastery of a particular concept. 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 this will facilitate increased heat transfer, 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.

### 4.4 Diagnostic Test conclusions

The Diagnostic Test was intended to inform the development of the Test Question. The main contributions to the construction of the Test Question were as follows.

- **The topic that was chosen included a variation on the idea presented in Q2 and Q7**- These were associated with the perception of temperature, thermal equilibrium, and the concept of conductivity.
- **The same topic would be presented in 2 contexts**- This was based on the implication from results of Diagnostic Test, that students were not consistent when presented with a common concept in different contexts.
- **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 as there were a number of responses in Q14 and Q15 that did not attempt a scientific explanation at all.
5 The Test Question

5.1 Development

To adequately reveal conceptions, it was vital that the Test Question was able to encourage scientific, non-rote responses without being too easy or difficult. Using information from the literature and results from the Diagnostic Test, these criteria were met.

The ultimate design of the Test Question consisted of a structured response where the student must first choose one topic from a bank of six and then explain why they made this choice. The concepts were chosen to represent some of the underlying elements of the question. They were intentionally general, so as not to appear leading or confusing. Terms such as ‘specific heat’ and ‘thermal equilibrium’ were considered, however, they were not ultimately included as they were too technical (especially for students with junior science backgrounds only). The cold transfer option was unique in that it was not an accepted scientific concept. Although it is not clear to what extent the presence of this concept affected the student’s choice, the existence of this concept in the Diagnostic Test indicated that it was assumed to be a real scientific concept by a significant proportion of students. All six terms were therefore familiar and general enough to cue a response regardless of physics background, yet were technical enough to encourage a scientific explanation.

The question is effectively presented as a single question with two parts (Figure 5.1). Note that for analysis purposes, the two parts to the question were labelled Q1 and Q2 although this is not their representation in the actual test (where they are part a) and b) of one question). In both parts, a correct explanation would involve; A recognition that objects that are in contact with each other or a common third object will have reached thermal equilibrium after a reasonable amount of time; that the hand or foot is not a food thermometer; and that a sensation of coldness is a result of the relative thermal conductivity of a material. In the first part, analysed as Q1, the situation involves bathroom or kitchen tiles and bedroom carpets. In Q2, the two objects are the plastic and glass bottles in a self-serve refrigerator.

Figure 5.1 Answered test question
5.2 The sample

The sample included first year university students from the University of Sydney. This included a large sample of the first year physics students (total n=535) and the first year primary education students (n=63). A Masters of Education class (n=16) was also sampled but was not used in the majority of the analysis. Information regarding personal details of sample were collected from the cover sheet of the Test Question (see appendix D). The main degrees enrolled in for each group are presented in Figure 5.2 and Figure 5.3 illustrates for each group, the highest level of prior physics education.

In semester two, physics students at the University of Sydney select one of three available physics courses, Environmental, Technological or Advanced. For the purposes of this study, the students were classified according to the group they were in semester one. For example, even if a student was enrolled in Technological Physics for semester two, they will belong to the group relating to the stream they were enrolled in for semester one (Fundamental, Regular or Advanced) since it still represents the degree to which they had experience with formal physics instruction and therefore their level of expertise by the earlier definition.

There were 139 students in the Fundamentals group, 345 in the Regular group and 51 in the Advanced group.

5.3 Method

In scientific research, replication is key for ensuring reliability. This is not the case for qualitative research, where it is rare that exact methods are reproduced. There are however, many techniques and approaches which have been developed to ensure research is valid, accurate and reliable. My research was grounding in the techniques mentioned in Section 2.3 and can be specifically described as:

- Inductive not deductive
- Involving ‘Soft’ Data (instead of ‘Hard’ Data)
- Cross-sectional research (not longitudinal)
- Descriptive (rather than exploratory or explanatory)
- Using what is known formally as a ‘survey’
- Facilitated primarily by coding

The actual analysis of the data was a multistage process that began with the entry of the data (student information if given, and student responses) into Excel. After this, the data required formatting to be imported into the NVivo program, which was a straightforward but time consuming task. This step should be considered if using NVivo since it may affect how the data is collected and/or entered. Once imported the responses were coded. After this process was complete, all querying, searching and graphing could proceed.
5.3.1 Method: Coding in NVivo

The coding scheme was effectively single tiered (consisting of horizontal elements). To develop the final scheme, I used both a priori coding (deductive and predetermined) and generative coding (inductive and stemming from data). In the program, responses are coded to ‘nodes’ which store the information as sections of text which are hyperlinked to the original data. Ultimately the responses were coded to 7 different nodes. The nodes represent collective coded responses and are either ‘free’ or part of a ‘tree’ in the case of the one hierarchical node.

This program allows for responses to be coded to multiple nodes and this is the main advantage over the qualitative methods used earlier. In the SOLO analysis for example, coding occurred to ‘nodes’ which represented levels (Table 2.4). This limited analysis to comparing sophistication of responses, and although this is useful and sufficient in some cases, one can quickly appreciate the advantages of flexible coding as facilitated by NVivo, where various themes can be examined concurrently, and a rigid structure is not enforced.

The descriptions of the nodes I created for this study are presented in Figure 5-4. I began with a number of nodes and ended with seven, two that I discarded are presented in the Figure 5.4 for illustration. One node was added as a tree or hierarchical node due to the nature of the responses. This was the ‘Cold transfer’ node which was added as a stem to the ‘Cold’ node to differentiate the two characteristics associated with cold, the first relating to cold as a property of an object and the second was the notion that cold was able to be transferred or move in some way.

