

Doing Positive Work:
On student understanding of thermodynamics

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Statement of Originality

To the best of my knowledge, this thesis contains no copy or paraphrasing of work published by another person, except where duly acknowledge in the text. This thesis contains no material which has been previously presented for a degree at The University of Sydney or any other university.

Helen Georgiou

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Included papers and presentations

The following reference list includes refereed papers and presentations that arose from this doctoral program and on which some of the chapters of this thesis are based.

Refereed papers

Georgiou, H., Maton, K., & Sharma, M. D. (2014) Recovering Knowledge for Science Education Research: Exploring the 'Icarus effect' in student work. *The Canadian Journal of Science, Mathematics and Technology Education*, in press.

Georgiou, H., & Sharma, M. D. (2010). A Report on a Preliminary Diagnostic for Identifying Thermal Physics Conceptions of Tertiary Students. *International Journal of Innovation in Science and Mathematics Education*, 18, 32-51.

Georgiou, H., & Sharma, M. D. (2011). University students' understanding of thermal physics in everyday contexts. *The International Journal of Science and Mathematics Education*, 1-24.

Book Chapter

Georgiou, H. (2014). Putting physics knowledge in the hot seat: The semantics of student understandings of thermodynamics. In K. Maton, S. Hood & S. Shay (eds), *Knowledge-building: Educational studies in Legitimation Code Theory*. London: Routledge.

Conference papers (refereed)

Georgiou, H., Sharma, M., O'Byrne, J., & McInnes, B. (2009). *University students' conceptions about familiar thermodynamic processes and the implications for instruction*. The UniServe Science 2009 Conference proceedings, Uniserve Science, Sydney.

Conference presentations

Georgiou, H., & Sharma, M. D. (2010a). *A comparison of tertiary students' thermal physics conceptions across three English-speaking countries*. Paper presented at the The 19th Australian Institute of Physics Congress incorporating the 35th Australian Conference on Optical Fibre Technology (AIP/ACOFT 2010), Melbourne.

Georgiou, H., & Sharma, M. D. (2010b). *An Intercultural Exploration of Conceptions in Thermal Physics*. Paper presented at the UniServe Science, "Creating active minds in our science and mathematics students.", The University of Sydney, Sydney.

Georgiou, H., & Sharma, M. D. (2012). *Analysing student responses using LCT*. Paper presented at the First annual Legitimation Code Theory science and mathematics symposium, Sydney.

Georgiou, H., & Sharma, M. (2012). *Exploring students' (mis)conceptions of physics*. Paper presented at the 7th International Basil Bernstein Symposium, Aix-en-Provence, France.

Georgiou, H., Sharma, M. (2012). *Why it is important to publish 'null' results: A project involving no change in learning gains from Interactive Lecture Demonstrations in first year thermal physics*. Paper presented at the World Conference on Physics Education, Istanbul.

Conference presentations (poster)

Georgiou, H., & Sharma, M. D. (2011). *They should have taught them that in High school*. Paper presented at the The Australian Conference for Science and Mathematics Education, Melbourne University, Melbourne.

Georgiou, H., & Sharma, M. (2013a). *Interactive engagement in thermodynamics lectures: successes and failures*. Paper presented at the American Association of Physics Teachers (AAPT), Portland, Oregon.

Georgiou, H., & Sharma, M. (2013b). *Physics Knowledge and its effects: a study of student responses in thermodynamics using Legitimation Code Theory*. Paper presented at the Physics Education Research Conference (PERC), Portland, Oregon.

Abstract

This thesis addresses several aspects of the teaching and learning of thermodynamics in the context of first year university Physics. Thermodynamics is a topic that attracts far less attention at the first year level, both in terms of instruction time but also in the literature.

The first part of the thesis focuses on the teaching aspect, and reports on a two-year experiment that involved introducing Interactive Engagement techniques in lectures to facilitate ‘Active Learning’. Two different Interactive Engagement techniques were compared, the Interactive Lecture Demonstrations and the Interactive Exercises, across four first year Physics thermodynamics ‘streams’ at The University of Sydney (approximately $N=600$). In the first year, 2011, there were no differences in learning outcomes between the four streams as measured by the Thermal Concepts Survey and the final first year Physics exam (each technique was trialled in two classes). In 2012 the Thermal Concepts Survey reveals a difference in the streams, with one of the streams which received the Interactive Lecture Demonstration program performing significantly better than the others. Both programs were characterised in terms of the activity of the lecturer and in terms of student engagement. Evaluation surveys and interviews were deployed to gather more information about how the programs were received by the students.

The second part of the thesis focuses on student understanding. First, student understanding is examined using existing measures, such as the quantitative analysis of the Thermal Concepts Survey and qualitative analysis of short answer responses to a series of thermodynamics questions/problems (the Interactive Exercises). Several specific findings were made, highlighting particular aspects of thermodynamics that caused difficulties for students. In order to address some of the limitations in these existing approaches, and to provide more explanatory analyses, a novel approach was pursued and developed. This approach, Legitimation Code Theory, was used to examine student understanding of thermodynamics through the focus on the organising principles of knowledge. The analysis using Legitimation Code Theory reveals that the nature of the scientific knowledge students encounter has real effects on their engagement with the subject, and this, in turn, has consequences for instructional practices.

It will be argued that Legitimation Code Theory is a powerful framework that can provide substantial utility for the study of student understanding and to science and Physics Education Research in general.

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1 Personal Orientation

As I began my post-graduate studies, I was strongly motivated by my experience as a new teacher of physics. Two things struck me during that experience, the first being that physics topics were extraordinarily difficult to teach (successfully), and the second, that physics did not play a central (or any) role in most people's lives. There was one thing, however, that did not surprise me at all: students could reach a 'transformation' when physics instruction was successful. I also felt that some concepts or areas in physics were more effective in helping students arrive at these transformations; I found particular success with thermodynamics, which formed a part of the A-level curriculum in England, where I held my longest teaching position. During this period, I considered questions such as why it was so difficult for students to come to a comprehensive understanding of physics, what can be done to help with this, and why some physics subjects were more challenging to teach than others. These fundamental questions are common ones in science education research. In fact, many lecturers of physics, and particularly those who subsequently engaged with Physics Education Research, have similar stories of coming to realise that their lectures were not as successful as they had thought. Edward F. 'Joe' Redish provides a fascinating account, in his 1998 Millikan lecture, of the discovery of students' disappointing grades on exam problems, despite all of his efforts:

I was sure that I could teach the subject in lecture. After all, it wasn't very difficult, and I had great confidence in my ability to make things clear ... I wrote clear definitions on the board and walked a pattern and made them graph it in their notebooks. I gave examples that were realistic and related to their experience. I used our high quality demonstration equipment ... And then I gave their problem on my mid-semester exam. (Redish, 1999, p. 569)

Eric Mazur's 'confessions of a converted lecturer' talk and associated paper recounts a similar story:

I had been teaching an introductory physics course for engineering and science majors ... since 1984. Until 1990 I taught a conventional course consisting of lectures enlivened by classroom demonstrations. I was generally satisfied with my teaching –my students did well on what I considered difficult problems, and the evaluations I received from them were very positive. As far as I knew, there were not many problems in *my* class (Mazur, 2007, p. 2).

These accounts indicate a mismatch between what is measured by formal assessment and what is known as conceptual understanding. Conceptual understanding was what these lecturers wanted for their students. Why was it so difficult to achieve? Moreover, why is it so important? Jan Meyer and Ray Land present a compelling theoretical construct they refer to as the ‘threshold concept’, which I believe helps conceptualise these questions:

A threshold concept is akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress. As a consequence of comprehending a threshold concept there may thus be a transformed internal view of subject matter, subject landscape, or even world view. This transformation may be sudden or it may be protracted over a considerable period, with the transition to understanding proving troublesome. Such a transformed view or landscape may represent how people ‘think’ in a discipline, or how they perceive, apprehend, or experience particular phenomena within that discipline (more generally) (Meyer & Land, 2006, p. 3).

For me, much of the content in thermodynamics seemed to resonate strongly with the idea of Meyer and Land’s ‘threshold concept’. After instruction, students were more likely to emerge with a view that was more ‘physics-like’. I later discovered that Marcia Linn (and others) makes a similar link between thermodynamics understanding

and sophisticated scientific literacy (Hurley, 2005; Linn, 1993). The splendour of thermodynamics has not escaped even the most famous of physicists:

A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Therefore the deep impression that classical thermodynamics made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts (Einstein, 1973).

However, I was soon to find that thermodynamics, arguably one of the most fundamental of the physics subjects, was not amongst the most represented physics subjects throughout formal instruction, and thus also not amongst the most studied in educational research. For this and other reasons, the lofty questions I began this project with beget even more questions, many of which I could not feasibly answer in a doctoral program.

Furthermore, I was ignorant of the nature and precariousness of the academic field I was to enter. In making the professional transition from studying or teaching science to educational research, I expected everything to change apart from the foundation of my motivation: to study something scientifically. I reached a point where I began to question even this foundation and was surprised to observe the term –scientism– commonly used as a pejorative accusation. As a physics teacher and physics graduate looking at physics education, it was enlightening to be exposed to views completely outside of my own. It was once pondered; ‘what should they know of England who only England know?’, and it is certainly true that I learned a great deal about the scientific endeavour through the eyes of those outside of it.

The pages following shall document the scholarly exploration of many of these issues.

2 Introduction and Outline

This thesis is the result of a major research endeavour that examined both the teaching of thermodynamics and student understanding of it in the context of first year Physics. On the one hand, the project has a relatively uncontentious focus: encouraging Active Learning and negotiating instructional design in an under-researched subject (thermodynamics), and on the other, arguably the most contentious, student understanding and theories of learning. Despite the structural bifurcation, the study was always intended to be experienced as a coherent whole, each part as important as the other. That is, to understand if and how we can teach better we must comprehend student understanding better. The first part presents the two-year implementation of an Active Learning program in first year Physics that was successful in improving student learning. This part of the thesis will report on all aspects of the implementation of the Active Learning program, including: a characterisation of the thermodynamics lecture course, a description of how the Active Learning program was implemented and received, the learning outcomes of the Active Learning program, the general issues associated with its insertion into a first year course, and some reasons for its various degrees of success. The second part presents the development of a framework that aims to examine student understanding of thermodynamics through the focus on the organising principles of knowledge, using Legitimation Code Theory (LCT). This part of the thesis will first report on student alternative conceptions of thermodynamics through existing methods. A new approach will then be presented as LCT is used to analyse one group of student responses to a thermodynamics problem. It will be argued that LCT is a powerful framework that can provide substantial utility to science and Physics Education Research in general.

The two main aims of the project are related but also independent, particularly with respect to their relationship to the extant literature. The first part, concerning Active Learning techniques, emerges from a comprehensive and cumulative body of work, albeit one that more prominently reflects other physics subject areas, such as

mechanics. The substance of the second part which focuses on student understanding, does not extend as easily from one single body of work. The literature review will therefore present these two research agendas as outcomes of more than half a century worth of work in the science and Physics Education Research fields and the field of educational research more generally.

In Chapter 3, therefore, the literature review will centre around a historical (and current) account of the theoretical, epistemological, methodological and the practical considerations around the teaching and learning on physics. The review on this aspect is comprehensive and necessary if a new theoretical framework is to be presented to the field. The literature review will cover the fundamental (or ‘basic’) work on student understanding generally, but will also present some of the practical, instructional products of the research agenda (the ‘applied’), which includes the Active Learning agenda. The review will culminate in the presentation of a new approach and will outline the relevant and fundamental principles of Legitimizing Code Theory.

Chapter 4 will outline the local context. The wider Australian educational setting is described first, followed by results from a brief survey about thermodynamics in high school. The university setting, the sample, the outline of the experiment and the details about the first year Physics course will also be provided in this Chapter.

Chapter 5 will detail the research tools and the learning activities. The learning resources that form part of the Active Learning implementation, which were either borrowed from the literature or original developments, are described in detail, as are the tools used to evaluate the program. These tools include the Thermal Concepts Survey, the tool used to characterise the lectures and the various evaluation surveys.

Chapter 6 is a short introduction to the two chapters following, and demarcates ‘Part One’ of the thesis, involving the Active Learning implementation.

In Part One, Chapters 7 and 8 represent findings from ‘Study One’, which was the first iteration of the Active Learning program in the first year Physics course, and ‘Study Two’, which involved the integration of several methodological improvements based on Study One results. Each chapter occasions slightly different aims; however, both include a report of the student outcomes and attitudes towards the program, as well as a characterisation of the implementation in both years.

Chapter 9 is a short introduction to the two chapters following, and demarcates ‘Part Two’ of the thesis, which focuses on student understanding.

In Chapter 10, student understanding is examined through conventional means, namely, through quantitative measures based around the Thermal Concepts Survey. Chapter 10 will also report on findings stemming from qualitative analyses of short-answer responses.

Chapter 11 is the report on the application of Legitimation Code Theory. This chapter will involve an explanation of how LCT was enlisted, which concepts of the theory were applied and a comprehensive description of the analysis of student responses using these concepts. The implications for instruction are also discussed.

The thesis will conclude with Chapter 12, a discussion around the merits of the new approach and a general discussion of the thesis as a whole.

3 Literature Review

3.1 Descriptions of student understanding

Descriptions of student understanding –otherwise known as research on conceptual change, concepts and alternative conceptions (summarised from here on as ‘conceptions’ research for brevity) –is undoubtedly the central focus of science education research (Chang, Chang, & Tseng, 2010; Cummings, 2013; Lee, Wu, & Tsai, 2009; Tsai & Wen, 2005). It is based on the following fundamentals:

- that students of all ages, cultures and abilities demonstrate common difficulties in almost all scientific domains, and
- that these difficulties are persistent, often remaining unchanged after formal instruction.

These fundamentals echo through the decades of literature on the topic; from the beginning of the research program (Nussbaum & Novak, 1976) to the most recent publication as of writing (Lelliott, 2013). Particularly astonishing are the reports that students emerge from science instruction with little to no improvement in conceptual understanding (Hake, 1998; Halloun & Hestenes, 1985).

The conceptions movement was driven by notion of ‘constructivism’, summarised under the statement of: “knowledge is constructed in the mind of the learner” (Bodner, 1986, p. 873). Constructivism helped provide an explanation as to why some students held and maintained conceptual difficulties –students construct their own knowledge and doing so erroneously could explain why these difficulties, or misconceptions, existed and persisted. Constructivism is a contested and diversely applied expression in education (and beyond) but, as embraced by the science education research community, constructivism was associated with a period of significant influence and reform. It also brought epistemological considerations to the fore:

... somewhere during the five year period 1978-1983 the seeds were sown for constructivism to become a dominant way of making sense of mathematics and then science education (Tobin, 2000, p. 232).

A new field of study has acquired a new vocabulary which focuses attention on the pupils own ideas ... The vocabulary was picked up by others, thus launching constructivism (Solomon, 1994, p. 4).

To appreciate fully the significance of the epistemological considerations in constructivism, some philosophical and epistemological perspectives are briefly summarised. See Table 3-1.

Epistemology examines the very nature of what knowledge is, how knowledge may be acquired and to what extent any given 'subject' can be 'known'.

Positivism asserts that knowledge be derived from logical and mathematical means, in addition to sensory experience, and, moreover, that there is valid knowledge, or 'truth', *only* in these forms of scientific knowledge.

Empiricism posits that knowledge is derived from sensory experience; what can be observed or measured, evidence derived from experimentation.

Relativism holds that perspectives have no absolute validity; they have only relative, subjective value according to individuals' differences in perception.

Subjectivism affords primacy to subjective experience as the only 'knowable truth' and the basis for all measure and law.

Table 3-1 Glossary of theoretical terms

3.1.1 *Misconceptions and misnomers*

The first clear agenda for research on students' scientific understanding was to identify student difficulties (initially known as misconceptions) and to explore their nature and tenacity. Lists of misconceptions across different age groups and for different topics – including thermodynamics – were compiled (see, for example Table 3-2). This practice would continue throughout the forty years of the research agenda.

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

Table 3-2 A selection of common misconceptions from studies centred on young children and university students

One important epistemological shift in this practice was the acceptance that students were coming to class with pre-formed ideas rather than being a 'tabula rasa' and knowledge was actively constructed rather than passively "transferred intact from the mind of the teacher to the mind of the learner" (Bodner, 1986, p. 873). Millar says of constructivism, for example:

it has taken science education research into the classroom (and) by making the specific details of learning of subject matter the focus of attention, it is challenging once-dominant paradigms of science education research that treated the learning process as a 'black box' and looked only at inputs and outputs (Millar, 1989, p. 587).

Ausubel, quoted by Novak, famously states:

If [he] had to reduce all of educational psychology to just one principle, [he] would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly (Ausubel, 1968, p. vi).

A second major epistemological shift was the discussion around the *value* placed on student's ideas. Initially, a deficit model was identifiable; where student's ideas were incorrect and instruction was to provide a remedy. Consider the following excerpts from Warren, one of the earliest researchers in thermodynamics education:

One hundred and forty eight university entrants in various branches of science and engineering were asked to define heat and internal energy, and to state their relationship. Not one gave meaningful definitions of both these quantities, nor was there a single statement of the first law of thermodynamics (Warren, 1972, p. 42).

energy is not something of which anyone can be aware by commonplace experience ... It is a very advanced concept which must be learned through systematic instruction, which can only be understood if the student has first mastered several difficult basic ideas ... and has an extensive knowledge of elementary physics ... the only way to overcome these difficulties is by teaching the subject logically to students who have been properly prepared (Warren, 1982, pp. 295-296)

Warren took the view that physics concepts have one unambiguous definition and students may acquire understanding of a concept after logically structured preparation. This view eventually fell out of favour. The general discomfort around accepting an exclusive way of knowing (Greene, 1994) strongly influenced conceptions research and is most obviously reflected in the changing terminology (Abimbola, 1988). 'Misconceptions' or any term that implied a singular or objective truth or fact was rejected in preference for accommodating multiple legitimate ways of knowing.

‘Superstitions’, ‘misconceptions’, ‘mistakes’, ‘misunderstandings’ (Helm, 1980; Matteson & Kambly, 1940; Vicklund, 1940) fell out of favour to ‘preconceptions’ (Ausubel, 1968), ‘prior schemata’ (Posner, Strike, Hewson, & Gertzog, 1982), ‘alternative frameworks’ (Driver & Easley, 1978) and ‘alternative conceptions’ (Hewson, 1981). Gauld (1987) notes that during this period, there were over 20 different alternative terms for misconceptions.