<table>
<thead>
<tr>
<th>Node: Satisfactory response</th>
</tr>
</thead>
<tbody>
<tr>
<td>This node represents responses that would be considered ‘satisfactory’. It was intended to highlight that ‘satisfactory’ does not necessarily imply coherent or integrated understanding. Satisfactory is assigned for responses that contained the following:</td>
</tr>
<tr>
<td>- State/imply or refer to the notion that the hand is not a reliable thermometer and therefore not measuring the actual temperature of the object (usually combined with a recognition that the objects are the same temperature because of thermal equilibrium)</td>
</tr>
<tr>
<td>- Mention that the coldness experienced is the loss of heat from the hand</td>
</tr>
<tr>
<td>- Mention the reason why the loss of heat occurs differently in the carpet/tiles or glass/plastic situations. Usually with reference to either the conductivity of the materials or the rate of heat transfer.</td>
</tr>
<tr>
<td>‘Satisfactory’ also includes responses that would be acceptable in a standard exam, or as alternatives in a multiple choice test. Responses coded here could therefore be quite brief.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node: Analogous concepts recognised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students recognised the similarities in related concepts between the two contexts. Specifically, that the hand is not a good ‘thermometer’ and that it is sensing the cold more in the object that is able to conduct/transfer heat better or quicker.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node: Objects at different temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students explicitly state that the objects are at a different temperature and this is why they feel hotter/colder. Responses are inherently ignorant of the process of thermal equilibrium in this context. Only explicit references are coded here.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node: Glass is an insulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students label glass as an insulator. These responses were coded because the statement is largely irrelevant with respect to the question. In fact, the statement that glass is an insulator results in contradictory responses, because the glass is in fact the better thermal conductor of the two.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node: Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students refer to or imply that cold is either a ‘stuff’ or substance, and that it is transferred or can be transmitted from one place to another. The sources coded as cold also implicitly distinguish “cold” from “heat”.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discarded Node: Contradictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discarded node: Exceptional responses</td>
</tr>
</tbody>
</table>

Figure 5.4 Nodes and Coding. These are the descriptions or criteria of the Nodes.
The existing nodes were straightforward and relatively objective. Creating further nodes would compromise validity, given the time constraints and availability of experts for collaboration. For example, the discarded Contradictions and Exceptional responses nodes would require much more discussion for developing solid criteria of the node and assessing individual responses.

The process of constructing and adjusting the nodes is explained below.

**Construction of a sample:** 208 responses were selected to create a sample where coding could be trialled. These responses were in matching proportions with respect to group as compared to the original data.

**General coding:** Initially, any potentially interesting segments of text were coded and there were therefore a large number of nodes. Most of these nodes were eventually discarded.

**A priori coding: ‘Heat’ ‘Cold’ and ‘Satisfactory response’ nodes:** These nodes were present at the outset of coding as informed by the Diagnostic Test and the literature and remained as established nodes.

**Generative coding: ‘Analogous concepts recognised’ ‘Glass is an insulator’ and ‘Objects at a different temperature’:** These nodes were not present at outset but were established whilst becoming more familiar with the data.

**Adding of node:** The ‘Cold transfer’ node was added as a stem from the ‘Cold’ node to capture the different aspects of this node. This was the only ‘tree’ node, which indicates it is part of a hierarchy.

**Validation of coding scheme for sample:** Validation was approached in two ways. Initially, a predictive approach was taken to ensure the development of the nodes was valid and unbiased. This predictive approach required the panel of experts to assess a list of responses that had been given to them. Although they were unaware of this, each list consisted of responses which were coded to one particular node (for example, a list of some responses coded to the Cold node are presented in Appendix E). The panel were asked to write descriptions of the nodes, therefore ‘predicting’ the nodes and verifying the coding. All nodes apart from the Satisfactory response node (which was validated by the second method) were verified by this predictive approach. This ensured the similarities recognised by the researcher were not artificial and the judgments made were legitimate. To complement this approach, and for the remainder of the process, the researcher employed a second approach. Using this approach, validation was achieved through experts verifying the coding by assessing individual responses. For example, the following response (from Appendix E) was initially coded to Cold, and then also Cold transfer. “Because coldness is going from the ground to her feet therefore cold transfer”. Experts would discuss whether this was valid coding and conclude one way or another with justification. This was a simple example for illustrative purposes.

**Calibration:** Individual responses which were contested by the members resulted in a discussion of the coding scheme. Agreement was reached after this discussion and in some cases, adjustments to the coding was necessary.

**Coding extension:** Coding process was extended to entire population.

**Validation of Coding scheme for whole sample:** Since there were over 14000 references (coding activities), the panel was not able to review the full coding as performed by the researcher. Instead, random samples were sent to members of the panel of experts for validation by the second method (confirming). If adjustments were necessary, responses could be either ‘un-coded’ or ‘re-coded’. Most of the time this occurred in isolation (only the one response was adjusted); however some adjustments would also require extension to the whole sample. For example, some of the responses coded to Heat were adjusted during this validation process. To confirm coding to Heat, a criterion was developed for coding where responses were coded only if they used of the following words “flow, absorb, keep, taken away, lost, gained, given, removed, escaped, retained, and radiated” but not if they used the words “transferred” or “conducted”. The researcher was able to then adjust the coding scheme for the rest of the sample.

**Analysis:** See section 5.4

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1 The researcher’s supervisory group at the University of Sydney Physics Education Research group who were experts in either physics or educational research. Members included Manjula Sharma, Brian McInnes, Ian Sefton and John O’Byrne. Christine Lindstrom, Alexandra Hugman, Ian Johnston and George Pinniger were also involved in discussions and participated in the first ‘predictive’ validation only.
5.4 Analysis and Results

The results presented here will focus on the following aspects related to the analysis of the Test Question.

- Significant conceptual difficulties with the concept of thermal equilibrium are still apparent (Section 5.4.1)
- novice-type and expert-type students’ conceptions about thermal equilibrium are different (Section 5.4.2)
- The misuse of language and scientific terminology goes some way to explaining many conceptions of the students, especially with regards to the concepts of heat, cold and insulation (Section 5.4.3)

5.4.1 Conceptual difficulties in thermodynamics

Answering a question correctly or doing well on a test does not necessarily indicate a coherent understanding of a subject (Niaz, 2000). In this section comparisons were made between the approaches towards the two questions to more fully capture possible conceptual difficulties. Both the concept choice and explanation were compared. The concept choice involved a simple comparison of categorical data while comparing the explanations involved comparing the coding in both questions.

Table 5.1 displays the seven nodes, the conceptions that are implied by responses coded to these nodes, and some typical responses from the data. The final two columns display what proportion of the total responses was coded, as well as the number of responses and references coded. For example, 24% of the total sample was coded to the node Cold, which implied a notion of cold as a substance. This equated to 146 total responses coded to this node, and 173 individual references. The excess in this case captures the fact that two or more discontinuous sections of student responses could be coded to any one node. This could have occurred if for example, a student used the explanation of cold transfer for Q1 as well as for Q2. Spelling errors in the typical response column are those of the student.

<table>
<thead>
<tr>
<th>Node</th>
<th>Implied conceptions</th>
<th>Typical response</th>
<th>Proportion of total responses coded to node (%)</th>
<th>Number of responses coded/number of references coded</th>
</tr>
</thead>
</table>
| Analogous concepts recognised | - Tiles in Q1 are analogous to glass bottle in Q2  
- Carpet in Q1 is analogous to plastic bottle in Q2  
- Environment of fridge interior in analogous to environment in house  
- Objects in fridge/house are the same temperature  
- The hand is not a good thermometer  
- Objects feel different because of the rate of heat transfer from the foot/hand | Q1 Concept  "Conductivity"  
Q1 Explanation  "The carpet and tiles are probably a similar temperature, however, the tiles conduct heat better, so they are more effective at taking away heat from her feet, creating that cool feeling"  
Q2 Concept  "Conductivity"  
Q2 Explanation  "Same thing. The glass transfers heat faster than the plastic, creating that cool feeling" | 15 | 86 |
| **Cold** | Cold is a property of an object  
Cold is a kind of stuff  
Cold is different from heat/hot  
Cold is able to be transferred from one place to another | “The carpet in the bedroom helps to insulate the room against the cold”  
“The glass keeps the cola cold”  
“the glass would be able to trap the cold for much longer period of time”  
“therefore the glass bottle retains the cold” | 24 | 146/173 |
| **Cold transfer** | Cold is able to be transferred/conducted or moved from one place to another | “The cold is more easily transferred from the tiles than from the carpet due to the materials of each”  
“The cold air from the tile is transferred to her feet”  
“Carpet transfer heat to feet whereas tiles transfer cold to feet”  
“The glass bottle conducts the cold better than plastic.” | 13 | 80/87 |
| **Glass is an Insulator** | If an object is an insulator, it is an absolute insulator, whose properties of insulation do not change  
Glass is an absolute insulator  
Insulators and therefore glass cannot be relatively thermally conductive  
Insulators keep cold in  
The bottle and the liquid it holds are not at the same temperature  
The bottle reflects the temperature of the liquid inside | “the glass is a better insulator than the plastic”  
“The glass bottle helps insulate the cold drink for longer”  
“Glass is a greater insulator”  
“The insulation of glass is better than plastic, hence keeping the drink cooler for longer” | 17 | 100 |
| **Heat** | Heat is a property of an object  
Heat is a kind of stuff  
Heat can be moved or transported (not necessarily transferred) from one body to another (absorbed, kept, flows, is taken away, lost, gained, given, removed, escaped, retained, radiated, leaving)  
Heat is different from cold | “The heat in her body is taken out”  
“Heat moves from warmer to colder objects”  
“When she steps onto tiles, heat from feet disappear!”  
“The glass takes the heat away from her the best”  
“Heat was coming out of her feet into the tiles making them feel cold” | 32 | 193/219 |
| **Satisfactory response** | The sensation of cold is heat leaving the body  
Materials have different thermal properties | “The two materials (carpet and tiles) have different conductivity properties. Tiles being better conductors allow heat to transfer between her body more effectively as compared to the carpet”  
“Heat is transferred from her feet to the tiles. Leaving her feet cold.”  
“Glass conducts heat better than plastic although they are both insulators. The glass bottle feels colder to the touch, but on a hot day it will gain heat more effectively thus heating the drink more rapidly. Rebecca should have chosen the plastic to keep her drink colder” | 50 | 299/412 |
| **Objects at different temperature** | Skin or touch can determine temperature  
Objects in contact with each other do not necessarily reach the same temperature | “The bathroom/kitchen’s floors are cooler than that of the bedroom”  
“Therefore when she walks on the tiles she will feel the difference in temperature, since the tiles are colder”  
“Glass has a better conductivity than plastic therefore the glass bottle actually is colder than the plastic bottle” | 17 | 103/118 |

Table 5.1 Summary of the coding. The implied conceptions, typical responses, and the proportion of total students being coded to each node is presented.
Concept choice

Since the question required a choice of concept for each part of the question, there was an aspect of categorical data in addition to the qualitative coding scheme. The results from analysing the categorical data are presented in Figures 5.5 and 5.6. These graphs report the number of students selecting each concept from the given list for Q1 and Q2 respectively. The most popular choices for both questions combined were conductivity, heat transfer, and insulation. It is immediately clear that the particular concepts chosen were different for each question. The largest disparity was the increased frequency of heat transfer as a selection for Q1 and the preference for conductivity and insulation for Q2. The ‘Other’ category represents a student who has selected two responses instead of one, or responses which failed to select a choice (but still attempted the explanation).