Driver et. al further explain that:

The empiricist’s view of science suggests that scientific ideas and theories are reached by a process of induction ... pupils or practicing scientists observe facts objectively... if one subscribes to such a view then alternative interpretations of events imply either incorrect observations or faulty logic could be called ‘wrong’ ideas (rather than) recognised as partial explanations of limited scope (Driver & Easley, 1978, p. 62).

The acceptance of multiple legitimate versions of a scientific concept opens up dialogue concerning the conditions of legitimacy and the assignment, to student’s conceptions, of varying degrees of legitimacy. Students’ ideas, for example, could be considered categorically at odds with scientific knowledge, or they could be tolerated as a building block towards accepted scientific knowledge, or in the most extreme form of relativism, they would be just as legitimate as scientific knowledge. Osborne provides one view in this dialogue, in asserting that “there are entities for which we have well-established arguments ... and reliable theories that have superior explanatory power than those of common-sense reasoning”, and questions the expectation that a student may be in a position to be aware of the value of these ‘entities’: “But how is the child to judge that the scientist’s description is more viable?” (Osborne, 1996, p. 58). He also flags the insufficiency of constructivism to explore this issue.

Clearly, these questions indicate a maturation of the field and, as the field matured, so did the scope of the research. A bibliography of the conceptions work had been produced in the seventies and maintained for a period of time by Helga Pfundt and

Reinders Duit. Duit neatly summarises the development of the ‘conceptions movement’ and the constructivist influence in the introduction to this bibliography:

Initially, the focus was on students' conceptions of various science topics. As this area has developed towards constructivist perspectives of conceptual change the emphasis of the bibliography has also changed (from students' alternative frameworks and science education to students' and teachers' conceptions and science education). The new name of the bibliography takes these changes into account. This is the last version of the bibliography available. After more than 30 years it has become more and more difficult to adjust the initial system of keywords to the rapid developments in science education research. (Duit, 2009).

The revisions to this bibliography indicate a history of a field in which there existed an initial, strong focus on categorisation that led to a wider adoption of constructivism and, ultimately, gave way to a diversification. It is at this point that researchers claimed it is no longer possible to maintain the bibliography without considerable effort. The last update includes upwards of 8000 records.

Although the issue of legitimacy was not to become a dominant theme in the study of student understanding in the science education research literature, ‘theoretical’ discussions were nonetheless prioritised, and culminated in two opposing perspectives on the nature of personal knowledge structures which became termed ‘theory-like’ or ‘piece-like’ (Özdemir & Clark, 2007). Accepting either of these two perspectives would affect how the researcher interprets student understanding (and therefore also conceptual change) (see, for example, diSessa, 2006; Guzzetti & Hynd, 1998; Özdemir & Clark, 2007; Vosniadou, 2008).

3.1.2 The nature of students' conceptions- ‘theory-like’ or ‘piece-like’

The proponents of the ‘theory-like’ description of student conceptions include Carey (1985), McCloskey (1983), Chi (1992) and Vosniadou (2002), who believe students' conceptions are concrete manifestations of theory-like cognitive structures. This

research is influenced by the Kuhnian and Piagetian ideas, since they assumed students have certain epistemological and ontological commitments, and these assumptions, like those of science itself, are paradigmatic and difficult to shift. The essence of the theory-like perspective is that each individual idea or set of ideas stems from a coherent theory that is present within the mind of the student from an early age. These ideas are well articulated, strongly held and persistent. One theoretical concept resulting from taking a theory-like perspective on student understanding is the concept of ‘ontologies’. Chi (1992) shows that, when engaged in science learning, students practise ‘ontological classification’ and she describes conceptual change as overcoming ontological *misclassification*. For example, students often classify ‘heat’ as a fluid; they talk of it as ‘flowing’ (Table 3-2). To physicists, heat, strictly speaking, is an energy transfer due to a temperature difference (Warren, 1982). In taking such a view, overcoming this misclassification is not merely, as Warren puts it, a matter of “systematic instruction...teaching the subject logically to students who have been properly prepared” (Warren, 1982, pp. 295-296) but instead, it is an ontological re-classification that should be explicitly facilitated (Chi, 2000).

The opposing ‘piece-like’ view purports that knowledge is constructed from elements that are ‘quasi-independent’; elements that are linked or connected through dynamic activation which occurs in the learning context. These pieces, or elements, are described at different levels, from the most discrete and concrete to the more complex and ‘abstracted’. For example, Minstrell (2001) talks of discrete and independent units called ‘facets’ that characterize a student’s scientific repertoire. Minstrell’s collection of facets is extensive, and ranges from characterizing the ‘scientific method’ (e.g. Experimenting: changing things and seeing what happens) to describing individual scientific ideas (e.g. Heavier falls faster). The use of facets allows for the identification of the ideas of students; ideas that are shown to be present in a large number of students of the same age and ability and which are problematic to learning. These facets are considered to be a ‘crude’ and functional way of becoming aware of students’ thinking in the classroom context.

Another theoretical construct to emerge from the piece-like perspective is the ‘phenomenological primitive’ (p-prim)(diSessa, 1993). A p-prim is a unit of knowledge that describes a general mechanism or action that students believe is an irreducible feature of reality (requiring no further explanation). For example, if a student believes that the reason it is hot in summer is because the Earth is closer to the sun at this time in its orbit, then this student may hold the p-prim ‘closer is stronger’. ‘Closer is stronger’ is both intuitive and true in other contexts, such as the opposite poles of magnets attracting each other, or feeling warmth from a fire, and so a justification is not considered necessary. The p-prim has a further characteristic of being quickly substantiated and difficult to abandon. Successful conceptual change, or learning, would involve reorganizing the structure around which the p-prim is embedded. That is, the ‘expert’ may still exhibit the same p-prim as the student, but the student’s is part of a ‘very broad and shallow explanatory system’ whilst the expert’s p-prims are part of a more complex system such that “the physical laws are the explanatory unit, rather than a slew of p-prims” (diSessa, 1993, p. 143). The identification of a p-prim presents a way of representing elements of student understanding, which helps to facilitate communication amongst researchers and students and, like Chi’s ‘ontologies’, helps explicate and describe the basis of the difficulty.

3.1.3 The Resources Framework

The Resources Framework (RF)(Redish, 2004) is the most sophisticated and comprehensive assimilation of theoretical concepts to develop from the ‘piece-like’ view, and offers a structure into which smaller units –or resources –are integrated. P-prims and facets, both ‘resources’, may be considered different grain sizes of interest in this structure. This is also the case with mis- or alternative conceptions. Redish writes, on the necessity for a subsuming theoretical structure, that “A shared language and shared assumptions that can both guide and allow us to compare different approaches and ways of thinking” (p. 2). Redish also states that his account of learning is based on research from cognitive science, neuroscience and sociolinguistics in an effort to “help transform a collection of independent ‘facts’ into a coherent science, capable of evaluating, refining, and making sense of our accumulated experimental data” (p. 1).

The RF is based on the idea of connections between resources and amongst resources (concepts, facets, p-prims etc.), where resources are ‘quasi’ independent rather than manifestations of a coherent ‘naïve’ theory. This places the RF at odds with the views of theory-like proponents, such as Vosniadou. The choice of which resource is utilised, in the theoretical respect, is dependent on the research context or question that needs to be addressed, so that the use of facets may be more illuminating in one particular case and p-prims in another. The theoretical framework, which is multidisciplinary and explicated in a substantial document and subsequent papers, is centred on explaining ‘local conceptual coherences’ in student thinking. Redish has proposed three different classes of cognitive mechanism that can contribute to local conceptual coherences in student thinking: those relating the effect of context, those relating to the structure of knowledge and those relating to effect of personal ‘epistemologies’.

On context

Neuroscience strongly informs the context aspect of the framework –although the resultant principles do not depend upon specific neuroscientific mechanisms. For example, based on the neuroscientific description of memory and memory activation, the following principle is proposed:

The activation of a particular resource in response to a presented stimulus can depend not only on the stimulus but on the context – the activation pattern existing in the brain when the stimulus is presented (Redish, p. 15).

Figure 3-1 A schematic of the associations made between 'resources'. The different shades represents 'resource' activation in different contexts and the arrows represent the associations (Redish, 2004, p. 15)

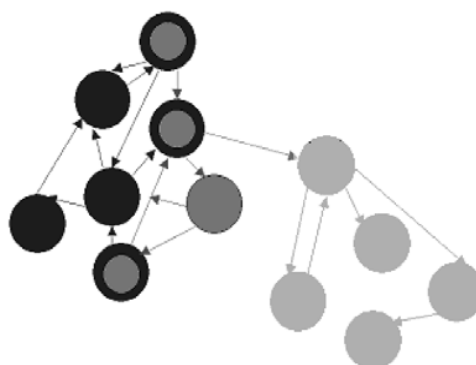


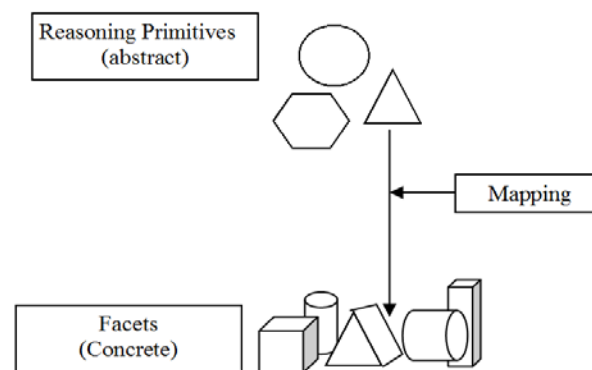
Figure 3-1 shows a representation of this mechanism: the nodes do not necessarily represent neural networks or physical ‘nodes’; they represent some abstraction of a ‘knowledge piece’. Important, is the presence of several resources and their activation (and therefore the implied suppression of others under different circumstances). Redish, diSessa and others suggest that this is a useful representation in that it reduces the tendency to apply the ‘misconceptions’ model of replacing incorrect ideas with scientifically consistent ones, and allows for a variety of different cognitive responses to the same stimuli –even with respect to just one individual.

However, they also admit that due to the huge numbers of activated resources for even a short, simple learning task, we are a long way off from using this as a model in any empirical sense; the nodes and their connectives are figurative, rather than characterising.

Knowledge and knowledge structures

The knowledge and knowledge structure aspect of the framework centres on the nature and structure of a student’s knowledge. Apart from simply taking a ‘pieces-like’ view, Redish also ascribes organization to these pieces. Consider the characteristics of the resources mentioned so far: facets are ‘concrete’ (or least abstracted) nodes and p-prims are slightly more abstracted ones. P-prims are more abstracted in that they are the more general form of a number of more specific pieces; they may cover more than one specific idea (being closer to the fire or bringing the magnets closer together). Redish is able to convincingly extend and integrate these two concepts by assigning internal structure to p-prims such that they represent two levels of ‘abstraction’ where the less abstract level is now replaced with the ‘facet’. P-prims, therefore, now consist of ‘reasoning primitives’ and ‘facets’ (Figure 3-2). Reasoning primitives are more abstract and ‘map onto’ ‘facets’. Facets are redescribed as more specific details about physical objects or quantities. Redish believes that dividing the p-prim into two levels of abstraction overcomes the problem of a ‘daunting’ number of p-prims that would exist otherwise.

Figure 3-2 Reasoning Primitives 'map onto' concrete statements 'facets' (adapted from Redish, 2004, p. 21)



The three theoretical concepts (or resources) mentioned thus far may therefore be considered to represent different levels of a hierarchy of abstraction. The RF itself loosely defines the subsuming structure of this hierarchy as the knowledge present in a student’s mind. Redish explains “at its core, my theoretical framework describes students’ knowledge as comprised of cognitive resources in various forms and levels of hierarchy” (2004, p. 20). Section 3.5.3 in the final portion of this literature review will show how although the abstract-concrete nexus identified here is a good first step, ambiguities in theoretical concepts in the RF, as well as the assumed homogeneity of the (two mentioned) categories, pose limitations that restrict its interpretive power.

‘Epistemology’

In the third relevant aspect of the framework, Redish discusses how external factors, the environment, ‘affect’ and motivation, may influence memory activation and shape knowledge structures. Redish explains that one of the many resources individuals utilise to construct knowledge is the ‘epistemic’ resource. Epistemic, here, denotes the nature of the knowledge an individual is encountering:

“A small child may know what’s for dinner because “Mommy told me” (*knowledge as propagated stuff*). She may know her doll’s name because “I made it up” (*knowledge as fabricated stuff*). A student may “know” that a big car hitting a small car exerts a bigger force on the small car than the small car exerts on the big one because “the big one is stronger” (*knowledge by p-prim*)” (Redish, 2004, p. 30).

Redish explains that a device that is useful for thinking about the environments in which epistemic resources are enacted is ‘frames’. Redish describes frames as circumstances (physical or otherwise) which influence student’s choice of epistemic resources. Students in one frame may misconstrue what is happening because they believe they are acting in another and therefore apply inappropriate resources. Thus, we must consider that when students enter a classroom, they ‘frame’ what is going on. This framing process has many components:

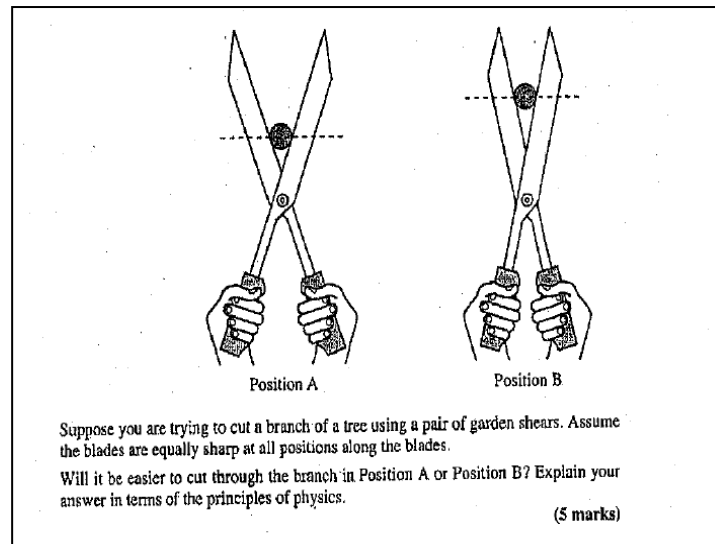
- a social component (Who will I interact with and how?)
- a physical component (What materials will I be using?)
- a skills component (What will I actually be doing?)
- an affect component (How will I feel about what I’m going to be doing?)
- an epistemological component (How will I learn/build new knowledge here? and What counts as knowledge here?)

Redish explains that the ‘epistemological’ aspect of framing is the most important in teaching and learning contexts (p. 34). He further shows how a ‘mismatch’ in framing can be problematic, that students frames can be robust, and that attending to framing ‘clashes’ results in positive learning and motivational outcomes.

One example that supports the account of ‘epistemic resources’ and ‘frames’ is an experience resulting from a question regarding torques (Figure 3-3), provided in the first year Physics tutorials at The University of Sydney (Section 4.4.1). Each year, students would confidently state that the branch should be placed at the point furthest from the pivot. They would reason that due to the application of $\tau = Fd$, this is the point where the maximum torque may be achieved. A (scientifically) consistent answer however, would need to consider that the torque on the blade will be equal to the torque on the handle at equilibrium. Given the force required to cut the branch is some fixed value, and the distance from the pivot to the handle also remains fixed, there is a relationship between the force of the hand on the branch and the distance from the

pivot to the branch: the closer the branch is to the pivot, the smaller the force required from the hand.

Figure 3-3 Tutorial Question on Torques (also past exam question)



On reaching this explanation during discussions with their tutors and each other, the students recognise that they are familiar with this outcome; they have physically experienced placing an object nearer the pivot on a pair of scissors to make cutting the object easier. When asked why they did not utilize this intuition or experience when answering the question, students would often reply “because that’s real life and this is physics!”.

This example shows how ‘frame clashes’ may affect learning, (common sense frames clashing with physics knowledge frames), and how being aware of these frames allows the instructor to help the students reach a better understanding (by acknowledging it is acceptable to use common sense in some situations). However, the issue with this approach is that it falls into the trap of the p-prim; it describes knowledge as a plethora of categories that are not only too numerous to work with, but, again, also not clearly defined. For example, what are the qualities of the different kinds of knowledge that make them different?

These are precisely the problems that invited a different approach from LCT, since one of the most powerful aspects of theory is its description of the organizing principles of knowledge. LCT is concerned with explicating the characteristics that *make* knowledge different (and therefore produce these different frames). That is, how can we describe qualities of knowledge that allow it to be classified as ‘knowledge as propagated stuff’ or knowledge as ‘common sense’ or knowledge as stated by an ‘authority’? These questions will be further detailed in Section 3.5.

3.1.4 A summary of conceptions and theory

The Resources Framework is neither a theory of knowledge or of learning; it is a coherent and subsuming structure through which other research agendas and scientific findings can be embedded to give them more explanatory power. A particular example can be made of conceptions research. One of the most problematic aspects of the early conceptions research was that misconceptions, whether in description or through methodological analysis, were assumed to be discrete, homogenous and somewhat fixed. The misconception that heat is a substance, for example, is depicted as a unitary structure that may or may not be linked to other knowledge, it takes the same form whenever identified in a student’s thinking and should be replaced with the correct conception relating to heat being an energy transfer. In incorporating findings from the literature that show student’s ideas being context dependent and dynamic, the RF can instead characterise misconceptions as inappropriate ‘mapping’ between primitives and facets. Using this framework, external factors are expected to ‘activate’ different arrangements of these resources meaning that this mapping may occur differently in response to different environments and contexts.

There is a secondary, ‘meta’ advantage of the RF; it is really the only theoretical framework in science education research. Those researchers developing the RF identify as belonging to the field of Physics Education Researcher (PER). PER is a unique subset of what is known in science education research as the Discipline Based Educational Research (DBER) coalition. No other DBER faction has engaged in

consistent, progressive efforts to develop any other theoretical program apart from the RF and as such, no other theory dominates.

Ironically, PER is also one of the most focused on the other ‘applied’ end of the spectrum. It is described as the development of ‘research-based ...tools and processes for practitioners’ (Burkhardt & Schoenfeld, 2003, p. 3). In fact, some researchers in PER are concerned that the focus on theoretical or social aspects weakens the position and influence of the field and would prefer it be a powerhouse for the improvement of practices (McDermott, 1990). Furthermore, although the resources framework is tolerated, many other social and educational theories are not (Morais, 2002) and methodological and practical research is accepted to proceed (and be published) without any specific reference to theory (See also, Section 3.4).

This seemingly contradictory characteristic of the field of PER will be explicated in the next section, where the more ‘applied’ developments in the field are described. These practical advances, synonymous with PER, do not rely on any theoretical or epistemological constructs and include the Expert-Novice work and the work on Active Learning.

3.2 PER: practical developments

3.2.1 Interactivity and Active Learning

Second only to conceptual change and conceptions in terms of prominence in the science education research agenda is the matter of ‘Instructional Practice’ (Chang et al., 2010). This is not surprising, given that many in science education, particularly physics education, are part of science faculties and are encouraged to work on improving local teaching programs. In the context of the large lecture classes of first year Physics courses, the literature is uncommonly consistent in recommending Active Learning practices as a way of improving instruction above all others (Hake, 1998; Meltzer & Manivannan, 2002). Active Learning reflects the strengthening of student participation for the purpose of positively affecting student learning and attitudes towards learning.

Although it is unsurprising that during an undergraduate degree the level of involvement of students in their studies is related to their success and enjoyment of them, this area of research looks at specific instructional interventions that facilitate this involvement. The instructional method used to facilitate Active Learning (in science education research) is generally known as ‘Interactive Engagement’ (IE).

The Active Learning movement stemmed from the constructivist movement but, often, academic papers on Active Learning do not refer to constructivism or only refer very broadly to it, instead simply highlighting student involvement –‘hands on, mind on’ – or student-centeredness as theoretical grounding. An appropriate theoretical framework is not suggested or called upon from this large body of research, nor is its requirement, in terms of delivering local improvements in learning due to specific instructional developments, convincing.

Descriptions of the most common types of IE employed in science education are provided below.

Demonstrations: Demonstrations involve an instructor illustrating a concept or idea with reference to scientific equipment or other physical or virtual apparatus. Demonstrations have a very long history in science education –particularly physics – and have always played a part in the standard undergraduate course as a way of showing physical phenomena or scientific processes on a larger scale. Demonstrations are very popular with undergraduate students, with evaluations persistently returning opinions of them being the ‘best part’ of the course. However, some time ago, it emerged that the use of Demonstrations has not been critically examined as much as it should; that their usefulness has been taken for granted and more research should be drawn on when designing or using Demonstrations (Garrett & Roberts, 1982). Since then, several issues associated with Demonstrations have been further examined, mainly those identified to be associated with the question of whether there was any academic advantage beyond entertainment value (Crouch, 2004). The community now

makes a distinction between just ‘Demonstrations’ and demonstrations that engage the learner in a more meaningful way, such as those which also include the use of Peer Instruction, Personal Response Systems or Interactive Lecture Demonstrations.

Context-rich problems: Context-rich problems are best described by what they are not, rather than what they are. They are not like the ‘traditional problem’; the type of problem that is solved through algorithmic or mechanistic means and which often includes highly idealised and stylised physical situations. Many problems that fall under the ‘traditional’ label are quantitative and have a unique, precise answer. Students solve these problems by finding the correct equation, manipulating this equation and performing an accurate calculation (Redish, Saul, & Steinberg, 1998). Often, instruction would involve making these problem solving steps explicit such that students are trained into an approach rather than come to a deeper conceptual understanding (McDermott & Redish, 1999).

The alternative, context-rich problem, is open-ended and “related to everyday life situations” (Enghag, Gustafsson, & Jonsson, 2009, p. 455). Table 3-3 shows a comparison between a ‘traditional’ and ‘context-rich’ problem in mechanics.

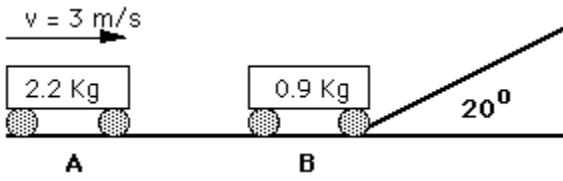
Traditional problem	Context-rich problem
<p>Cart A, which is moving with a constant velocity of 3 m/s, has an inelastic collision with cart B, which is initially at rest as shown in Figure 8.3. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height h of the carts before they reverse direction.</p> 	<p>You are helping your friend prepare for her next skate board exhibition. For her program, she plans to take a running start and then jump onto her heavy duty 15-lb stationary skateboard. She and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. She wants to reach a height of at least 10 feet above where she started before she turns to come back down the slope. She has measured her maximum running speed to safely jump on the skateboard at 7 feet/second. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned. She tells you that she weighs 100 lbs.</p>

Table 3-3 A comparison between traditional and context-rich problems

The context-rich problem shown in Table 3-3 is preferable to the traditional problem for the following reasons (Heller & Heller, 1999):

- It portrays real objects that tie physics to the real world.
- Students must make a decision about which physics to mobilise and which assumptions are relevant
- Student must select which representations are best, rather than use the ones presented to them in the question
- Variables are not pre-defined, encouraging the students to consider which variables would be relevant

Active Learning is encouraged by “creating physics problems that are contextualised and anchored in the lives of learners (so) that the physics problem solving is meaningful and interesting to learners and relevant to their own lives” (Enghag, Gustafsson, & Jonsson, 2007, p. 449). Although context-rich problems have been mildly successful in improving student understanding, more success has been noted in motivational aspects, particularly with students ‘taking ownership’ of their own learning and for encouraging social participation within the scientific culture when used in peer learning environments. Despite these findings, research on context-based problems (and context-based instruction) remains considerably under-developed (Taasoobshirazi & Carr, 2008).

‘Clickers’ or other form of Audience Response System (ARS): These systems, electronic or otherwise, involve students revealing their reckoning to the instructor, usually by selecting a multiple-choice alternative. The reasoning for this technique is to involve all students in the class and is geared towards the large lecture format. Some instructors have utilised and continue to use the individual whiteboard as a mechanism for compiling feedback from students due to its price and convenience; however, at the tertiary level electronic systems are much more widespread (Fallon & Forrest, 2011; Lasry, 2008). Electronic devices have the advantage of tracking student responses over a period of time and also storing responses for future analysis. They are known under many pseudonyms (“kee-pads” in the United States and “handsets” or “zappers” in the United Kingdom) but generally consist of a remote-control-like device with numbered or lettered buttons that work wirelessly with corresponding software to allow two-way

communication. More recently, freeware has allowed students to use their own devices (Tremblay, 2010) making the technique more accessible. At the same time, more sophisticated systems like Pearson's 'Learning Catalytics'¹, have also been developed to cater for more comprehensive usages. ARSs have been associated with many positive outcomes including engagement, retention and increased learning outcomes (Beuckman, Rebello, & Zollman, 2007; Brady, Seli, & Rosenthal, 2013; Caldwell, 2007; Draper & Brown, 2004; Kay & LeSage, 2009; Keller et al., 2007; Knight & Wood, 2005; MacArthur & Jones, 2008; Sharma, Khachan, Chan, & O'Byrne, 2005; Willoughby & Gustafson, 2009).

Peer Instruction: Peer Instruction is a teaching method popularised by Eric Mazur of Harvard University and involves shifting the nature of the activities taking place in formal class time. Usually, this shift occurs away from lecturer presentation of material and towards student discussion of concepts and problems (Mazur, 2001). In Mazur's model, Peer Instruction involves allocating activities or readings before the lecture, so that during the lecture, students consider a concept or problem first individually, then with their peers, and then engage in a feedback loop with the lecturer. This approach has been reported as successful yet effortful to successfully implement and maintain (Lasry, Mazur, & Watkins, 2008; Mazur, 2001; Turpen & Finkelstein, 2009). In more recent years, Peer Instruction has been appropriated and in some cases has morphed into 'Flipped' teaching, which has gathered enormous momentum within and beyond higher education (The White House, 2013). This move has been facilitated by developments in the quality and accessibility of online resources, particularly instructional videos, which students may engage with outside of and usually before formal class time.

Workshop Tutorials: Workshop Tutorials is an initiative that comes out of the University of Washington and involve an interactive, cooperative, student driven problem solving environment which will often take place in addition to lectures (and in place of recitations). The tutor is facilitator and students work in small collaborative

¹ <https://learningcatalytics.com/>

groups to solve context-rich problems that have been the product of a collaborative and iterative research process (McDermott & Shaffer, 2002). Workshop Tutorials have been shown to be highly effective for first year Physics courses (Galili, 2011; McDermott, 2001; Sharma, Mendez, & O'Byrne, 2005).

Laboratory sessions: Laboratory sessions are common but not always mandatory requirement of a first year Physics course. They involve working with experimental equipment to strengthen laboratory skills and consolidate important scientific concepts. Usually, this activity occurs outside the lecture course. Early laboratory work followed a prescriptive process but developments in educational research have resulted in more 'inquiry based' techniques which involve more autonomous thinking on behalf of the student (Buntine et al., 2007; Hofstein & Lunetta, 2004).

Interactive Lecture Demonstrations (ILDs): Interactive Lecture Demonstrations are a teaching technique developed by Sokoloff and Thornton (1997) whereby students interact with a demonstration through a series of worksheets that are designed to illicit student ideas and develop them through discussion with peers and feedback to the instructor. It effectively involves a combination of a range of research based techniques including Peer Instruction and sometimes ARSs (Bonwell & Eison, 1991; Mazur, 2001). The ILDs were developed in many physics topics such as mechanics, heat and temperature and optics, and there exists a large body of research that documents their implementation and success (Sharma et al., 2010; Sokoloff & Thornton, 2004). During the implementation, the students are handed two identical sheets (of different functions): one on which to write their predictions and hand in, and the other, to keep as a record of the outcomes of the demonstrations. Each demonstration involves: an introduction to the equipment, an introduction to the problem, time for students to make a prediction both individually and with peers and finally, a presentation of the results. During this last stage, students record the 'correct' outcome on the sheet they will keep (see also Section 5.1.1).

Studio teaching: Studio teaching involves students working in a ‘studio’ classroom environment which usually takes the form of a room that combines a lab, homework and tutorial. Although the studio teaching model may vary, the main premise is that students work collaboratively in small groups on context rich problems and with experimental equipment. They also have access to significant resources and high tutor to student ratios (Beichner et al., 2007; Cummings, Marx, Thornton, & Kuhl, 1999). In its purest form, it is arguably the most interactive form of teaching physics. However, it has also been adapted to work in large lecture theatres under the same name or as SCALE-Up with less effect (Beichner et al., 2007).

To avoid the controversy that often surrounds listing, the following issues should be considered in regards to the IEs mentioned above. First, the descriptions provided refer to the ideal form of each technique. Whether this ideal form is achieved when implemented in practice is dependent on a number of factors including: individual instructors interpretation of the implementation, student cooperation, time and apparatus constraints and educational ability (Prince, 2004). Some researchers would also disagree with the nomenclature or descriptions, as has been the case in the literature around the Problem-Based-Learning or Inquiry debates (Camp, 1996; Kirschner, Sweller, & Clark, 2006) and even ‘Student-centered’ approaches, which exhibit “ a marked tendency for there to be more discussion and lip-service paid to the idea, than actual practice” (Farrington, 1991, p. 16). Also, many of these approaches may involve one or more additional IE at some point during the implementation, such as the use of clickers in Peer Instruction or the use of Demonstrations in Workshop Tutorials.

Despite the general consensus of the triumph of IE approaches, there exists criticism which ranges from the logistical to the philosophical and is deserving of consideration. Firstly, it is widely reported that some IE techniques are time consuming to prepare, employ and maintain (Wieman, 2009). Wieman has noted that even if IE techniques are introduced and employed by one member of staff, it is not easy to convince others to cooperate (2009), resulting in a relatively small sphere of influence:

Physics Education Research (PER) practitioners have engaged in substantial curriculum development and dissemination work in recent years. Yet, it appears that this work has had minimal influence on the fundamental teaching practices of the typical physics faculty (Henderson & Dancy, 2008, p. 79).

Because physics education researchers are almost always also physics lecturers, and these IE techniques are meant to be used by lecturers, the reasons that research based instructional design is not taken up by faculty are of importance. In this respect, pedagogical techniques like Active Learning are susceptible to criticism by instructors of physics because they are part of a movement that is often placed in opposition to ‘traditional’ modes of teaching. Such binary oppositions are common in the educational literature: “Phonics (versus) whole language approach(es), skills-based versus experience based, concrete versus abstract, directed versus discovery- the categories and their curricular offshoots seem endless” (Alexander, Murphy, & Woods, 1996, p. 31) and this can negatively impact on the respective research areas. ‘New’ or ‘non-traditional’ modes of teaching are often criticised for being different versions of a previously seen technique or ‘flavour of the moment’ and although these criticisms may, in some cases, be valid, Alexander et al. explain that it also may be a problem between the design of the innovation and its implementation. They argue that the innovation may fail due to implementers not having a ‘rich understanding’ of it, which leads to superficial application, or that they do not have “an extensive knowledge of the literature or research that underlie these innovations, resulting in the reinvention or recycling of old movements under new labels” (1996, p. 31).

It is also demonstrated that if not properly implemented, IE techniques may not result in Active Learning at all (Turpen & Finkelstein, 2009). For example, if clickers are used for testing a sequence of multiple-choice questions with no time for challenging certain popular but incorrect student responses and there is no time for discussions, then the use of the clickers may not have the desired outcomes. To that effect, the Andrew’s et al. study (2011) outlines that many positive results from interventions focusing on increasing interactivity have involved science education experts actually

conducting the IE and show no improvements when corrected for a random selection of instructors. Although many studies on Active Learning reveal positive reactions towards IE techniques, (Vernon & Blake, 1993), it is also clear that students feel somewhat uncomfortable in approaches such as Peer Instruction, which often significantly alter the standard lecture format.

Amongst these concerns, conclusions about exactly what the ‘active ingredient’ in Active Learning is have not been fully scrutinized (Bonwell & Eison, 1991; Prince, 2004). For example, a recent study around IE implementation in Biology shows that learning gains are not merely related to increasing interactivity but more to the specific objective of the IE, such as addressing misconceptions (Andrews et al., 2011), engaging with context (Buncick, Betts, & Horgan, 2001), or introducing other ‘research based activities’ (Cummings, Marx, Thornton, & Kuhl, 1999).

In an effort to address the issue with transparency, some researchers have identified the need for instruments designed to assess the fidelity of the implementation (Granger et al., 2012). These instruments are designed to provide information about what the instructor was doing, what the students were doing and how effective the programs implementation was (see for example, Section 5.2.3), although such instruments are not yet the norm for Active Learning studies.

3.2.2 Developing from Novices to Experts

The next major ‘practical’ focus in PER that will be discussed is the work on ‘novices’ and ‘experts’. This research is based on early assumptions around the hierarchical nature of development. For example, Nussbaum and Novak’s study explains that children ‘had five different notions or concepts’ about the earth (Nussbaum & Novak, 1976, p. 542) where notion five contains all the ‘necessary aspects of the concept’ and where ‘each succeeding notion exhibits some significant attainment that the lower one lacks’ (p. 546).

Expert-Novice research was concerned with the cataloguing of individuals' understanding and thus provided a means of facilitating development. These characteristics could be conceptions- alternative or otherwise - or more general characteristics, and occurred in a large range of contexts (Table 3-4 and, for example, Feldon, 2007). Much of the Expert-Novice literature however, focused on problem solving. It was found that students who exhibited knowledge structures that were cohesive and well organized were more successful and thus more expert in problem solving (Elstein, 1994). In Physics, it was observed that during problem solving, students exhibited superior pattern recognition skills and had the ability to see past the surface features of a question (Sutherland, 2002).

Novice	Expert	Reference
Sort problems by superficial similarities	Sorts problems according to underlying physics and solution principles	(Chi, Feltovich, & Glaser, 1981)
Tend to solve problems based on manipulation of formulas	Refer to theory primarily, and employ formulae more appropriately	(Larkin, McDermott, Simon, & Simon, 1980; Larkin, 1983)
Intuitive knowledge is more fragmented and linked to the context in which it was encountered	Knowledge is more suitably linked and transferred	(diSessa, 1993)
Talk in terms of equations	Can more aptly describe the actual physical situation	(Gick, 1986)
Many alternative conceptions	Fewer or no alternative conceptions	various

Table 3-4 A comparison of the characterisation of novices and experts based on selected research

Although this kind of research is successful in capturing large-scale patterns across developmental stages, these stages have a very large grain size and often fail to successfully characterise and therefore agree on what constitutes the 'expert'. For example, when referring to work on individual epistemologies (how students perceive scientific knowledge), Elby and Hammer assert that the act of simply determining novice or expert assignments based on multiple-choice surveys in problematic (2001). Even though one may agree science is not 'objectively inherent in nature' and instead 'tentative, evolving... and subjective according to scientists' perspectives', the former idea may actually be more fruitful in legitimate scientific practices and in the learning of science. They explain that "literature fails to distinguish between the correctness and productivity of an epistemological belief" (2001, p. 554).

Hence it is not just ‘what’ an expert is thinking that is important, it is also ‘why’. The former issue is well serviced by the categorisation-based research agenda but the latter can only be answered by looking at the social and epistemological aspects. Osborne asserts that “knowledge and understanding of the epistemology of science is an essential aspect of any education in science, and any approach which neglects a consideration of it is incomplete and epistemologically thin” (1996, p. 55). Relevant social considerations that have influenced science education research are provided in the next section.

3.2.3 A Social turn

Steiner and Mahn point out that the birth of sociocultural theories occurred with Vygotsky, who ‘conceptualized development as the transformation of socially shared activities into internalised processes’ whilst rejecting the Cartesian dichotomy of ‘the internal and the external’ (John-Steiner & Mahn, 1996, p. 192). The external approach to the construction of knowledge refers to behaviourism while the internal can be considered as encompassing ‘individual views of learning’ and therefore has its focus on subjective experiences (Leach & Scott, 2008). Individual, or subjectivist, views of learning form the basis of most work in science and physics education research. That is, there is a strong focus on what is ‘in the mind’ of the student. Consider the following theoretical constructs which appear at various times throughout the conceptions movement: conceptions, p-prims, conceptual ecologies, mental models, even the Expert-Novice field of research –these terms all refer to individual knowledge. Although there is, undoubtedly, a social shift in such research, knowledge construction is almost always described as occurring firmly within the individual. Even when social factors are considered, they are considered as acting as influences on a separate system; the working mind. For example, in Redish’s RF, context (the environment or stimuli) results in different arrangements of resources being activated (Figure 3-1) and interactions with peers or ‘tools’ (epistemic forms) are ultimately described again as activations of resources. These resources are both considered to be in the mind of the student.