With regards to the combination of concepts, the most popular preference was one that involved two different concepts: heat transfer and insulation (for Q1 and Q2 respectively). Same choice combinations were relatively frequent with approximately one-fifth (n=120) of total responses selecting either conductivity combined or heat transfer combined.

Clearly, the selection of the most appropriate concept choice was dependent on the context of the question. This provides clues about exactly how these conceptions are arranged, and what ideas are connected. Insights into why there was a lack of consistency across the two questions are explored in the next section.

Coding of Explanations

This section extends upon the observation that the two questions were approached differently. The way in which they were different is explained by the coding profile (number and type of responses coded to each node) for each question as shown in Figure 5.7. There is a noticeable difference between the questions with regards to the coding profiles. The examples illustrating this difference are presented in Figure 5.7 and corresponding explanation:

![Figure 5.5 Frequency of each concept choice for Q1](image)

![Figure 5.6 Frequency of each concept choice for Q2](image)

![Figure 5.7 Comparison of coding in Explanation of both questions](image)
- **Satisfactory response:** There were a significantly higher number of responses coded to the Satisfactory response node in Q1 than there was in Q2. Within the definition of satisfactory, there is no implication that these responses were necessarily complete. What this does imply, is that presenting thermal equilibrium in Q1 will yield a higher proportion of students who can satisfactorily explain it, than if the same concept was presented in Q2 (given the same criteria). This indicates that question types and contexts are important factors in tests, and that a range of questions on the same topic may reveal different aspects of student understanding.

- **Cold, Cold transfer and Heat:** Cold transfer and Cold are part of a hierarchical node structure, where the Cold node includes the Cold transfer node. Conceptions coded to Heat appeared more in Q1, while Cold coded conceptions appeared more frequently in Q2. This is consistent with the conception that heat and cold are separate entities, but also, it seems to indicate that students believe the two act the same way: "As the glass is capable of losing the coldness (absorbing the heat) more quickly". It seems as though an underlying concept is recognised, but not yet fully integrated and therefore context-dependent.

- **Glass is an insulator:** This node is exclusively a Q2 node. Most responses in this node refer to insulation as blocking or preventing the flow of cold or heat. These conceptions and others listed in Table 5.1 were more obvious in Q2 than in Q1 because the insulator in Q2 was a vessel that also contained another substance (drink). This additional detail seemed to result in confusion of the properties of insulators; there was no such confusion in Q1. Note that the additional information in Q2 was not relevant to correctly answer the question.

In summary, this comparison indicates that students who are able to sufficiently explain a concept in one context may encounter difficulties in explaining the same concept presented in different contexts. This is consistent with the description of a novice learner, who fails to identify relevant and essential information and instead use knowledge which is peripheral and therefore unrelated (Table 2.2). It is also consistent with the observation that everyday notions related to heat, cold and insulation may supersede scientific concepts depending on how they are presented.

The connection between concept choice and explanation is not as straightforward as expected. Although the student was requested to chose a concept and explain their choice, sometimes an explanation would make a tentative reference or no reference to the concept choice. This implies a misunderstanding of the concept itself, or an inability to suitably integrate the knowledge of the concept within an explanation. The following examples demonstrate this observation. The concept chosen by these students is in the brackets. All spelling errors are those of the students.

> "Again certain types of materials maintain temperature better than other so that heat/cold won't change as quickly" (Insulation)

> "The glass insulated coldness better than plastic, therefore it will feel colder than that of the plastic bottle" (Conductivity)

> "When she feels the glass bottle it is colder than the plastic bottle. The beverage has been in the fridge to a long enough time to before that it is at thermal equilibriumm and thus the drink must also be colder" (Temperature)

> "The cold drink loses its cold more rapidly from glass bottle, than the plastic. This is why the glass bottle feels colder. However this just means it is going to warm quicker tha plastic bottle" (Heat transfer)

> "Since the glass has a larger heat capacity, according the e=mct when the heat transfrer for both be the same, it will take the glass bottle longer time to get warm" (Heat)

The requirement of the selection of a concept was a useful technique which could complement qualitative methods associated with probing student conceptions. Further research is needed to determine how much emphasis students placed on concept choice when answering the question, and how relevant the concept choice is when gauging conceptions of students.
5.4.2 Characteristics of novice-types and expert-types

Literature reports that when approaching a problem in physics, an appropriate knowledge structure is required to make sense of and solve the problem. This is exhibited by experts when solving a problem, while novices tend to have separate representations for problems with the same underlying content or structure (Eylon & Linn, 1988). The current approach is based on the assumption that describing characteristics of expert- and novice-type learners may help encourage conceptual change (by identifying stages of development before and after instruction), and that identifying conceptions associated with different groups may feed into differentiated instructional techniques for those groups.

The analysis will involve a comparison of concept choice with respect to group, followed by the comparison of the approach to the explanations as indicated by the coding scheme.