Leach and Scott argue that such individual, subjectivist models will always be incomplete (Leach & Scott, 2008). They believe that the emphasis should be shifted more clearly to the social, such that social factors do not merely influence cognition, but become primary in the process of knowledge construction. They state, for example, that ‘in formal learning situations, the concept of ‘viability’ has ‘more to do with social reinforcement than reinforcement from perceptions of the physical world’ (Leach & Scott, 2008, p. 94).

Sociocultural views fundamentally assume all higher mental functioning in the individual is derived from social life. “In the first instance, language and other semiotic mechanisms provide the means for scientific ideas to be talked through on the social plane ... the process of internalisation is where individuals then appropriate tools first encountered on the social plane” (Vygotsky, 1978, p.128 in Leach & Scott, 2008, p.128, p99). Driver et al. add that:

making meaning is thus a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members. As this happens they ‘appropriate’ the cultural tools, particularly language, through their involvement in the activities of this culture (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 7).

One important issue, which was highlighted through sociocultural perspectives in science education, was the primacy of language; language is no longer simply a means of transportation of meaning, nor should it be considered neutral; language is a central tool through which meaning is mediated. The centrality of language should be no great surprise to scientists, as the ‘scientific language’ is perhaps amongst the most specialised of languages, and one which has shaped the history of science. In thermodynamics, for example, the word ‘heat’ has represented variable and ambiguous physical processes throughout history, arguably influencing the development of the science of thermodynamics (Morris, 1972). This word continues to be used to represent

multiple meanings, resulting in calls for clarification or disposal (Doige & Day, 2012; Romer, 2001; Wiser & Carey, 1983; Zemansky, 1970).

In many ways, the social turn in educational research signalled a further epistemological shift; it moved the focus away from the individual and further rejected positivist notions. However, the interpretation of sociocultural views tended towards a description that either posited ‘many individuals’ as being the repository of knowledge, and thus merely compounding issues in the ‘subjectivist’ approach, or saw knowledge as the ‘disguised interests of social groups’ (Maton, 2014). Maton (2014) explains that this false dichotomy –between positivist and relativist constructivism– obscures knowledge itself, a claim further expanded in Section 3.4.1.

As always, these theoretical views strongly influenced methodological and instructional approaches. More attention was placed on the social environment as studies shifted to consider ‘authentic’ learning environments, rather than conducted in isolation or as sterile psychological experiments. Learning was considered an apprenticeship into a culture and instructors were facilitators rather than the suppliers of knowledge. However, while sociocultural views of learning became popular ‘ways of thinking’, their lack of proliferation in the science education literature indicates that the methodological and instructional consequences were not yet appropriately amenable or adequate.

3.3 Methodologies

3.3.1 History of methodologies in Physics and science education research

The relationship between theory, research methods and changes to practice is significant since developments in one sphere translate into another. This relationship can be both fruitful and detrimental. A short history of research methods and the significance of educational research on practice will be presented in an effort show both aspects of this interrelationship. Specific examples of the most common quantitative and qualitative methodologies widely used in science education research (and this

major project) will be presented to show their specific utility as well as their limitations.

In the constructivist and misconceptions studies of the 1970's, it was common to utilise the 'clinical interview' methodology, popularised by Jean Piaget, the father of 'constructivism', to ascertain children's ideas (although it is often stated that Piaget had no interest in education, and constructivism, as conceived by Piaget, was of a very different nature to the form it 'morphed' into for educational purposes). In the interviews he conducted, which often included drawings, models and apparatus, Piaget would quiz students, ask for predictions and explanations, and record understanding. Many misconceptions authors adapted this method. Erickson, for example, conducted interviews to gauge students' understanding of thermodynamics concepts (Erickson, 1979). Ten students were quizzed about their ideas around certain situations involving experiments or demonstrations with

heat. The goal of this approach was to produce a 'conceptual inventory' of each student; a representation of each student's beliefs of certain categories (Figure 3-4). One student, for example, under the category '1.0 Composition of heat', expressed the idea that 'there are two types of heat- hot heat and cold heat' and for '2.0 Movement of heat' this student

said 'heat moves through all substances'. Research that revealed students' preconceptions or existing ideas in this way subsequently influenced instructional practices. Most tangibly, instructional practices were changed to promote awareness amongst both the student and the instructor. "Teachers should be aware that their students may develop their own versions of the concept." (Nussbaum & Novak, 1976, p. 547). Specific strategies recommended to achieve this aim in the classroom included "providing opportunities for pupils to make their own ideas explicit" and "encouraging

Figure 3-4 Categories of conceptions (Erickson, 1979b, p. 225)

- | |
|--|
| <p>(a) Nature of Heat</p> <ul style="list-style-type: none">1.0 Composition of Heat2.0 Movement of Heat3.0 Effects of Heat4.0 Source of Heat5.0 Heat and Matter <p>(b) Nature of Temperature</p> <ul style="list-style-type: none">6.0 Description of Temperature7.0 Change of Temperature8.0 Temperature and Heat |
|--|

the generation of a range of conceptual schemes” (Driver & Tiberghien, 1985, p. 200). Teachers were encouraged to engage in anything from surveying their students informally to producing wholesale teaching programmes based on the existence of student’s own ideas (Bentley & Watts, 1994). Instruction was therefore considered to be necessarily more ‘student-centred’ in that it was now vital that student’s ideas were garnered and that students engaged in discussions both amongst themselves and with the instructor. Although, retrospectively, the valorisation of ‘student-centeredness’ has questionable foundations (see, for example, Farrington, 1991), it nonetheless allowed a context for this kind of research to flourish.

Student’s ideas were also categorised with respect to what can be considered ‘quality’ (as opposed to content). Piaget’s ‘stage theory approach’ (stages of aptitude as defined by certain criteria) was the basis for a large portion of research focused on determining

Figure 3-5 Descriptions of differentiated levels for conceptions of heat (Shayer & Wylam, 1981 p.428)

Level	Descriptions
I	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.”
II	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.
III	Heat differentiated from amount of substance and sensation of hotness. Have an implied caloric-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.

encouraging student sophistication in science. Categories defining each of these (or other, adapted) stages were therefore used in methodologies ascertaining student’s progression and were also referred to when considering the development of instructional programs in schools. Several researchers and even some policy makers drove to shape curricula, assessment and classroom practice around these stages. Shayer and Wylam (1981), for example, conducted a study in the context of

understanding thermodynamics concepts to investigate at which stage students should encounter heat concepts by producing a table adapted to the context of learning about heat concepts that was representative of Piaget's own hierarchical levels (Figure 3-5). The analysis would indicate not only the level of sophistication level that the students were currently operating at, but what the next stages of progression would look like. There existed a reasonable level of success when describing and developing understanding in this way, however, practitioners attested to confusion around what to do when students fit in several stages at different times and when students are operating above or below their expected developmental levels in different subject areas. It was also not always clear exactly how progression through the stages could be facilitated or accelerated (Case & Fry, 1973; Linn & Their, 1975).

3.3.2 Quantitative: Pre- and post- testing

As the precipitation of PER from the broader science education research field occurred, the Piagetian methodologies became less popular and other, more specific methodological developments surfaced. Research methodologies, quantitative and qualitative, had to adapt to suit needs that are ever more specific and for PER, this need was centred on the practitioner, and involved measuring the outcomes of instructional development. To determine whether instructional developments have been successful and to what degree, or if mis- or alternative conceptions have been overcome, some sort of measurement of student learning must take place. In PER, this occurs largely through testing students before instruction, after instruction and sometimes weeks or months later. This pre- and post- is often mentioned as the field's main achievements in ascertaining the success of a particular implementation (Cummings, 2013). Instruments used in pre- and post-testing include tiered multiple choice exams to account for reasons for selections (Caleon & Subramaniam, 2010), brief free-response questions (Kautz, Heron, Shaffer, & McDermott, 2005) and even interviews (Clark, 2006). However, the straightforward multiple-choice test –intended for very large samples and often including distractors that represent known misconceptions –remains amongst the most popular. These multiple-choice tests themselves have myriad labels including surveys, concept tests, concept inventories,

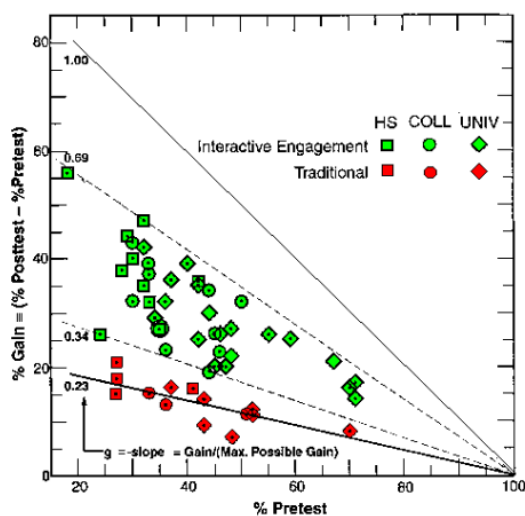
conceptual surveys, and topic specific labels such as ‘Thermal Concept Inventory’ or ‘Force Concept Inventory’. Often with conceptual surveys, distractors have been canvassed from the students themselves through interview sessions and results from these tests are also subsequently triangulated using other qualitative results. Due to all of these characteristics, these surveys are considered the most successful way of assessing students’ conceptual understanding (Ding & Liu, 2012).

The Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992), a multiple-choice instrument aimed at first year university students or high school Physics students is the most well known of all the pre-post instruments although instruments exist for almost all other scientific subjects and educational levels; including, for example, evolution, higher-tertiary optics, quantum mechanics and many others (Duit, 2009)². Survey research has also extended beyond ‘concepts’ (scientific content) to include nature of science ideas, motivation, self-efficacy, epistemology etc. These tests all share the common feature of being used before and after instruction to measure some difference. In the area of thermodynamics, several different multiple-choice style instruments exist (Kautz, Heron, Loverude, & McDermott, 2005; Kautz, Heron, Shaffer, & McDermott, 2005; Loverude, Kautz, & Heron, 2002; Meltzer, 2004; Wattanakasiwich, Talaeb, Sharma, & Johnston, 2013; Yeo & Zadnik, 2001).

The methods commonly used to measure whether change has occurred for quantitative (multiple-choice) instruments include t-tests or ANOVA and also a newly appropriated measure, the ‘Normalized Gain’ ($\langle g \rangle$), a measure specially designed for use with concept tests, particularly the FCI (Hake, 1998; Marx & Cummings, 2007). The $\langle g \rangle$ measurement is considered a more appropriate quantitative measure of student achievement since it takes into consideration pre-scores as well as overall gain and may be used for individual students or large groups. Hake (1998) has also produced a graph of gains versus pre-tests scores using thousands of individual test scores that outlines what is considered a low, medium or high gain for the FCI (Figure 3-6).

² Numerous tests in a variety of disciplines may be found at http://www.flaguide.org/tools/tools_discipline.php#anchor_astro

Figure 3-6 Results of 62 classes on the FCI (Hake, 1998, p. 65). The pre-test score is plotted against the gain



Survey research has resulted in significant insights and developments within the teaching and learning of physics. Hestenes et al. state at the time of publishing the test that three important revelations occurred hand in hand with developing and implementing the FCI;

- 1) Commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects
- 2) conventional physics instruction produces little change in these beliefs and
- 3) this results is independent of the instructor and the mode of instruction (Hestenes et al., 1992, p. 1).

Instructors at all educational levels and in many different subject areas share this opinion, particularly with respect to the low levels of conceptual understanding present, even after instruction. Survey research and concept tests continue to be the main measure by which to ascertain whether one teaching approach is better than another (Ding & Liu, 2012).

Although the tests at the heart of such survey research strictly adhere to what quantitative researchers would call ‘rigorous standards’, such as classical test theory (Engelhardt, 2009) and item response theory (Morris et al., 2006), there are several

limitations noted by authors in support of survey research as well as those against it. Hake warns about question ambiguities, making correct selections for incorrect reasons, uncontrolled variables in the testing conditions, motivational and Hawthorn/John Henry effects (Hake, 1998). There is also the obvious risk of student guessing.

Qualitative researchers would say that many of these limitations may be overcome through the use of qualitative methods. However, qualitative methods are still developing in PER, and there is a tendency to under employ the aspects that make qualitative methods more comprehensive. Otero and Harlow, for example, in their primer on qualitative research in PER, do not mention at all how taking a particular theoretical stance affects approaches to research. When describing how the nature and function of qualitative research they simply state that:

The primary method for analysing qualitative data is through a process 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 labelled using a cover term (code). Ultimately, the researcher will use these codes to find patterns and meaning in the data (Otero & Harlow, 2009, p. 40).

How the researcher finds meaning is not made explicit and therefore it is implied that such questions are not subject to discussion. Often, this results in qualitative methods that result in providing relevant student quotations or that result in categorisation. Two specific examples will be described in more detail.

3.3.3 Qualitative: Structure Of Observed Learning Outcomes and Phenomenography

The Structure of Observed Learning Outcomes (SOLO) is a taxonomy that facilitates the categorisation of student outcomes with respect to some hierarchical structure of quality. SOLO was originally conceived by Biggs and Collins (1982, Table 3-5) and has since been appropriated for a wide range of contexts from numeracy in biology (Lake,

1999), and organic chemistry (Hodges & Harvey, 2003), computer programming (Jimoyiannis, 2011) and thermodynamics (Georgiou, Sharma, O'Byrne, & McInnes, 2009). The process involves classifying student responses, whether they be written answers or structured interviews, to one of the taxonomic levels, based on certain criteria. The original criteria, as well as an additional example from a much later refinement of the taxonomy are provided in Table 3-5.

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

Table 3-5 SOLO taxonomy levels and descriptions.

Level	Characteristics of responses for each category	Example responses
Prestructural	Messy, random responses that made little sense.	The water is too cold
Unistructural	Real world links with tendencies of naïve beliefs (some p-prims (diSessa, 1996)). Some mention of unrelated biology or chemistry references.	Water doesn't allow heat to escape, causing colder conditions
Multistructural	Use of Physics concepts, but these were either not primarily related to question, or incomplete	Air has less density than water molecule which means that each atoms move more freely in air state
Relational/ Extended Abstract	Understanding of physics behind question. Errors, if any are mainly in use of language or expression.	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

Table 3-6 An application of the SOLO approach used in (Georgiou, 2009). The question asked why 16 degree air was more comfortably than 16 degree water.

Table 3-6 shows an application of the SOLO approach in first year Physics. It shows that students in the 'Relational/Extended abstract' categories were able to accurately integrate more than one scientific concept to explain what was happening in this

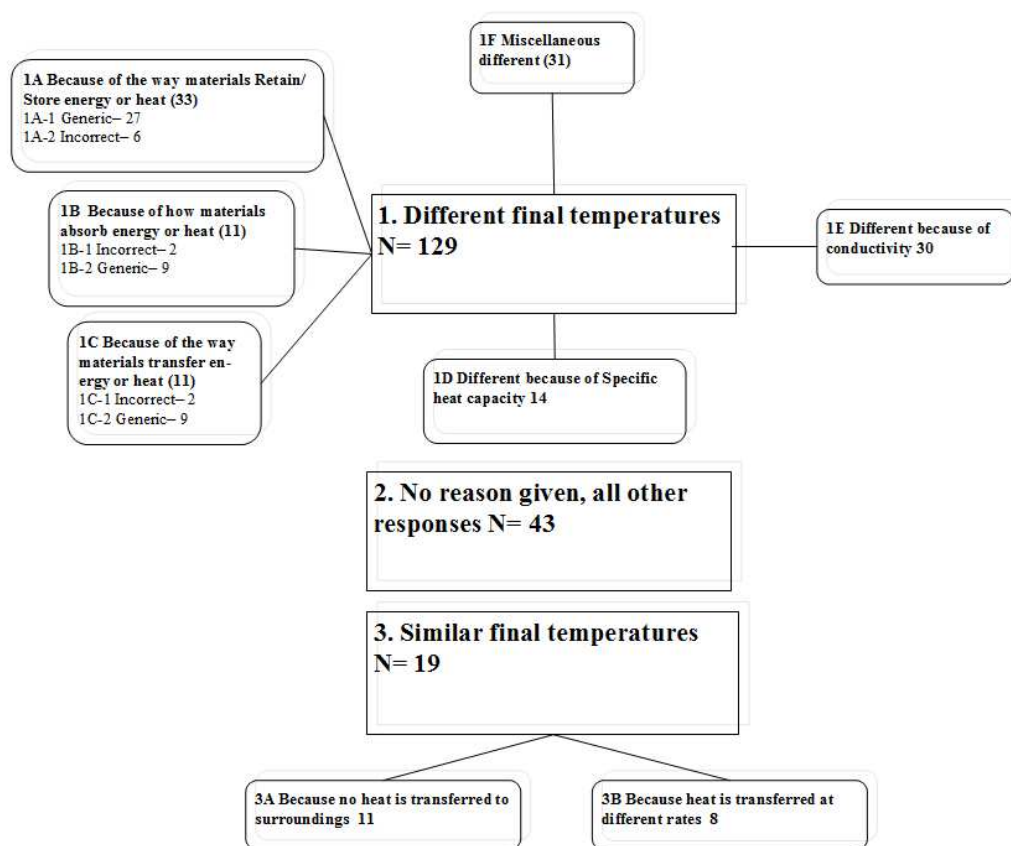
particular exercise, while the Prestructural category involved responses which were tautological or trivial in nature. The difference, for example, between the Relational/Extended Abstract stage and Multistructural stage is the degree to which students recognise the various scientific systems or large number of processes involved in each of the phenomena. Such classification makes learning outcomes transparent, both for the researcher and the practitioner, and the latter has reported great utility with this approach across disparate contexts. One advantage, often cited, is the objectivity it affords. In particular, the approach has been found to be consistent with independent measures, such as learning motivations, language skills and year of study (Chan, Tsui, Chan, & Hong, 2002).

The SOLO taxonomy is reminiscent of the Piagetian stage theory approach. However, researchers utilising the SOLO framework do not refer specifically to Piagetian constructivism and do not usually address concerns that are not related to practical application. A quick review of several key papers using SOLO over the last twenty years show an absence of theoretical positioning. It can therefore be considered a less theoretical, more practical descriptive methodology. SOLO remains in popular use today.

With ‘phenomenography’, the second methodological approach expanded on in this section, the focus is on categorising with respect to content rather than, as with SOLO, making judgements about quality or sophistication (Marton, 1981). Phenomenographic approaches have been used widely but are particularly prominent in science education research. The basic premise being that student responses or interviews are coded into categories that reflect the variety in the responses; similar responses are grouped together. The specific classification criteria may take on different forms, depending on the application, but are often part of a hierarchical or otherwise systematised structure. Marton explains it as ‘finding and systemizing of forms of thought in terms of which people interpret significant aspects of reality’ (Marton, 1981, p. 177). Again, as with SOLO, there is no explicit theoretical aspect to phenomenography (in educational research), although the acceptance and description of different ways of seeing embraces

both a subjectivist stance (people see things differently) and also accepts there is a reality (people are seeing things differently, but these things are real). Through being descriptive, phenomenographic studies in science education research need not explicitly refer even to these assumptions. It is such, through removing any unnecessary impediments to interpreting student responses that phenomenographic research has been a useful tool in revealing the spectrum of student understanding under certain conditions (Jones & Asensio, 2001; Richardson, 1999; Sharma, Millar, Smith, & Sefton, 2004; Stefani & Tsaparlis, 2009). An example of how the phenomenographic approach is used in thermodynamics is shown below, where the question related to the final temperature of liquid in a group of Styrofoam cups (Figure 3-7).

Figure 3-7 An excerpt from a phenomenographic analysis (Georgiou, 2009)



Both the SOLO and phenomenographic approaches to coding work within certain conditions. Firstly, there is the ambiguity of assigning meaning to student responses. This is an oft repeated criticism that has not been satisfactorily addressed. The more

comprehensive the student's response, the more likely the researcher is interpreting the response legitimately, however, many analyses look to cover a few concepts in as efficient a time period as possible, meaning they must make value judgements about what the students mean. This is particularly difficult when researchers have some idea of what they are looking for. Using a SOLO taxonomy also becomes problematic when student responses to particular questions cannot be easily classified. That is, if levels of sophistication are not readily ascertained (Chan et al., 2002; Chick, 1998). Particularly common, surprisingly, is the mistaking of the extended abstract with the pre-structural levels (Chan et al., 2002). Phenomenographic analyses can also greatly underestimate the nuances in the data, particularly as responses are often assigned to only one category (Richardson, 1999). Interrater reliability, the name given to the agreement between different coders on coding categories, is also dependent on the sometimes arbitrary correct selection of 'high' or 'low' levels of reliability (Anderson, Mitchell, & Osgood, 2008).

Although each of these approaches became more and more sophisticated over time, the sophistication was in the mechanics of the method, rather than the understanding of it. This paucity in epistemological or theoretical discussion is arguably the basis of the more general and tenacious criticisms of these practices. For example, more often than not, the methods mentioned above are arbitrarily adapted to each specific context such that it is difficult to see what makes this a SOLO or phenomenographic approach. That is, what aspects of the methodology may be changed such that it retains its integrity? There also exists a somewhat blurry boundary between research methods and pedagogical methods. For example, the SOLO approach is considered meaningful only when longitudinal analyses are utilised, or if sample sizes are large, such that it is legitimate to generalise about a particular level of sophistication. Most recently, studies use SOLO to assign solitary student responses in categories, neglecting the research on the tenacity and flexibility of student's ideas. This is particularly the case in classroom practice³.

³ The Essential Secondary Science Assessment in New South Wales, for example, is based on the SOLO taxonomy

The clearest advantage that these approaches have on most other coding in PER (particularly multiple choice diagnostics) is that they refer to a conceptual framework. Like the use of the framework involving Piagetian developmental stages or Bloom's taxonomy, the shared language allows communication across different contexts and times. This is preferable to the alternative, where researchers will code ad hoc within the context of the individual study (Otero & Harlow, 2009). Ultimately, there is a trade off between describing the individual study and translating findings across studies. In short, supporters assert that it is beneficial to qualitatively summarise conceptions with some structure and consistency, whilst its critics object to the vagueness of the method (Ashworth & Lucas, 1998).

3.4 Limitations- remaining questions

Academic and public sentiment on educational research, science education research included, gives the sense of a field in disarray (Constas & Ripple, 1987; Riding & Wheldall, 1981). It is argued, on the one hand, that the research agenda has resulted in widespread reform and improvement and on the other, just as persuasively, that there is a lack of convincing evidence for any pervasive positive outcomes at all (Duschl, 1988; Lather, 2004). Pleas for the 'integration' of miscellaneous factions are abundant and persistent (Galton, 2000; Yslas Velez, 1996) and there are unsettled disputes within the field on whether the focus should reside more on local improvements in instructional practices or 'basic' research into teaching and learning. These persistent and legitimate criticisms should not continue to be ignored, particularly in research areas that have reached somewhat of a plateau.

As far as conceptions research goes, several important and persistent criticisms should be considered more deeply. Specific criticism towards the conceptions and conceptual change movement include that it is predominately deficit-driven, focusing on what students do not know and are not able to do and that it is overly simplistic in that it focuses on unitary, fixed conceptions (Bauer, 2013; Stark, 2002). Catalogues of misconceptions have been likened to ‘stamp collecting’ thereby exhibiting very low interpretive power (Caravita & Halldén, 1994).

More generally, the field’s theoretical basis of constructivism has also attracted significant criticism for having ‘low precision’ and not being clearly defined. Solomon argues that although the language of constructivism has allowed a functional and productive research field, he warns that “if constructivism obscures other perspectives, either by its popularity or its blandness –that could be damaging.” (Solomon, 1994, p. 17). Some have considered constructivism much more damaging, particularly in terms of constructivist teaching or instructional programmes, due to it being detached from any theoretical meaning (Matthews, 1994; Sjoberg, 2007). Driver and Easley (1978) appreciated these weaknesses (problem with teaching or with constructivism as a coherent framework) when they published their seminal article and it does not seem time has developed a suitable response. Furthermore, the ideological conflicts also pose a problem. Sjoberg explains: “It seems to distinguish the good guys (constructivists) from the bad guys (traditionalists)” (p. 1).

One example to illustrate the charge of triviality against the constructivist movement is to consider the trends within the conceptions research in science education. In describing student’s ideas, the embrace of constructivism signalled a rejection of positivism for a sort of relativism. Student’s ideas were considered more valuable than before and the cataloguing of misconceptions was considered obsolescent. Years on, constructivism is referred to more as a convenient scaffold necessary for publication, rather than a meaningful theoretical basis of knowledge construction. Studies released just this year, for example, still discuss misconceptions as a collection of ideas; the

various alternative terminologies intended to highlight the shift away from positivism are now referred to as inconveniences:

For this study, the term ‘misconception’ (also termed in the literature as alternative conceptions, alternative frameworks, alternative ideas, conceptual misunderstandings, conceptual prisms, erroneous ideas, errors, false ideas, incomplete or naive notions, intuitive notions, mistakes, misunderstanding, non-scientific beliefs, oversimplifications, preconceived notions, preconceptions and untutored beliefs) was broadly applied to any belief which is contrary to current scientific understanding regarding the topic (Francek, 2013, p. 33).

In this particular case, either the positivist-relativist dichotomy implied by constructivism was not seen as relevant, or constructivism in itself did not provide strong enough boundaries to frame the study of conceptions. Any development here has been limited to the particular concept area that is being investigated, rather than development of the theoretical basis of the study of misconceptions themselves. This can only end in endless refinements of conceptual surveys that identify or confirm or reject the existence of misconceptions, and reduce the conceptions research to stamp collecting once more –despite these misconceptions being shown to be manifold and dynamic.

Some consider the general lack of theory in science education research amongst its most serious limitations (Fensham, 2004; Usher, 1996). Joining Redish in arguing for theoretical deference in PER specifically, Reif (2000) asserts that any significant progress in the field is entirely dependent on stronger frameworks. Due to the positivist/empiricist influence of scientific research on science education research, theoretical, and particularly epistemological, considerations are not as emphasised as in other educational research fields. Fensham, for example, in interviewing over 80 influential science education researchers, states that they “carry out their studies in ways that suggest that theory has little importance for them. If they do use the word, it tends to be as a source of descriptors for their findings, rather than as something

beyond the findings that their studies are designed to refine or refute” (p. 80). He also states that science education relies on borrowed theories (usually from cognitive science and psychology) with which researchers superimpose concepts onto their data. He believes this provides nothing more than a descriptive framework that does not develop over time. Fensham explains that this is because science education researchers are ill equipped to deal with epistemological or theoretical considerations, as most come from scientific backgrounds, from being researchers for a significant period before turning to educational research. In many cases, they have not been exposed to the ‘humanities’. Referring to Posner et al.’s (Posner, Strike, Hewson, & Gertzog, 1982) conceptual change model specifically, Fensham explains that “it served for them as a useful frame to discuss the findings of their own studies, but in no sense were they trying to extend, test or redefine its features” (p. 111). Many researchers themselves attest that they are ‘agnostic about a theoretical stance’, and even contest that theoretical dispositions are a disadvantage (Otero & Harlow, 2009, p. 43). Some have even argued that the broadening of research to embrace social (and other) theories betrayed the ‘base’; to service practitioners (Cummings, 2013).

Furthermore, between science education researchers and other social researchers there exists some divergence, meaning developments across the different fields are not likely to provide utility outside of the field in which they were produced. Cummings states that as part of her commissioned report into PER, several key researchers expressed:

that they sensed social scientists had (and perhaps still have) little respect for the work done in the field of PER believing that physics education researchers ignore the work of social scientists, PERs’ methods are crude or our choices of topics are superficial (p. 7).

One does not have to look very far to discover that ‘the work of social scientists’ does not feature prominently in PER studies either. Matthews, for example, laments the time it has taken for even the history and philosophy of science to inform science education endeavours (Matthews, 1994). One specific issue that will be foregrounded

from this discussion is that of ‘knowledge blindness’, which will be explained in the following section.

3.4.1 Knowledge blindness

Joseph Schwab (1978) described a heuristic for the study of science education, which he called ‘commonplaces’. Schwab’s original four commonplaces comprised the teacher, student, subject matter, and milieu (environment), which he emphasised as equally important:

None of these can be omitted without omitting a vital factor in educational thought and practice. No one of them may be allowed to dominate the deliberation unless that domination is conscious and capable of defense in terms of the circumstances. (1978, p. 371)

Helms and Carlone (1999) suggested Schwab’s heuristic “provides the opportunity to meld perspectives from metascience disciplines and science education to connect theory and practice” (1999, p. 242) and could improve understanding of classroom practices. However, as yet, not all four commonplaces have received equal attention in science education research. As mentioned above, ‘the student’ and ‘the teacher’ have been the focus of considerable and sustained research; student conceptions and instructional strategies have been dominant objects of study for the field. The ‘milieu’ has come to increasing prominence since the 1970s with the rise of sociocultural theories. ‘Subject matter’, however, remains relatively underexplored - it is a ‘commonplace’ that is rarely discussed.

This ‘knowledge-blindness’ is not confined to science education research - it reflects a wider ‘subjectivist doxa’ in educational research (Maton, 2014, pp. 3-8). Since the late 1990s a growing number of ‘social realists’ (Maton, 2010; Maton & Moore, 2010; Moore, 2009; Wheelahan, 2012) have argued that knowledge has been largely neglected by educational research, thanks to a “widespread belief that ‘knowledge’ entirely comprises a state of mind, consciousness or a disposition to act, is wholly sensory in

source, and must be inextricably associated with a knowing subject” (Maton, 2014, p. 4).

They highlight that psychologically-influenced approaches typically focus on students’ learning processes, and sociologically-influenced approaches typically foreground how students’ experiences are shaped by power relations (whether with the teacher or within the milieu). Both thereby tend to foreground the knowing of knowers and background knowledge; both obscure the nature of what is being learned, treating knowledge itself as homogeneous and neutral. Knowledge as an object of study emergent from but irreducible to the ways and contexts in which individuals or groups know has been largely obscured. In contrast, social realists highlight a growing body of work (see below) that reveals how different forms of knowledge have effects, including on the foci of other ‘commonplaces’. Student learning outcomes, for example, are formed through interactions not simply with a phenomenon but also (and often only) with existing knowledge of different kinds – commonsense knowledge, popular forms of scientific knowledge, educational knowledge – and the forms taken by these knowledges help shape students’ understandings (Maton, 2013; Maton, 2014).

Typically, in PER, ‘subject matter’ considerations have been displaced by the ‘student’. Consider, for example, ‘epistemological framing’ as described by the RF. In it, the “student’s perception or judgement (unconscious or conscious) as to what class of tools and skills are appropriate in a given context” (Redish & Bing, 2009, p. 1) is highlighted. It is shown that student’s ideas about the nature of scientific knowledge, such as being “fixed and absolute or as being relative to one’s point of view” (2009, p. 3) influence how a student approaches instructional tasks. This work valuably foregrounds differences in the forms taken by student conceptions of knowledge. However, were this to be equated with (rather than complemented by) conceptualisation of the knowledge itself, an understanding of ‘subject matter’ would be reduced to analysing ‘the student’.

As a further example, Redish, in defining an ‘epistemic form’ as “an external structure or representation and the cognitive tools to manipulate and interpret that structure” (p. 30) goes on to say that “when I refer to an epistemic form, I really mean the cognitive structures that we possess for using and interpreting the results of manipulating the structures” (p. 31). Again, this focus remains on the ‘subjective’ knowledge of the individual, forgoing the opportunity to examine how characteristics of these external structures guide individual cognition.

Even if such a view is extended to embrace knowledge as well as knowing, this first step requires developing further to overcome the tendency of existing models towards an undifferentiated and often atomistic image of science knowledge. For example, diSessa (1993) foregrounds pieces of knowledge in physics that students believe are an irreducible feature of reality (p-prims). Leaving aside this focus on students’ understanding, the p-prims themselves are homogeneous in form and science education is reductively conceived as the sum of learning individual parts. In the RF, the homogeneity of the form taken by p-prims is differentiated into two types of knowledge (the abstract primitive and the more concrete facet) that have distinct functions for explaining the natural world. It is clear that organising knowledge in terms of context dependence rather than discrete atomistic categories reduces the ‘number of parts’, but it is unclear why this should mean only two levels of context-dependency are considered.

While pointing in the right direction, therefore, these models require development to overcome the limits of the *kind of theorising* such approaches embody. Typologies, including Bloom’s (Bloom, 1976; Krathwohl, 2002), ‘PCK’ (Shulman, 1986) and such widely-used but ill-defined dichotomies as abstract/concrete, struggle to capture both empirical practices, which rarely fit within their lists of types, and processes of change within and between types. They thus need to be developed to conceptualize the organizing principles that generate diverse types of knowledge practices.

Although the science education literature does not necessarily focus on knowledge in the theoretical or empirical sense, there is a persistent reference and appreciation for the effects of knowledge on the teaching and learning of physics. Solomon explains that “formal over-arching knowledge systems, such as science or jurisprudence” are “at almost the opposite pole to lifeworld knowing” and should both exist simultaneously in the student’s minds (Solomon, 1994). Posner et al., express in their seminal conceptual change model paper, that it is the student’s “separation between ‘physics’ and ‘the real world’ that prevents their making conceptual changes (Posner et al., 1982, p. 206). Instead of meaningful learning, students simply learn to play the game of physics, however disconnected its rules are. Caravita et al., add that in “mastering ‘playing the game of physics... the students must first become aware of what kind of game they are playing’” (Caravita & Halldén, 1994, p. 109). Even more explicitly, Taber supports the general promotion of the difference between an individual’s knowledge structure and that of the discipline, citing both Gilbert and Watts and Phillips (Taber, 2009).

Henri Poincaré (1985, quoted in Scribner, 1963) summarises the sentiment in these views in his description that science is no more a collection of primitive parts than a house is a pile of bricks – scientific knowledge embodies an architecture based on organising principles. It is apprenticeship into these organising principles as much as, if not more than learning specific atomic propositions that comprises the work of science education.

Maton calls these references a ‘call to arms’ and points out that although the significance of knowledge is accentuated, the elusiveness of an appropriate means for analysis does not encourage anything further (2014). Morais similarly points out that the level of functionality of theory to service analysis of empirical practice (and vice versa) affects the ‘order’ in a field. They note that the current ‘disorder’ is “partially responsible for the rejection of sociological by many educators” (Morais, 2002, p. 564), and go on to cite science educators specifically. That is, there are many approaches that are not being considered by educators and researchers because there is not an appropriate means for analysis.

Solomon finally adds that all perspectives, theoretical or otherwise, are important, as no single perspective is likely to provide a full picture of science education (Solomon, 1994).

Legitimation Code Theory addresses these limitations in both its focus on the organising principles of knowledge, and in providing a means for analysis. The relevant tenets of the theory as well as the methodological toolkit utilized in this project are provided in the next section.

3.5 A New Theory

3.5.1 Legitimation Code Theory

Legitimation Code Theory (LCT) is an explanatory framework for analysing and changing practice. It forms a core part of social realism, a broad ‘coalition’ of approaches which reveal knowledge as both socially produced and real, in the sense of having effects, and which explore those effects (Maton, 2014; Maton & Moore, 2010). LCT extends and integrates ideas from a range of theories, most centrally the frameworks of Pierre Bourdieu and Basil Bernstein.

This ongoing theoretical development is in close relation with empirical research. LCT is a practical approach and designed to be an open-ended endeavour that foresees its own repeated refinement, deepening and extension through substantive studies (Maton, 2014). The framework is rapidly growing as a basis for empirical research into education at all institutional levels and across the disciplinary map – from primary schools to universities, from physics to jazz – in a widening range of national contexts, as well as beyond education (Maton, Hood & Shay, 2014)⁴. The framework of LCT comprises a multi-dimensional conceptual toolkit, where each dimension offers concepts for analysing different organizing principles underlying practices.