Concept choice

The choice of concept for each question was clearly different for the different groups as illustrated in Figures 5.8 and 5.9. This was expected to some degree as not all concepts were equally acceptable or appropriate for explanations of the questions. The two most popular choices for the Advanced group for both questions were heat transfer and conductivity. These two selections are considered the most relevant given the details of the question although acceptable responses were possible with most of the other choices. Conductivity dominated overall for the Advanced group, with at least 40% of students selecting this concept for each of the questions. Tracing this back across other groups, we notice a definite decline in this choice for the Regular, Fundamental and Primary groups for both questions. Although it is difficult to recognise any other significant pattern in Q1, in Q2, 40% of Primary students have selected Insulation, compared to less than 20% for the Advanced group, making it a clear favourite with this group as well as for the Fundamental and Regular groups.

Although the selection of insulation does not directly imply an alternative conception (such as the Glass is an insulator node), there are aspects of this choice that may indicate a deficiency in the appropriate integration of thermal concepts. Scientifically, an explanation based on insulation includes only one aspect of the process described in the question. Essentially, an explanation of relative rates of conductivity or heat transfer would be necessary for a fully integrated response. Insulation has often been cited as a troublesome concept with difficulties associated with the confusion between a thermal or electrical insulator and the idea that insulators are not uniform substances. Two insulators may have vastly different properties from one another, and a single insulator may act differently under certain conditions.
**Coding of Explanations**

Figure 5.10 highlights the differences in approaches between the groups with reference to the coding scheme. The data are consistent with the idea that expert-type groups tend to have a more integrated knowledge structure. The main differences between the Advanced and more novice-type groups is that 50% of the Advanced group had explicitly recognised the same underlying concept in the two questions (Analogous concepts recognised node) drawing analogies between the different subject matters and environments. The Regular group had the next highest proportion of responses coded to this node, although this was a much smaller 14%.

Not surprisingly, there was less of a tendency for the Advanced group to state that the two analogous objects were at different temperatures (Objects at different temperature node), and there was a definite decline in responses coded to Cold and Cold transfer for this group compared to all other groups. The Fundamental and Primary groups had a similar coding profile, which is expected since they differ in expertise (by the earlier definition) only slightly. However, there is an interesting exception. The Primary group had more responses coded to the Satisfactory response node, and yet they also had more responses coded to the Glass is an insulator node. This could imply that a reasonable explanation was learnt by rote, and that conceptual difficulties were revealed when the same question was presented amongst different details. The Fundamentals had fewer ‘Satisfactory responses’ but also fewer references coded to Glass is an insulator. In this way, the coding scheme was able to help explain the differences between the different groups. Although this particular coding scheme is not a comprehensive representation of all themes in the data, the development of the scheme and the snapshot it provides is still insightful and effective. An improved scheme may help improve descriptions of the characteristics of novice and experts and identify the conceptions which may be important for conceptual change.

### 5.4.3 Misuse of language and scientific terminology

In thermodynamics, more than many other subjects, conceptions are highly influenced by language and the social environment. In this study, many of the alternative conceptions of students can be the result of improper use or misunderstanding of scientific language, or may arise through the encounters they have in their everyday experiences with heat and thermal processes. The study addressed the associations with notions of heat, cold and insulators through a standard word analysis in NVivo, and the exploration of the nodes Cold, Heat, and Glass is an insulator.
**Word analysis**

The types and amounts of words (of length 3 letters and above) in student responses were strikingly different for the two questions. There tended to be a larger frequency of ‘catch’ words like conductivity and transferring and yet words such as energy (77 in total for Q1 and 42 in Q2) and specific heat capacity (52 in total for both questions) were much less frequent. Proportionally, the word insulation was used more in Q2, while ‘transfer’ was more frequent in Q1. This analysis was performed primarily to explore the capabilities of NVivo and was therefore quite preliminary. This function could possibly be used in conjunction with concept choice and coding analysis to determine more conclusively which words are more frequent, which are more likely to be misused, and which terms or words are being integrated and connected to each other by the students.

**Heat, Cold and Insulation**

Figure 5.11 shows the proportion of students in each group that had responses coded to the Heat, Cold and Glass is an insulator nodes only. The proportion of responses coded to the Cold node is noticeably different across groups. The Cold node is heavily associated with the Primary and Fundamentals groups, with approximately 34% of students from each group being coded here. Less than 5% of Advanced students were coded to this node, indicating that Cold node conceptions tend to diminish with increasing expertise in physics. The consistency in coding to the Heat node across groups indicating that the heat concept is much more robust across physics expertise. Although the proportion of students coded to Heat varied much less, the changes in other nodes indicated that conceptions associated with this node were not all uniform. Although maintaining Heat node conceptions did not appear to exclude being coded to Satisfactory response or even the Analogous concepts recognised node, it is still unclear what effect conceptions related to this node have to the understanding of thermal processes. The Heat node implies a caloric theory of heat transfer and some studies justify and suggest the use of the this model for teaching thermal concepts, especially to younger students (Linn & Songer, 1991). Clark (2006) stresses that the use of accessible models like the caloric model (instead of kinetic theory) or concepts such as insulators and conductors (instead of thermal conductivity) must be carefully considered in curriculum design He and admits that such concepts although accessible, do not encourage ontological re-organisation of heat (from a substance to a process).

5.5 **Test Question conclusions**

The main conclusions from the Test Question include the observation that first year university students still have significant difficulties in consistently explaining basic and familiar thermodynamic processes. These difficulties were revealed when exploring conceptions in detail and sometimes only when presenting concepts in different contexts. Conceptions were found to be different in the expert-type and novice-type groups of the study, highlighting the characteristics of different levels of development of thermal concepts. Further research is needed to identify how concept development occurs in thermodynamics and why alternative conceptions remain robust, but it is suggested that the familiarity of these thermal processes in everyday life may be a highly relevant factor. The present study confirms these results as student conceptions about heat, cold and insulation still reveal inconsistencies and tend to relate more to everyday descriptions or experiences with thermal processes.
6 Implications for instruction

Instructional techniques developed from investigations into student conceptions have benefitted many areas of physics and science education at all levels of instruction. For example, David Meltzer, who has focused on conceptual difficulties in thermodynamics at university for over a decade, has developed a tutorial based on the conclusions of his research regarding introductory students perceptions about entropy (Christensen, Meltzer, & Ogilvie, 2009). The tutorial has shown some success in increasing students understanding of entropy change, primarily by providing conflict as a means of addressing alternative conceptions. Meltzer remains committed to improving these already promising results, an endeavour which would require consistent application in this area of research (Meltzer, 2005).

The results from the Diagnostic Test were presented at the UniServe conference this year and received interest from first year thermodynamic lecturers. Since these basic concepts are rarely explicitly covered or assessed at university and since literature on tertiary level basic thermodynamic conceptions is sparse, such research is valued. Studies show that merely informing lecturers of student conceptions may lead to an increase in student understanding (Burkhardt & Schoenfeld, 2003). Less immediately, the results imply other issues that could be significant for any level of physics education:

**Basic concepts may be assumed as mastered but may persist and cause difficulties in later studies (5.4.1)**

The fact that students are leaving university lacking in the ability to sufficiently explain everyday physical situations may be need to be addressed with further work investigating if and how subsequent learning is affected.

**Novice-type and expert-type learners have certain common characteristics which require tailoring or differentiation (5.4.2)**

The present study clearly shows that novice-type and expert-type students are different with respect to the level of sophistication of their conceptions, and also the presence or absence of specific conceptions (such as glass is an insulator or cold transfer). This kind of research may be relevant in raising the awareness of this and tailoring instructional approaches and techniques.

**Recognising the effect of simplifying explanations of scientific processes or using scientific terminology inaccurately (5.4.3)**

Everyday observations and uses of words which have both scientific and common meanings creates robust conceptions (and alternative conceptions), especially in thermodynamics. Words such as heat, cold and insulator were of particular interest in this study as they caused a great deal of confusion and resulted in misunderstanding of the underlying physical processes.

**Contributing to our understanding and fostering of conceptual change through synthesising research**

Many authors have recognised the need to probe deeper and describe changes in conceptions in thermodynamics. This is not surprising given the influence of constructivist theories and commitment to fostering conceptual change in science education. If instructors wish to change something, it is clear that they might benefit from research which tracks or reports this change in some fashion. Clark (2006) summarises work of researchers specifically fixed on this purpose, highlighting several authors who have descriptively summarised conceptions of students either over time or of different levels of expertise and used this to help structure learning to facilitate conceptual change. One of these studies, conducted by Linn and Songer (1991) emphasised that practices informed by models of learning and instruction can produce elimination of certain misconceptions, especially when given ample time. Authors are synthesising findings from studies but much more research is needed to solidify understanding (Liu, 2001).
7 Weaknesses of the study

As many different methods were used in this project, I refer the reader to Table 2.5 to review the associated general disadvantages and limitations of each method.

The main obstacle in the present study was the difficulty in the interpretation of students understanding. The following excerpts should illustrate specific difficulties

Responses that are silly: “Cause like heat comes from insulation, and like cooks your feet”
These responses are difficult to code because of uncertainty about whether they were meant to be humorous or were genuinely a valid response

Responses that are short: “what is cold will want to get hot”
It is sometimes difficult to be ascertain the meaning behind very with short responses especially without further investigations such as interviews

Responses that are generically difficult:
“This scenario is also based on the material properties of glass and plastic. Glass is not an insulated material and is also thicker than plastic, preventing the flow of heat energy with surroundings move so than plastic. So the glass bottle will remain colder for longer”
Although there was recognition of the different properties of the glass and plastic, this response was difficult to code. Was the student saying the glass was not ‘insulated’ or ‘an insulator’? And which surroundings were they referring to?

This problem was addressed through the adherence to a narrower and relatively objective coding scheme. This effectively became the main weakness of the study however it provides a steady base from which further analysis may proceed.

8 Future work

Since the coding is non-destructive, the original data remains intact and therefore the use of NVivo allows for the immediate resumption of further analysis even if an entirely new approach is required. Future work could involve the differentiation of responses within existing nodes, creating a hierarchical structure. An example of this may be a hierarchical node labelled ‘Insulators’ which captures all of the students’ conceptions about insulators. The ‘Glass is an insulator’ responses would be a sub-category of this broader node. It may also include widening the scope horizontally by adding new nodes. Below are some notions that could be considered for new nodes within the current data:

- That the liquids inside the bottles were at the same temperature but the vessels themselves were not
- The meaning behind the use of the term ‘transfer of temperature’
- The notion that cold is a complete loss of heat or lack of heat
- The misunderstanding of specific heat capacity.
- Spreading of heat
- The prevalence of the idea of ‘Going from hot to cold’

Future development of this project may also involve comparing responses in the Diagnostic Test, Test Question, and end of year physics examination marks for the common groups of students.

Requests were made for a summary of the main alternative conceptions of university of students by delegates attending the UniServe Science Conference. A comprehensive list incorporating results from the Diagnostic Test and the Test Question is currently being developed to serve these requests.