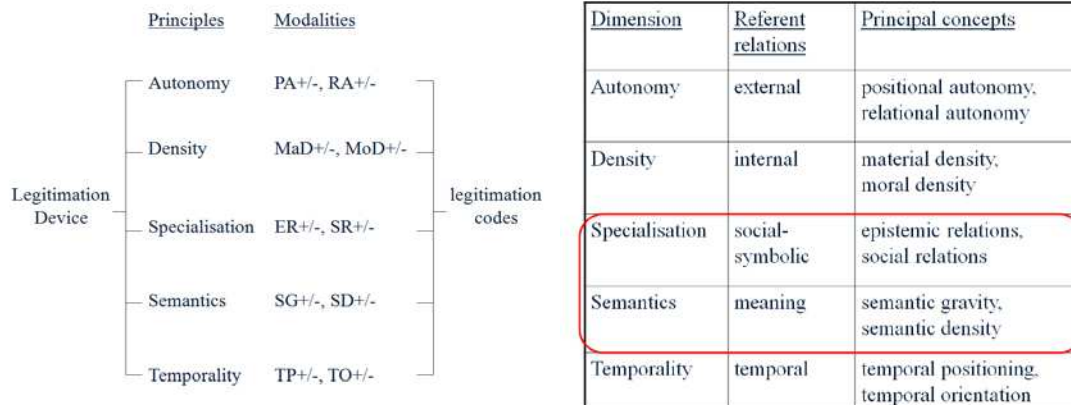
⁴ Numerous examples of this body of work can be found at the LCT website: <http://www.legitimationcodetheory.com>

Maton explains further:

Each field has its own distinctive ways of working, resources and forms of status that are specific in terms of their realizations yet similar in terms of their underlying generative principles. Within each field actors cooperate and struggle to maximize their relational positions in its hierarchies by striving both to attain more of that which defines achievement and to shape what is defined as achievement to match their own practices. LCT highlights that actors' practices thereby represent competing claims to legitimacy, whether explicit or tacit (such as routinized ways of working) - they are languages of legitimation. These strategies to shape the 'rules of the game' are themselves shaped by relations between actors' dispositions (which are in turn shaped by previous and ongoing experiences in fields) and the current structure of the field. The organizing principles of dispositions, practices and fields are conceptualized by LCT in terms of legitimation codes, each 'code' representing in effect a currency proposed by actors as the ruler of the field. (Maton, 2014, Ch. 1)

The framework has five dimensions (Figure 3-8) only two of which will be mentioned here; Specialization and Semantics. Within Specialization, we work with Specialization codes and within Semantics, semantic codes.

Figure 3-8 The five dimensions of Legitimation Code Theory. This research focuses on Specialization and Semantics.



3.5.2 LCT(Specialization)

Specialization is concerned with what makes something distinct, or ‘special’, or in educational contexts: how knowledge comes to be legitimate. In simpler terms, how you come to ‘know’ in a particular field. Specialization has its roots in Bernstein’s descriptions of different discourses; it is a dimension in LCT that extends the Bernsteinian concept of ‘knowledge structures’. Bernstein highlights the relationship between ‘knowledge structures’ (like science), the ‘recontextualisation’ (like curriculum) and ‘reproduction’ (as in pedagogy and evaluation). These ideas are further explicated in Luckett (2012). Bernstein described the discourse of teaching/education (the vertical discourse) as consisting of ‘hierarchical’ and ‘horizontal’ knowledge structures (1999). There is a second discourse that refers to common-sense, everyday knowledge that is “likely to be oral, context dependent and specific, tacit, multilayered and contradictory across but not within contexts” (Bernstein, 1999, p. 159). The distinction between these two discourses has been recognised in science education research, as there is often the discussion around how ‘commonsense’ notions may interfere with scientific ones. Bernstein notes that these two discourses have very different characteristics and consequences.

Within the vertical discourse, which deals with theoretical bodies of knowledge organised in disciplinary fields, there is a further distinction: two knowledge structures which are entitled ‘hierarchical’ and ‘horizontal’. A hierarchical knowledge structure,

such as physics “...attempts to create very general propositions and theories, which integrate knowledge at lower levels, and in this way show underlying uniformities across an expanding range of apparently different phenomena” (p.162). The actors within hierarchical knowledge structures are thus motivated toward achieving the goal of greater integration.

Horizontal knowledge structures such as the humanities “consist of a series of specialised languages with specialised modes of interrogation and criteria for the construction and circulation of texts” (p.162). The different modes in literary criticism, for example, include Feminism, Modernism, Structuralism, Post- colonialism etc. and it is clear that these distinct modes do not aim towards integration and in many cases have incommensurable philosophies.

The focus with LCT goes beyond broadly describing characteristics of knowledge structures to revealing the ‘codes’ using a specific ‘language of legitimation’ in an effort to understand practices. The basis of legitimation is emphasised differently between fields, through relative strengths of relations between practices and their objects of study, ‘epistemic relations’, and relations between practices and their subject, ‘social relations’. Quantifying the combinations of these relations for a practice gives you ‘legitimation codes’ or the structuring principles of knowledge claims and practices.

Maton explains:

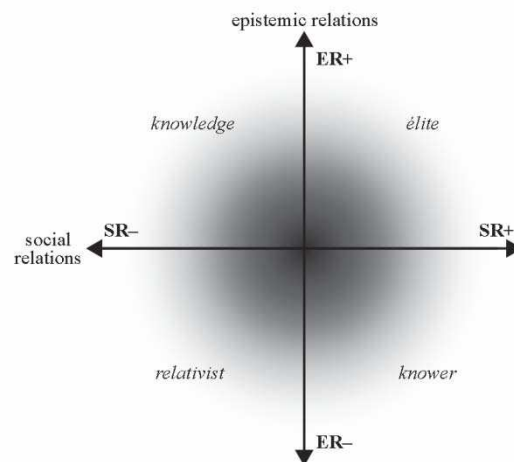
‘Specialization’ is the dimension conceptualizes languages of legitimation in terms of both relations within and relations to practices. Put another way, it highlights that every practice, belief or knowledge claim is about or oriented towards something and by someone. One can, therefore, analytically distinguish:

epistemic relations: between socio-cultural practices and their object or focus (that part of the world towards which practices are oriented);
and

social relations: between socio-cultural practices and their subject, author or actor (who is undertaking actions or making claims to knowledge).

In knowledge claims, these are realized as: epistemic relations between knowledge and its proclaimed object of study; and social relations between knowledge and its author or subject. (Maton, 2014, Ch. 2)

Figure 3-9 Specialization codes in LCT



Epistemic relations can be stronger or weaker (ER+, ER-). A stronger epistemic relation is characterised by strong boundaries between contexts, stronger control over these boundaries and over the focus within them. Working in a classroom to learn physics from a teacher exhibits strong boundaries; you know you are ‘doing’ physics. If the teacher dictates *how* you are doing physics, the activities, exercises etc, then you also have stronger control of the focus. The opposite would be true for weaker epistemic relations; you would not be so sure about exactly what you are studying and the focus is not set. Social relations can also be stronger or weaker (SR+, SR-), where stronger social relations indicate stronger boundaries over who claims knowledge in a field. If the ‘who’ is important, as in sociology or modern art, we have stronger social relations, if the ‘who’ is not important, if anyone can ‘know’, then social relations are weak. With reference to Figure 3-9, four Legitimation codes of Specialization can be described. The *knowledge code* (SR-, ER+) exhibits strong epistemic relations and weak social relations, knowing the procedures and having specialised knowledge is the

basis of achievement and the individuals are downplayed (e.g., physics). A *knower code* (SR+, ER-) emphasises the attributes of the individual and the knowledge and procedures are less important (as found in standpoint theories such as feminism). An *elite code* (SR+, ER+) indicates you must know the right procedures and knowledge but also be the right kind of knower (as found in architecture) and a *relativist code* (SR-, ER-) de-emphasises both (anything goes).

An example will help to show how this conceptualisation brings clarity to educational issues. Lamont and Maton (2008, 2010) examine the reasons for the low uptake for high school music studies in England. Despite changing assessment practices and including popular music, only 10% of the school population choose to continue their music studies at Stage 4 (14+). Using the specialization codes of LCT to examine curricular material, the authors explain that primary school music exhibits a ‘knower code’, as “achievement is defined in terms of pupils capacity to express themselves rather than demonstrate skills or knowledge” (2010, p. 69). As students move to the first three years of high school, they experience a ‘knowledge code’ as “aptitude, attitude and personal engagement are downplayed in favour of the demonstration of musical skills and knowledge and (there is) an emphasis on the formal elements of music and critical thinking”. At the next level, Lamont and Maton claim students are faced with an ‘elite code’, “requiring pupils to demonstrate both their capacity for personal expression and aesthetic sensitivity and their musical knowledge and technical skills.”

The framework thereby provided a means of characterizing the basis of achievement at different levels, highlighting code shifts through the curriculum (p. 69).

The study goes on to claim, through the empirical analysis, that the code shift that proved most problematic was the second: from the knowledge code to the elite code.

Although physics is assumed to be the archetypal ‘knowledge code’, very few researchers actually study physics empirically and the impact code clashes or shifts have on students of physics is so far underexplored.

3.5.3 LCT(Semantics)

The LCT dimension of Semantics constructs social fields of practice as ‘semantic structures’, whose organizing principles are conceptualized as ‘semantic codes’. Semantic gravity, which is the central analytical method underpinning this thesis, is part of the semantic codes of LCT, together with semantic density. As Maton describes it:

Semantic gravity (SG) refers to the degree to which meaning relates to its context. Semantic gravity may be relatively stronger (+) or weaker (-) along a continuum of strengths. The stronger the semantic gravity (SG+), the more meaning is dependent on its context; the weaker the semantic gravity (SG-), the less dependent meaning is on its context. All meanings relate to a context of some kind; semantic gravity conceptualizes how much they depend on that context to make sense.”

Semantic density (SD) refers to the degree of condensation of meaning within sociocultural practices, whether these comprise symbols, terms, concepts, phrases, expressions, gestures, clothing, etc. Semantic density may be relatively stronger (+) or weaker (-) along a continuum of strengths. The stronger the semantic density (SD+), the more meanings are condensed within practices; the weaker the semantic density (SD-), the less meanings are condensed. (The nature of these meanings, which may comprise formal definitions, empirical descriptions, feelings, political sensibilities, taste, values, morals, affiliations, etc., is analysed using other concepts (2008, p. 10).

Essentially, semantic gravity characterizes degrees of context dependence⁵. Unlike typological conceptions of knowledge, the notion of ‘semantic gravity’ is not a homogeneous box into which variegated and changing practices are to be reduced. Rather, all practices are characterised by semantic gravity, the difference lies in their relative strengths. Thus the concept represents a continuum allowing both for infinite gradation among practices and for tracing change within practices over time. Dynamising the continuum captures *weakening semantic gravity*, such as moving from the concrete particulars of a specific case towards generalizations and abstractions whose meanings are less dependent on that context; and *strengthening semantic gravity*, such as moving from abstract or generalized ideas towards concrete and delimited cases (Maton, 2013, p. 11). One can also describe the *gravity range* of practices (the difference between their strongest and weakest strengths) and the *gravity profile* that changes in strengths trace over time (Maton, 2014, Ch. 3).

3.5.4 The ‘external language of description’

This flexibility in the use of the concepts does not occur at the expense of empirical precision. LCT includes the notion of developing an ‘external language of description’, or means for translating between concepts and empirical data that show how concepts are realised within the specific object of study being explored (Chen, 2014). For example, an external language of description for ‘semantic gravity’ defines what is meant by ‘context’ and how relative strengths are determined in the data under analysis. Studies in LCT therefore have a way of ‘speaking to each other’; with the community very coherent and regular meetings constructive despite the range of disciplines or subject areas covered and methods are quantitative or qualitative, with no need for either to be valued more than the other⁶.

⁵ Context dependence when used in science education is usually an issue that is related to the lack of stability of student understanding across contexts (Section 3.1.3). However, this is not what context dependence refers to within the LCT framework.

⁶ See legitimationcodetheory.com for information about symposia

It should be emphasised that ‘semantic gravity’ is not the only concept in the dimension of Semantics, and Semantics is not the only dimension of LCT. Our illustrative focus on one small part of the framework is for the sake of brevity. Nonetheless, this concept is being widely adopted in studies of education, including biology and history (Martin & Maton, 2013), design (Shay & Steyn, 2014), engineering (Wolff & Luckett, 2013), environmental science (Tan, 2013), jazz (Martin, 2012), journalism (Kilpert & Shay, 2013), and teacher education (Shalem & Slonimsky, 2010). As this suggests, LCT concepts such as ‘semantic gravity’ have wide applicability, enabling research into knowledge practices in diverse contexts to cumulatively build on one another. Within LCT, studies of science inform and are informed by studies of the arts and humanities, as well as informal learning contexts, such as museums (Carvalho, 2014).

4 Context

4.1 Australian context

Australia's educational system is comprised of three broad but distinct types of school; 71% Public (government), 18% Catholic and 11% Independent (including secular and non-Catholic-religiously-affiliated schools) that are classified primarily with respect to sources of funding. Public schools are inclusive and fully funded by the government whilst Catholic and Independent schools are partly privately-funded, with Independent schools generally attracting much higher fees than Catholic. The Australian constitution requires that the states and territories are responsible for delivering schooling to children of school age. Each of the eight states or territories is therefore responsible for the operation and regulation of schools within their jurisdiction, including the provision of a syllabus. The states have until now enjoyed autonomy in this provision but from 2013 onwards will be required to base their respective syllabi on a new national Australian Curriculum. Australia performs relatively well on international standardised testing, ranking in the top ten for reading, science and mathematics (PISA, 2009). However, there is much disparity between the eight states and territories (ACARA, 2012).

The New South Wales Board of Studies (BoS) is the bureaucratic unit responsible for the state of New South Wales (NSW) and is the largest in the country. Most students attending The University of Sydney have completed the NSW course set out by the BoS, which included the year ten School Certificate (this award is now abolished) and the Higher School Certificate (HSC), which is the award on which university entrance is determined. A brief explanation of the relevant aspects of the NSW program is provided below.

4.1.1 Year 10 School certificate

Secondary education in NSW covers academic years seven through to twelve. Students begin year seven at the age of 12 or 13. Years seven and eight are known collectively as stage four, and stage five therefore covers years nine and ten. The outcomes of each stage may be covered any time during the respective two year period and at the end of year ten, students sit a state-wide exam in English, Mathematics and Science known as the School Certificate which is based on the content covered during stage five. Since schooling is compulsory until this stage, potentially all of students in the state will have completed the School Certificate course.

Throughout this junior high school period, although energy concepts appear throughout, the one direct reference to thermodynamics (or, more appropriately, thermal physics) concepts is the following: *4.6.6 heat energy a) identify processes of heat transfer by conduction, convection and radiation* (New South Wales Board of Studies, 2003). See also Supplementary Materials.

4.1.2 Teacher survey

As this investigation was to focus on thermodynamics concepts, given the paucity of thermal physics content in the junior science syllabus and the absence of it in year twelve physics, a small-scale examination on the nature of the delivery of this content was undertaken to provide insight into the baseline thermal physics experience of the first year university students at the University of Sydney (Usyd). The results of this investigation were not used as part of the quantitative aspect of this study but are nonetheless provided for illustrative purposes. Given the influence of the individual teacher and their acting as somewhat of a reflection of the general practices of school science departments, this small scale study is valuable for providing a sense of the quality and quantity of school driven thermal physics instruction experienced by Usyd first year Physics students.

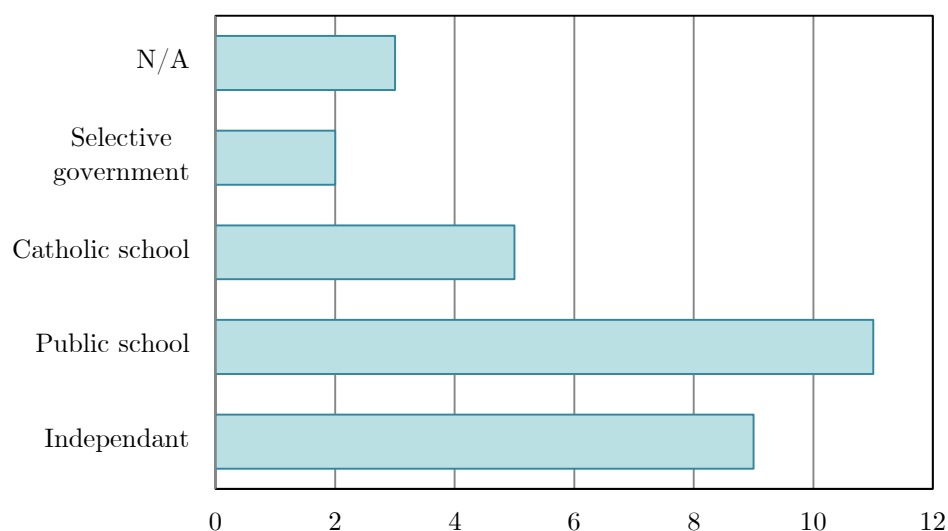
The teacher survey was administered through online Google Docs and by pen and paper to a variety of high school junior science teachers currently teaching in NSW.

The survey included questions aimed to reveal some details about curriculum implementation in science during a compulsory educational stage⁷. The full survey can be found in Appendix A.

The survey had three main sections; the first was demographic, the second focused on opinions about the current teaching of science in NSW and on the new Australian National Curriculum: Science and the final focused on the teaching of thermal physics specifically.

Sample: In total, 30 junior science high school teachers completed the survey. The

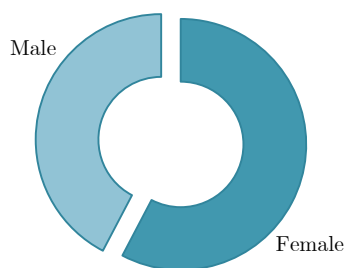
Figure 4-1 a. The sample consisted of a higher ratio of Independent school to Public school and is therefore not representative of the state; however, all types of schools are present in the sample.



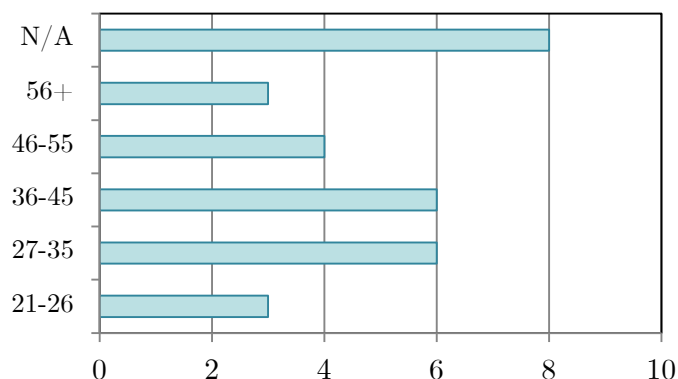
survey was published online, advertised at a local conference, on Twitter and through colleagues that had a connection to the SUPER group. Demographics are presented in Figure 4-1 (a-c).