Yeo and Zadnik are publishing further work on the Thermal Concept Inventory which formed the basis of the multiple choice section of the Diagnostic Test. Comparisons with these results will be possible.
9 Conclusion

Hestenes, Wells, and Swackhamer (1992, p. 2) proposed that “effective instruction requires more than dedication and student knowledge” but also “knowledge about how students think and learn.” This study was an in depth investigation using mixed methods, in an effort to reveal such details through probing the conceptions of first year university students at the university of Sydney in the topic area of thermodynamics.

There are a number of important conclusions from this study. The most obvious is the existence of a large proportion of students that experience difficulties with basic thermodynamic concepts. For physics students, these concepts may be important for future studies:

‘a significant proportion of upper-division students beginning advanced study of thermodynamics, in both physics and chemistry are struggling with fundamental concepts of heat, work and the first law of thermodynamics, normally presumed to have been mastered in their first year’ (Meltzer, 2004a, p. 1432).

In general, it is concerning to think that such difficulties may equate to a growing ignorance about familiar processes within the physical world. In particular, it was surprising to find very naïve beliefs regarding the existence of cold as distinct from heat, even amongst the more expert groups, and the vastly different explanations of the same underlying concept amongst slightly different details. Also of interest was the inappropriate dependence on familiar terms such as insulation. This term was used as part of a contradictory explanation to Q2 of the Test Question by one sixth of respondents even though the concept itself was not immediately relevant or necessary for a correct response.

Gauging students’ ideas or conceptions remains an obstacle for physics education researchers. Although multiple choice-style tests have been both popular and diagnostically affective, Tamir (1990) discovered that many students were not able to adequately explain their choice when subsequently interviewed, and concluded that the tests may be overestimating their knowledge. Other researchers have confirmed similar disadvantages, including the inherent problem of guessing, and the limitations preventing deeper insights into student conceptions. Multiple choice tests remain important because of their convenience in summarising conceptions of large groups of students but further, more qualitative tools have been recognised as necessary, especially when physics is still proving challenging for students at every level of instruction.

This study has revealed some novel results regarding student conceptions that may otherwise have gone unnoticed. Awareness of these conceptions could contribute towards the development of appropriate support for students; especially those who are allowing thermodynamics to fly under the radar because they are struggling with the basic concepts that underpin it.

10 Final thoughts

“Beauty is truth, truth is beauty,—that is all ye know on earth…” While this is certainly not a universal truth, there came a time when I felt it had a certain application to my understanding of thermodynamics.’ (Hurley, 2005, p. 6)

Many physicists recognise the beauty in understanding the physical world. Unfortunately, this experience will remain elusive for a large number of people, including students with some tertiary physics experience. Completing this project has equipped and inspired me to remain committed to the ambitious yet achievable objectives of physics education research.
11 References


Educational Psychology Review, 19(2), 91-110.


12 Appendices

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Appendix A- Diagnostic Test (thermal concept inventory)

For office use only: 09Pre_________

The University of Sydney

Contact: Helen Georgiou, School of Physics
A28
Telephone: +61 (0)2 9351 2051
Fax: +61 (0)2 9351 7726
Email: Georgiou@physics.usyd.edu.au

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: __________________________
Appendix A cont.

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.”
Appendix A cont.

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 object’s temperature.
   b) Sometimes increase the object’s temperature.
   c) May increase or decrease the object’s temperature.
   d) Do not have an effect on the object’s 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.
Appendix A cont.

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- Explanation of Statistical tests

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 analysis’. 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.

\[
\text{Facility}_i = \frac{\text{number answering item } i \text{ correctly}}{\text{total number taking test}}
\]

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

\[
D = U - L
\]

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.

An Introduction to Classical Test Theory as Applied to Conceptual Multiple-choice Tests
Paula V. Engelhardt Tennessee Technological University, 110 University Drive, Cookeville, TN 38505
Appendix C- Phenomenographic analysis of Q13

A phenomenographic analysis of Q13. The layout of responses is a replica of the physical storage of responses in each category as organised by the researcher. The responses were separated into 3 main categories; 1. Different final temperature, 2. No reason given and all other responses and 3. Similar final temperatures.

Correct responses were categorised in the 1A, 2A, and 3A where they were divided according to use of the terms Retain/Store, Absorb, and Transfer respectively. Some students got the order of the materials’ value of specific heat, and these were further divided in the subsection ‘incorrect’. Note that the ‘generic’ subsection contained all responses who either did not report an order, or listed the materials in the correct order or specific heat values.

1. Different final temperatures
   n= 129
   - 1A Because of the way materials Retain/Store energy or heat (33)
     1A-1 Generic- 27
     1A-2 Incorrect- 6
   - 1B Because of how materials absorb energy or heat (11)
     1B-1 Incorrect- 2
     1B-2 Generic- 9
   - 1C Because of the way materials transfer energy or heat (11)
     1C-1 Incorrect- 2
     1C-2 Generic- 9
   - 1D Different because of Specific heat capacity 14
   - 1E Different because of conductivity 30

2. No reason given, all other responses n= 43

3. Similar final temperatures 
   n= 19
   - 3A Because no heat is transferred to surroundings 11
   - 3B Because heat is transferred at different rates 8

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Appendix D- Test Question

Copy of Test question as administered

The University of Sydney

Contact:
Manjula Sharma, Rm 226E, Phys Bldg
Telephone: 02 9351 2051
Fax: 02 9351 7726
Email: m.sharma@physics.usyd.edu.au
Contact: Helen Georgiou
Email: georgiou@physics.usyd.edu.au

Thermodynamics question
2009

Instructions:

• This question should take about 10 minutes to complete.
• Read the questions carefully and answer by selecting a concept and explaining using this concept.
• You may use diagrams or tables in your answers
• There are no mark allocations for the questions.

Important:

Participation in this project by completing this test is completely voluntary.
No information will be disclosed to course coordinators.

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<th>SID:</th>
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<tr>
<td>&lt;17 17-21 22-26 27-40 40+</td>
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</thead>
<tbody>
<tr>
<td>Yr10 HSC Bachelor Postgraduate Other:</td>
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1. Answer the following questions by first choosing one concept from the box below and then explaining your choice with reference to each scenario. The same concept may be chosen for both parts. Your explanation may include the other concepts in the list, or any additional ones you feel are appropriate.

<table>
<thead>
<tr>
<th>Heat transfer</th>
<th>Cold transfer</th>
<th>Temperature</th>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>Insulation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) Rebecca’s house is carpeted in the bedrooms and tiled in the bathroom and kitchen. Rebecca has noticed that when she goes barefoot from her bedroom to the bathroom (or the kitchen), she experiences a noticeable feeling of coldness on her feet from the tiles.

Choose the one concept that is most associated with this scenario: ______________________

Explain how the concept you chose helps to explain Rebecca’s observation:

b) Later that day, Rebecca is deciding which beverage to choose out of a self-serve fridge. Her favourite cola drink is available in a plastic or glass bottle. Since it is a very hot day, she chooses the drink that feels the coldest; her choice is the glass bottle.

Choose the one concept that is most associated with this scenario: ______________________

Explain how the concept you chose helps to explain Rebecca’s observation:
Appendix E- Responses from Cold node

‘Cold’ node

Below is a list of 30 out of 88 references coded to the ‘Cold’ node. These references may be a full response or part of a response. The number of the reference is arbitrary (reference 1 is the first reference coded to the node). The percentage value following the reference heading is not used in this project but indicates what proportion of the total node is covered by that particular reference. Each of these references may be coded to other nodes and are hyperlinked back to the original data. This means you may choose to view the response it was drawn from and also the details of the student who made the reference.

Node: COLD

Reference 1 - 0.04% Coverage
Becoz the metal can transfer cold to human (hand) so she felt the glass one more cold than the plastic one
Reference 2 - 0.01% Coverage
transfer heat/cold
Reference 3 - 0.02% Coverage
But glass conducted the cold temperature better
Reference 4 - 0.02% Coverage
And Rebecca will experience a cold transfer after drinking
Reference 5 - 0.03% Coverage
The cold temperature of the drink is transferred through the glass
Reference 6 - 0.02% Coverage
glass bottle's cold transfer is faster than plastic
Reference 7 - 0.02% Coverage
Cold transfers more easily in the glass
Reference 8 - 0.02% Coverage
a tile which has cold transfer of temperature
Reference 9 - 0.03% Coverage
Glass conducts heat and therefore cold (the absence of heat)
Reference 10 - 0.03% Coverage
The cold from the tiles is being transferred to her body through her feet?
Reference 11 - 0.01% Coverage
Cold/Heat Transfer
Reference 12 - 0.02% Coverage
The cold from the floor transfers into her feet
Reference 13 - 0.09% Coverage
The plastic bottle is a good insulator and prevents the cold from escaping the bottle while the glass bottle is not a good insulator- enabling the cold to escape the bottle more easily making the glass bottle feel colder
Reference 14 - 0.03% Coverage
Because coldness is going from the ground to her feet therefore cold transfer
Reference 15 - 0.06% Coverage
Cold transfer is the transfer of heat to another body so that an apparent 'cold' (lack of heat) is felt. Heat goes from foot to tiles
Reference 16 - 0.04% Coverage
Cold transfer is the transfer of heat to another body so that an apparent cold (lack of heat) is felt.

Reference 17 - 0.02% Coverage

and will experience a cold transfer.

Reference 18 - 0.01% Coverage

Prevent cold flow of the liquid

Reference 19 - 0.04% Coverage

however there is no insulation from the tiles so all the coldness is transferred to Rebecca

Reference 20 - 0.02% Coverage

allows more cold in than plastic or cardboards container.

Reference 21 - 0.03% Coverage

Cold transfer is greater through the glass and so the cola in the glass is cooler

Reference 22 - 0.02% Coverage

better at transferring heat (or cold heat for that matter)

Reference 23 - 0.03% Coverage

The material glass is better at transferring cold temperature

Reference 24 - 0.03% Coverage

The material glass is better at transferring cold temperature

Reference 25 - 0.02% Coverage

feel colder due to the cold transfer from the fridge

Reference 26 - 0.01% Coverage

colder due to the cold transfer

Reference 27 - 0.05% Coverage

The glass bottle absorbs the cold and transfers this into the liquid, while plastic bottles don't absorb cold as well

Reference 28 - 0.03% Coverage

The carpet doesn't absorb the coldness of the atmosphere as well as the tiles

Reference 29 - 0.02% Coverage

The glass conducts the cold better than the plastic

Reference 30 - 0.02% Coverage
Appendix F- Word Analysis from NVivo

Word analysis in NVivo

The following table indicates the frequency of a selection of words used for each question. Some words like ‘she’ ‘then’ ‘and’ are omitted.

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<td>Glass</td>
<td>786</td>
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<tr>
<td>tiles/tile</td>
<td>797+120</td>
<td>Plastic</td>
<td>528</td>
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<tr>
<td>feet/foot</td>
<td>517+52</td>
<td>Heat</td>
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<td>carpet</td>
<td>476</td>
<td>Bottle</td>
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<td>cold/coldness</td>
<td>286+84</td>
<td>Colder/cold</td>
<td>206+188</td>
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<td>Insulator/insulation</td>
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<td>feel/feels/feeling</td>
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<td>Transfer/transferred</td>
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