⁷ The survey is still available to complete online by junior science teachers in NSW and can be found at: <https://spreadsheets.google.com/spreadsheet/viewform?formkey=dEZXTU5ZZ2plZzRQSmcwNlZyaC1sbVE6MQ>.

b. Gender of Participants



c. Age of Participants



Results: Questions one and two related to the teachers' impression of how much of their time was spent on the different science topics they taught. The science topics were the same for both questions. Teachers could select more than one option although most selected four, which was the suggestion made in the question. Questions one and two are provided below.

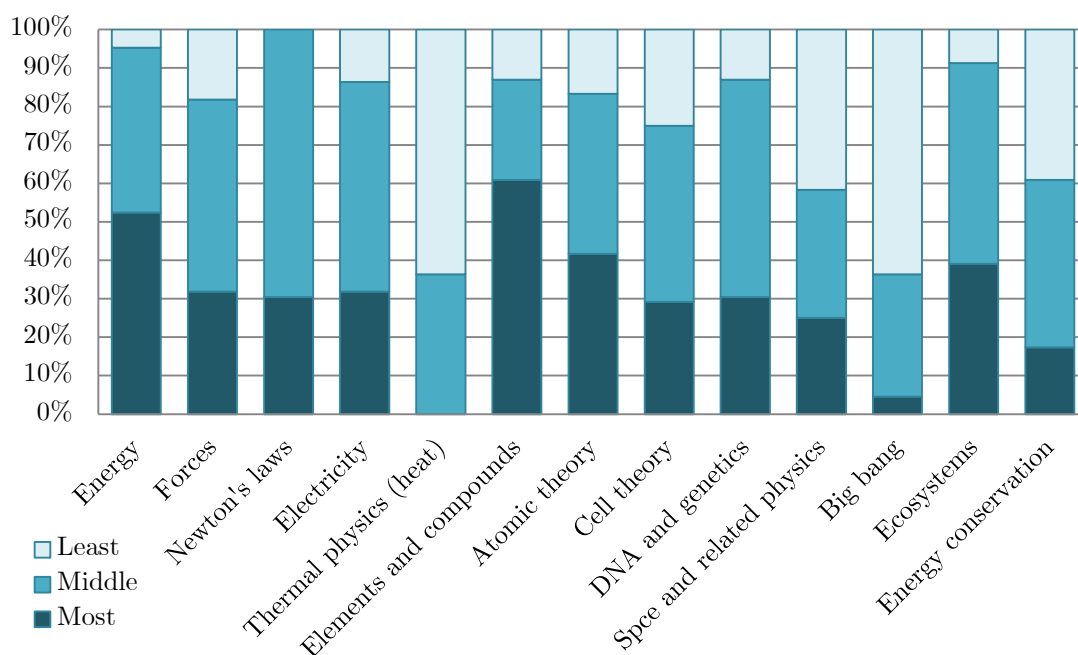
Question 1: Select about four of the following topic areas of junior science (years 7-10) that you instinctively feel you spend the **most** time on during the entire course

Question 2: Select about four of the following topic areas of junior science (years 7-10) that you instinctively feel you spend the **least** time on during the entire course

List (tick boxes): Energy, Forces, Newton's Laws, Electricity, Thermal physics (heat), Elements and compounds, atomic theory, cell theory, DNA and genetics, Space and related physics, Big Bang, Ecosystems, energy conservation, other (free response)

Responses are summarised in Figure 4-2. Three responses were added to the 'other' category for Question one for the most time spent on one topic. These all related to the scientific method and investigations work. Geology was added by one teacher for Question two, for the least time spent on a topic.

Figure 4-2 Teachers' reports of subjects with most and least coverage during junior high school science



Thermal physics was reported to be the least covered in the junior curriculum, followed closely by the Big Bang. Teachers felt they spent the most time teaching chemistry topics (elements and compounds), followed closely by energy concepts.

The next question related to the amount of time spent on thermal physics in stages four and five:

Question 7: How much time would you usually allocate for the statement provided above from the stage 4/5 syllabus?

The average time taken by the 30 respondents was exactly 3 hours, with the vast majority reporting three hours and a small number reporting both two and four.

The next question was an attempt to probe which topics beyond the 'three methods of heat transfer' stipulated in the syllabus were covered during the coverage of thermal physics topics. Question ten is provided below.

Question 10: There are many concepts related to this topic that are not listed in the syllabus. Place a tick next to the ones you have had time to teach when teaching 4.6.6 heat energy.

List (tick boxes): The scientific definition of temperature and the different temperature scales (Celsius, Fahrenheit and Kelvin), The scientific definition of heat as being energy in transit, the difference between heat and temperature and the ambiguity of the language used in science for these terms, thermal equilibrium (two bodies of different temperature exchanging energy until they are both at the same temperature), the particulate theory of matter, the microscopic picture of conductivity, that the hand is not a good thermometer (e.g., metals feeling cold compared to woods that are the same temperature), specific heat capacity, internal energy, entropy, Other (free response).

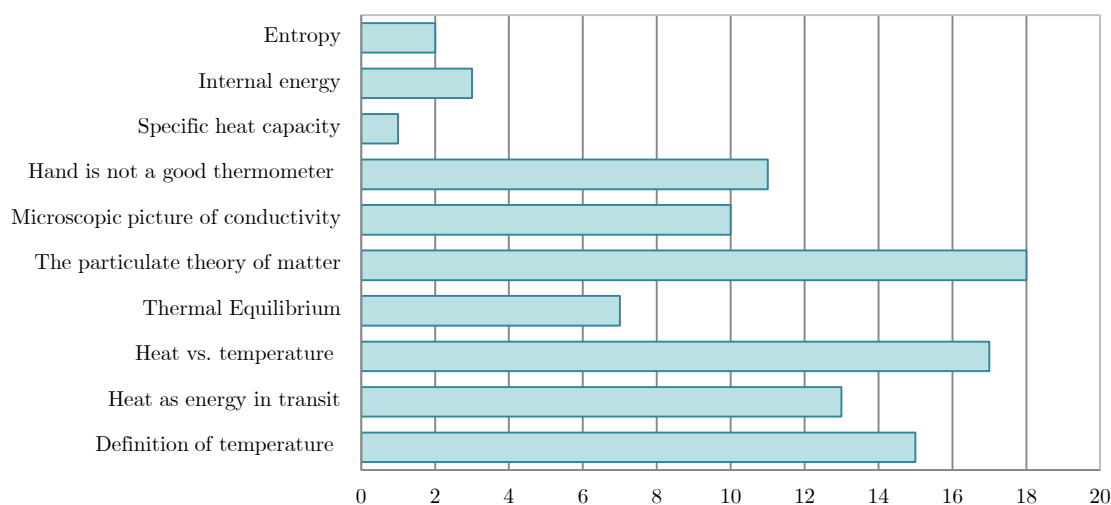
Many teachers reported covering these suggested options during their teaching on heat transfer. The most common additional concepts taught included the microscopic relationships or the particulate theory of matter (Figure 4-3). These concepts are stipulated under separate sections in the syllabus. Teachers also stated that they highlighted the difference between heat and temperature and defined heat as energy in transit, although the survey did not allow for elaboration on these assertions. No additional suggestions were made as part of the ‘other’ category.

Lastly, a question addressing the perceived importance of thermal physics was asked. Teachers were expected to make a selection between 1 and 5, 1 being ‘not important’ and 5 being ‘vital’.

Question 11: How important do you think thermal physics is to the scientific literacy of a student leaving high school?

The results show an average of 3.64 with no responses scoring less than three.

Figure 4-3 Common additional concepts covered in the teaching of thermal physics at the junior high school level



Discussion: The results from this survey paint a relatively clear picture about thermal physics instruction at the junior high school level. Despite teachers indicating that topics beyond heat transfer are covered (temperature, entropy, etc.), it is likely that due to time constraints, such concepts are not covered beyond the superficial level. This indicates that compulsory junior science instruction teamed with HSC Physics course instruction on average resulted in approximately three hours of formal school instruction for thermal physics concepts.

4.1.3 Year 12 Higher School Certificate

After Year Ten, students elect to continue to stage six, years 11 and 12, to complete the non-compulsory Higher School Certificate (HSC), an award designed to mediate entry into university. Students select their subjects, which have weightings known as ‘units’ where each unit corresponds to approximately 60 hours of classroom study per year. The minimum number of units required for completion of the Preliminary course (year 11) course is 12 and in year 12, the HSC course, only 10 units are counted towards the final grade. Assessments completed as part of the preliminary course are

not counted toward the HSC course, although to proceed, satisfactory completion of this course is a prerequisite. Students must study at least four different subjects and taking 2 unit English is compulsory. All science subjects are two units, these include: Physics, Chemistry, Biology and Earth and Environmental Science and Senior Science. Students receive a final grade, called the Australian Tertiary Admissions Rank (ATAR), which is an aggregate of 50% moderated school-based assessment and 50% final examination mark.

4.1.4 Physics

Although thermal physics is not explicitly covered in the Physics HSC course, the course objectives as stated by the BoS are provided below for illustration.

The Preliminary course incorporates the study of: The World Communicates, Electrical Energy in the Home, Moving About and The Cosmic Engine. The HSC course incorporates the study of: Space, Motors and Generators, From Ideas to Implementation and one option from the following list: Geophysics, Medical Physics, Astrophysics, From Quanta to Quarks, The Age of Silicon. These topics are contextual; they present physics content within the context of a general situation. Specific subject matter can be retrieved from the HSC syllabus document current to this study, also provided in the Supplementary Materials.

Table 4-1 shows the candidature for a selection of other HSC subjects, including all of the science subjects and gender participation for contextual comparison. Out of a total of 66,125 students receiving the HSC award (71,443 enrolled but not all fulfil the requirements for the final ATAR), 9,382 completed the Physics course in 2011 (a total of 13% of the candidature). Males dominate the study of Physics at the HSC level, 77% to 23% females.

Course Name	Male	Female	Total
Ancient History 2 unit	4983	7161	12144
Biology 2 unit	6466	10238	16704
Business Studies 2 unit	7500	7221	14721
Chemistry 2 unit	6050	4915	10965
English (Advanced) 2 unit	11252	15858	27110
English (Standard) 2 unit	17721	16663	34384
General Mathematics 2 unit	15610	16023	31633
Mathematics 2 unit	8854	7710	16564
Mathematics Ext 1 2 unit	5154	3670	8824
Physics 2 unit	7247	2135	9382
Total	34,505	36,938	71433

Table 4-1 A selection of HSC subjects completed and with respect to gender

4.2 The University and Physics

The University of Sydney is a research intensive metropolitan university with some 50,000 students. The number of students taking Physics at first year varies but each of the two years in which the study took place returned a sample of approximately $N=1200$. In the School of Physics, students enrol in one of three possible first year, first semester Physics courses based on their background or experience with physics in high school. The ‘Fundamentals’ course (approximately $N=250$) is designed for students who did not complete a high school Physics course (or performed very poorly in one) and wish to study physics out of interest or are required to study physics as part of their degree, as is the case with Bachelor of Medical Sciences. Despite no restrictions on this group for progression to a Physics major, these students rarely continue down this path. The ‘Regular’ course (approximately $N=500$) is designed for students who have studied and performed well in high school Physics and who may or may not continue to major in Physics. The ‘Advanced’ course (approximately $N=100$) is designed for students who have performed exceptionally well in high school Physics. These students are the most likely to progress to Physics majors.

4.3 The Regular course

The study was performed in Semester one of 2011 and 2012 with the Regular course which usually consists of Bachelor of Science, Medical Science or Engineering students. The students have little variation in university entrance rankings ($M=93$, $SD=5$), making this a relatively homogenous group. The Regular group was chosen primarily because thermodynamics was a module (the Fundamentals group does not study thermodynamics), and because it was the largest relatively homogenous group.

The Regular course consists of 13 teaching weeks and involves three one-hour lectures and one one-hour tutorial per week as well as eight three-hour laboratory sessions over the semester. The course contains three modules: mechanics, thermodynamics and oscillations and waves. The course assessment is by assignments (10%) through the online program Mastering Physics, tutorial attendance (2%), laboratory work (20%), an in-lab test (5%) and a final three hour examination (63%). The final examination consists of short and long response qualitative and quantitative questions (no multiple-choice).

As an incentive, an additional 2% was offered to the students above their overall assessment pro-rata for completing activities underpinning the study.

4.4 The non-lecture part of the course

4.4.1 *Workshop Tutorials*

The tutorials consist of problem solving in groups; ‘Workshop Tutorials’ as described in (Sharma et al., 2005) and Section 3.2.1. The tutorials generally involve class sizes of about 30-40 students and are facilitated by two teaching assistants. They contain demonstration equipment which the students may refer to during problem solving. Tutorial content follows as closely as possible to the previous weeks’ lecture content and therefore provides students with the opportunity to interactively engage with the lecture material outside of the lecture time. The three thermodynamics tutorial sheets may be found in Supplementary Materials.

Figure 4-4 One question (Question 2 from the qualitative section) from the first tutorial of the thermodynamics module

a. You are provided with a 10 kg person (!), a 10 kg block of copper, a bottle with 10 kg of ethanol, a container with 10 kg of water and a 10 kg lump of dry clay. Rank the materials in order of the most to least energy required to raise the temperature by 1°C. What assumptions are you making?

Material	Specific Heat Capacity ($\text{J.kg}^{-1}.\text{K}^{-1}$)
Human	3500
Copper	390
Ethanol	2428
Water	4190
Clay	920

b. It is often said that the presence of large amounts of water on the surface of the Earth has a moderating effect on daily temperature conditions. Thus it can get much warmer 50 km away from the coast in comparison to coastal areas. Why is this so?

c. It's a cold night and you fill a hot water bottle with hot water to keep your toes warm. Why is your hot water bottle able to keep warm for a long time?

Figure 4-4 (above) shows one typical tutorial question (of which there are usually two qualitative and two quantitative questions and one Demonstration question). The Demonstration questions in the Workshop Tutorials are based on equipment supplied to the tutorial room. Students rotate around the workstation which usually only consists of a single set of the equipment and corresponding worksheets.

Table 4-2 summarises the Demonstrations that the students would have experienced in the tutorials. Since the thermodynamics module spans three weeks, there were three thermodynamics-specific tutorials. Technicians' notes describing these Demonstrations are provided in the Supplementary Materials.

Tutorial	Demonstration
1. Heat and Temperature	Measuring temperature of air with and without a light source
2. Thermal properties of matter and the first law of thermodynamics	Water boiling below 100°C degrees in a syringe when reducing pressure The Drinking Bird Simulations
3. Processes and the Second law of thermodynamics	Stirling Engine Cyclic processes

Table 4-2 Demonstrations provided to students in workshop tutorial environment

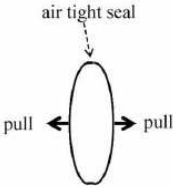
4.4.2 The final exam

A typical final exam question is provided for illustration (Figure 4-4). Note that Physics at Usyd is unusual in providing exams for Physics with no multiple choice questions at all. Usually, for thermodynamics, there are two 5 mark questions and one 10 mark question. One of the 5 mark questions is mostly conceptual; requiring little or no mathematics/quantitative calculations.

Figure 4-5 Exam question (Question 10, Semester 1, 2011). The exam is out of a total of 90 marks.

Question 10

Two identical slightly curved metal “Magdeburg” plates are placed rim to rim with airtight seals (as in the diagram) and the interior region is pumped down to a vacuum. The area of each plate is 1.5m^2 . This assembly is initially placed in air at 400K and at atmospheric pressure of $1.0 \times 10^5 \text{Pa}$.



(a) Explain qualitatively at a microscopic level (kinetic theory) why it is difficult to pull the plates apart.

(b) Calculate the force necessary to pull the two plates apart, approximating the curved plates as being flat.

A small puncture is then made through the seal and air at 400K is allowed to expand rapidly (adiabatically) into the region between the plates. The expanding air cools and then the metal plates cool.

(c) Explain physically why the expanding air cools and then the metal plates cool, referring to the changes in internal energy, work, and heat for the (ideal) gas.

(d) Explain why the entropy change of the expanding gas is zero.

(e) Consider the energy interchange between the air and metal plates as they come to equilibrium. Is the total entropy change greater than, equal to, or less than zero? Justify your answer by calculating the entropy change for an infinitesimal amount of heat dQ between the initially hotter plates and the air.

The entire assembly is now heated to 600K. The thermal radiation from the assembly is then observed and compared with the radiation observed when the temperature is 400K.

(f) By what factor does the overall energy flux of thermal radiation differ when $T = 600\text{K}$ rather than $T = 400\text{K}$. Assume that the assembly radiates as a blackbody.

(10 marks)

4.4.3 Mastering Physics assignment questions.

Students complete two of their six assignments (approximately 3% of a possible 10% for the assignment component of their total assessment) on thermodynamics with Mastering Physics, an online, Multiple Choice or Quantitative-type progress test software. The assignments are subject to copyright and cannot be expanded on in any further detail.

4.4.4 Laboratory work

There were no thermodynamics experiments in the laboratory course for Regular students in 2011 and 2012.

4.5 Lectures

Given that the students completed the same Mastering Physics assignments and engaged with the same questions and Demonstrations in the tutorials, we can confidently say that the most institution-driven variability in the course manifested itself in the lectures, where students were lectured in different ways by different lecturers with necessarily different dispositions (what the students do outside of the mandatory and supplied activities is beyond our control). The lecture slides and any other relevant material not subject to copyright restrictions may be found in the Supplementary Materials.

The thermodynamics module is a ten-lecture course that uses the textbook ‘Young and Freedman’s University Physics 12th Ed’ (Young & Freedman, 2007) and covers the topics outlined in Table 4-3. The ‘concepts covered’ column in this table contains the specific objectives, where the bolded concepts are expected to be mastered both qualitatively and quantitatively. Lecture numbers are approximate. The last lecture was set aside for students to complete the Thermal Concepts Survey, which will be discussed in more detail in Section 5.3.1.

Lecture	Topic	Concepts covered
1-2	Heat and Temperature	Temperature, the difference between heat and temperature, the Zeroth Law of Thermodynamics, the methods of heat transfer, phase changes, linear, areal and volumetric expansion, specific heat capacities
3-4	Thermal properties of matter	Avogadro's constant, Ideal gas law, p-V diagrams , the molecular origin of pressure, meaning of degrees of freedom, molar heat capacities
5-7	The first law of thermodynamics	Thermodynamic systems and processes, Work done by an ideal gas in various thermodynamics processes, relationship between heat and internal energy, first law, explain isothermal, adiabatic, isochoric and isobaric processes, use the idea gas equations
8-9	Second law of thermodynamics	Compare reversible and irreversible processes, the operation of an ideal heat engine and real heat engine, efficiency of the heat engine, p-V diagram for the Carnot cycle , performance of real an ideal engines and refrigerators, the change in entropy for a reversible process, the second law and entropy , the relationship between macroscopic entropy and microscopic disorder or disorder or complexity of a system.
10	All	Quiz- Thermal Concepts Survey

Table 4-3 Outline of topics covered in the thermodynamics module

4.6 Implementation- The Four Streams

The Regular course has four concurrent lecture streams due to both the cohort size and the capacity of the lecture rooms in the Usyd Physics Building. Module content is provided in a detailed syllabus and this is prescribed to be common between the concurrent streams. However, the lecturers have freedom to deliver lectures as they wish. This logistical freedom facilitated an ethical implementation of the Active Learning program.

Students were allocated into the four streams through an administrative process. In both years' administrations, two of the four streams experienced what we shall call the 'ILD program' and the other two did not. The students in these two 'non-ILD' streams experienced lectures as decided entirely by the lecturers apart from short exercises (the Interactive Exercises) given to the students to record their attendance and track their ideas throughout the course.

The 'ILDs' and 'Interactive Exercises' provided to students in all streams were administered in four of the ten lectures, Lectures one, three, seven and nine. Apart

from the implementation of the ILD or the Interactive Exercise, each lecturer had the freedom afforded by the system to lecture in their natural manner. No effort was made to influence the lecturer’s natural approach. A summary of the streams can be found in Table 4-4, including the times, days and whether they were ILD or non-ILD streams.

	Stream 1	Stream 2	Stream 3	Stream 4
2011	ILD full lecture series performed by Staff-1 and Researcher B M,W, F- 9am	ILD ILD lectures performed by Staff-1 and remaining lectures by Staff-2 and Researcher B T, Th- 9am, W-12pm	Non-ILD full lecture series performed by Staff-2 M, W, Th-2pm	Non-ILD Interactive Exercises administered by researcher A and full lecture series performed by Staff-3 M, W, Th-4pm
2012	Non-ILD full lecture series performed by Staff-3 and Researcher B M, W, F -10am	ILD full lecture series performed by Staff-2 and Researcher B T, Th- 9am, W-12pm	Non-ILD full lecture series performed by Staff-2 M, W, Th -2pm	ILD full lecture series performed by Staff-1 M, W, Th, 4pm

Table 4-4 Summary of the four streams: Lecture times and dates and lecturer

Three lecturers, coded as Staff-1, Staff-2 and Staff-3, were responsible for lecturing in both years. In 2011, Staff-1, who is also a physics education researcher with a record of publications, was responsible for Stream 1 but also helped Staff-2 to deliver the ILDs in stream 2. In 2012, the allocations were altered to improve study design and Staff-2 and Staff-3 implemented the program autonomously.

Students that belonged to the non-ILD streams completed Interactive Exercises in four of the ten lectures. As students entered the lecture theatre they collected a worksheet with a question and space for writing answers. During these lectures, the students completed the Interactive Exercises⁸ either individually or in groups. The exercises were mostly completed in the first 10 minutes of the lecture but were collected at the end of the lecture, as the students were leaving. The exercises consisted of short, contextually rich problems based on the previous weeks’ lectures; their contents are summarised in Table 5-3 in Section 5.1.2.

⁸ The exercises were labelled as ‘Interactive Exercise’ to avoid confusion when communicating the two programs to the students. They will be referred to in full to avoid confusion with ‘Interactive Engagement’ and the acronym ‘IE’.

An explanation of each exercise was provided in the first 5 minutes of the following lecture and students were supplied with the PowerPoint presentation used in the explanation (Appendix C). Common problems encountered by the students were compiled and presented during the presentation of the explanation. The lecture then continued as planned by the lecturer.

Students that belonged to ILD streams experienced the ILD program in four of the ten lectures. The ILDs went ahead as specified in the list in the Section 3.2.1 and took the majority of the lecture. The ILDs altered the existing lecture arrangement and the content of the lecture slides were therefore also altered to accommodate this. Staff-1, 2, and 3, Researcher A, along with Researcher B and technical staff attended a series of meetings to make these significant changes.

4.7 Contributions

As with any research, multiple people contribute in different ways. The SUPER group have contributed in validation in terms of insights on conventional categorisation and instrument construction. Karl Maton and Christine Lindstrom (later labelled as S3) have added direction and insight on LCT. The most significant contribution has been from Researcher B, Dr. Pornrat Wattanakasiwich, from Chang Mai University, who was a visiting Endeavour Fellow at the University of Sydney from February to June, 2011 and April, 2012. Dr. Wattanakasiwich developed the conceptual survey and some of the ILDs. Both will be further detailed in Chapter 5.

5 Development of Research tools and Learning Activities

This chapter will detail the various activities and instruments used in the two iterations of the Active Learning implementation (Chapters 7, 8). The learning activities will be described first, the observation tools and the evaluation of student experiences will follow, while the instruments used to gauge student attainment will be presented last. Some of these tools are used wholesale from existing PER research output, others were amended somewhat, while some were completely original developments. The scope of each description will reflect these characteristics; some will be described with more detail than others.

5.1 Learning Activities

5.1.1 Interactive Lecture Demonstrations

The Interactive Lecture Demonstrations (ILDs) were implemented to act as an IE method: to increase students' participation and involvement in lectures to improve attitudes to, and attainment in, thermodynamics. Of the range of ILDs used, some were applied directly from *The Physics Suite* (Sokoloff & Thornton, 2004), whilst original creations were also included to cover the range of concepts in the thermodynamics module at Usyd. The development of the additional ILDs is described in a separate research paper (Wattanakasiwich, Khamcharean, Taleab, & Sharma, 2012) and the ILDs themselves are authentic to the format and purpose of the original design. That is, they confront ideas known to cause difficulties, abide by the 8-step process (Table 5-1) and are supplemented by two worksheets, one for predictions, the Prediction Sheet, and the other for recording, the Results Sheet.

The eight-step process

1. The instructor describes the demonstration and does it for the class without measurements displayed
 2. The students are asked to record their individual predictions on a Prediction Sheet, which will be collected, and which can be identified by each student's name written at the top. (The students are assured that these predictions will not be graded, although some course credit is usually awarded for attendance and participation at these ILD sessions)
 3. The students engage in small group discussions with their one or two nearest neighbours
 4. The instructor elicits common student predictions from the whole class
 5. The students record their final predictions on the Prediction Sheet
 6. The instructor carries out the demonstration with measurements (usually graphs with micro-computer-based laboratory tools) displayed on a suitable display (multiple monitors, LCD, or computer projector)
 7. A few students describe the results and discuss them in the context and the demonstration. Students may fill out a Results Sheet, identical to the Prediction Sheet, which they may take with them for further study
 8. Students (or the instructor) discuss analogous physical situation(s) with different "surface" features. (That is, different physical situation(s) based on the same concept(s))
-

Table 5-1 The eight-step process from (Sokoloff & Thornton, 2004, p. 4)

Lec	ILD	Description	Ave.
.	no.		time
No.			(mins)
1	1	Metal at 90 ^o C cooling in air	6
	2	Metal at 90 ^o C cooling in water	4.5
	3	Water at 90 ^o C cooling in water	4.5
	4	Constant heat transfer to water for 80 seconds	2
	5	Heat pulse that increases water temp. by 8 ^o C for different mass of water	5
	6	Maintaining temp. of water with heat pulse	8
3	1	Constant heat transfer to 100g of water for 90 seconds	9
	2	50g Aluminium added to 100g water and constant heat transfer for 90 seconds	6
	3	50g aluminium added to 50g water and constant heat transfer for 90 seconds	7
7	1	Pee-pee boy (expansion of gas due to heat transfer)	7
	2	Pee-pee boy (expansion of gas due to heat transfer – greater temperature difference)	3.5
	3	Syringe and piston, thermal processes (constant volume)	14
	4	'Fog in the bottle'	5.5
9	1	Heat engines- steam engines	

Table 5-2 Outline of all ILDs in the thermodynamics module. The average time spent on the ILDs is also provided. All ILDs are from Sokoloff and Thornton (2004) except for ILDs in lecture 7 (Wattanakasiwich et al., 2012)

A summary of all ILDs used in the study is provided in Table 5-2, a 'snapshot' of the ILDs happening 'live' in the lecture theatre may be found in Figure 5-1 and Figure 5-2 depicts a completed Prediction Sheet (formatted). See Appendix D for the full suite of ILD sheets used in the study.

Figure 5-1 ILD Snapshot: The lecture theatre with audiovisual set up (left), the 'Pee-pee boy' ILD (middle) and the 'fog-in-a-bottle' ILD (right)



Figure 5-2 A student's completed 'Prediction Sheet' (ILD1, Lecture 1, Demonstrations 1-4 only)

Demonstration 1: A small piece of metal has been raised to a high temperature, around 80-90°C. Sketch below your prediction for the temperature-time graph for the piece of metal cooling in the room air. Be sure to carefully sketch the shape of the curve.

What do you think the final temperature of the metal will be? Zero degrees C? Room temperature? Something different?

It will reach Room temperature

Demonstration 2: Now the same piece of metal at a high temperature (around 80-90°C) is immersed in a cup filled with cool water (around 20°C). Sketch below your predictions for the temperature-time graphs of the piece of metal and the water in the cup. Be sure to carefully sketch the shapes of the curves.

What do you think the final temperature of the metal will be? (Zero degrees C? Midway between the initial temperatures of the water and the metal? Closer to the initial water temperature? Closer to the initial metal temperature? Other?)

What do you think the final temperature of the water in the cup will be? *Room Temp (eventually)*

Demonstration 3: Now a small film container filled with water at a high temperature (around 80-90°C) is immersed in a cup filled with room temperature water (around 20°C). Sketch below your predictions for the temperature-time graphs of the film container of hot water and the water in the cup. Be sure to carefully sketch the shapes of the curves.

Compare these temperatures to those in Demonstration 2. *higher*

What do you think the final temperature of the water in the film container will be? (Zero degrees C? Midway between the initial temperatures of the water in the film container and water in the cup? Closer to the initial film container water temperature? Closer to the initial cup water temperature? Other?)

What do you think the final temperature of the water in the cup will be? *Room temp (eventually)*

Same as above (small time)

Demonstration 4: Heat is transferred to water in a perfectly insulated cup (no heat can leak in or out) at a steady rate for 80 seconds, and then no more heat is transferred. Sketch below your prediction for the temperature of the water as a function of time.

5.1.2 Interactive Exercises

It was always the intention when undertaking this study that the 'control' group would partake in a carefully selected alternative program instead of experiencing the absence of one, as is usually the case with control groups. The reasons for this are twofold. Firstly, it was deemed ethically unsound to offer a very visible program to some students and not to others. Secondly, it was considered an opportunity to concurrently test a different 'form' of IE –one of lower interactivity but greater

convenience –against a known technique. This situation was deemed ethically acceptable since the use –and therefore success –of Interactive Lecture Demonstrations or Interactive Exercises in thermodynamics in Australia has not previously been reported. It was also important that students felt that the Interactive Exercises were generally advantageous to them. Students were serviced through timely feedback on the content of the questions, based on the collective responses. The Interactive Exercises were also designed to be logistically manageable as lectures were often on the same day and very close to one another (and because the preparation and administration of the ILDs was already administratively demanding). Also, the lecturers of the course were participating voluntarily and out of goodwill and any activities undertaken as part of the project were a reflection of the research group on the school.

Exercise no.	Description	Reference/Source
1	Two part problem involving thermal conductivity: why do tiles feel cooler to the touch than carpet? Why does a glass bottle feel cooler to the touch than plastic? Each part required a selection of a concept first, followed by an explanation as to why this concept was chosen to explain each scenario.	Original creation (Georgiou, 2009)
2	Cooling curve is provided for metal in large amount of water and students are asked to draw in graph that represents the curve in a much smaller amount of water.	Original creation
3	Cylinder of gas used for BBQs releases gas and frost is noticed on the outside of the cylinder. Students are asked to explain the presence of the frost.	Textbook (Young & Freedman, 1996, p. 553)
4	Similar to a Maxwell’s Demon situation with an air filter that only allows ‘hot’ particles to escape. Students are asked to explain how this might work and that the associated entropy considerations are.	Textbook (pp. 586-587)

Table 5-3 A summary of the Interactive Exercises

The development of these Interactive Exercises was therefore comprehensive and will be described here in some detail. The Interactive Exercises are a form of the IE: context-rich problem (Section 3.2.1). A summary of the exercises, including their content and schedule, is provided in Table 5-3 (above). The Interactive Exercises can be found in Appendix B.

Interactive Exercise One was developed as part of an Honours project which aimed to produce an original diagnostic tool for qualitatively probing student conceptions in

thermodynamics. The project had a particular focus on developing understanding of conceptions beyond multiple choice indicators, since there was a clear deficiency in the literature in this area. Specific aspects of the design of this diagnostic are elaborated on in the Honours thesis (Georgiou, 2009) but the ‘choice of concept’ was particularly important for guiding responses in a way that provided suitable data for analysing student understanding. Interactive Exercise One was successful in encouraging students, regardless of physics background, to provide their reasoning, and was therefore selected for administration in the very first lecture of the thermodynamics module.

Interactive Exercise 2 was also an original creation that was developed by the author and validated through formal discussion with physics education experts as well as Staff-1, Staff-2 and Staff-3. The content is based on content covered in the ILDs one to three which were seen by the ILD streams. These ILDs were based on the interpretation of Temperature vs. Time graphs.

Interactive Exercises 3 and 4 were only slightly amended from existing questions from the course textbook. Small changes were made to make the language and content suitable to the module content after consultation with the same physics education expert group and Staff-1,2 and 3.

5.2 Lecture Observation and Student Experience

5.2.1 Background

Many reports on the effectiveness of instructional programs do not include a discussion of whether the program was delivered as intended or how that delivery was assessed (Granger et al., 2012). Perhaps this is due to a culture, particularly in the PER field, of being both researcher and lecturer, making this reporting seemingly redundant. However, considering the ambiguities around operational definitions of educational terms (for example, ‘constructivism’, ‘Active Learning’, ‘Student-centred’) and the variability inherent in teaching, a description of the program may be just as consequential as attempts to quantify learning outcomes. That is, if we cannot be

certain that a particular program is in fact executed as intended, and if we are not fully aware of the characteristics of the program, conclusions drawn, particularly from pre- and post- test scores, may remain difficult to decipher. Hake, for example, in his comprehensive review of Interactive Engagement methods in physics, indicates that low gains may have been incorrectly assigned to IE classes due to ‘implementation issues’ (1998, p. 70), while Granger et al. (2012) make a more grave assertion in saying that support for student-centred learning, ‘taken as whole ... (is) contradictory and inconclusive’ (p. 105).

Furthermore, it can be reasonably assumed that to achieve true success, a program should be deliverable by a diverse range of educators –including, or especially, non-pedagogical researchers –and it is therefore imperative that these details, how the treatment was executed and how both students and teachers engaged with it, become more commonly reported.

5.2.2 Available tools

Currently, a handful of tools for characterising lectures or class time exist at the secondary level and in certain subject areas at the postsecondary level. For example, a tool known as the VaNTH Observation System (VOS) was developed out of a multi-university collaboration on a National Science Foundation-supported Engineering Research centre (Cox & Harris, 2003). The VOS was intended to gauge how effectively research-based models of teaching were implemented and also, to assess the standing of current engineering practices at the postsecondary level with regards to these models. Specifically, four questions were posed, including ‘What does a ‘typical class lesson’ in bioengineering look like (control)?’ and ‘what instrument can be used to capture these lesson differences?’ (between the ‘control’ and the new approach) (p. 329). The VOS was an important step in understanding what is happening during a trial and subsequent assessment of new approaches but it also provided researchers and teachers with a common language with which they could understand what was and wasn’t occurring in ‘traditional’ lessons. This particular tool was further developed by Cox and Cordray (2008) to address the fact that the VOS ‘has not been optimized’. These

authors developed an ‘index’ which intended to register the quality of pedagogy exhibited in these engineering courses. The original coding categories can be found in Figure 5-3. These codes were transformed into ‘code strings’ and quantified to produce an index which can distinguish different types of instruction.

Figure 5-3 VaNTH Observation System codes (Cox & Harris, 2003)

Who	To Whom	What	How	Media
Professor	Professor	1 factual question	Knowledge-centered	Board
Everyone	Everyone	2 higher order question	Learner-centered	Overhead
First student	First student	3 response	Assessment- centered	Computer
Same student	Same student	4 instruction	Community-centered	Simulation
Small group	Small group	5 social comment	Class Organization	Demonstration
Large Group	Large Group	6 activity-related comment		Video
Media	Media	7 acknowledge or praise		Response system
Visitor	Visitor	8 guide		None
		9 correction		
		0 no response		
		A active monitoring		
		P passive Monitoring		

Another, more widespread example is the Reformed Teaching Observation Protocol (RTOP), which was recently used as part of a large-scale project investigating the efficacy of student-centred learning published in Science (Granger et al., 2012) but has also been used widely in science education research in schools for many years. Sample questions from the RTOP are shown in Figure 5-4.

Figure 5-4 Questions in subscale four of five on RTOP⁹

1. *Students were involved in the communication of their ideas to others using a variety of means and media.*
2. *The teacher's questions triggered divergent modes of thinking.*
3. *There was a high proportion of student talk and a significant amount of it occurred between and among students.*
4. *Student questions and comments often determined the focus and direction of classroom discourse.*
5. *There was a climate of respect for what others had to say.*

⁹ Accessed on 13/8/2013 from <http://serc.carleton.edu/NAGTWorkshops/certop/interpret.html>

Although the VOS was content-specific and the RTOP was specifically designed for use in the K-12 context, their common purpose provides examples of the form of specific measures that have proven useful in our own implementation.

The adjusted instrument used in our implementation will be referred to as the Lecturer Activity and Student Engagement (LASE) tool. This tool is far less specific than its predecessors but offers a simple and practical way to gauge the activities occurring during the implementation of a new approach. It also helps uncover differences in approaches, particularly in a naturalistic setting. Most importantly, it makes what is happening in the lecture transparent.

5.2.3 The Lecturer Activity and Student Engagement (LASE) tool

As mentioned in Section 4.5, the main variety experiences by students in the Physics course occurred in the lectures (since the tutorials, assignments and laboratory sessions were equivalent). Therefore, it was the lectures that were coded as we tried to characterise differences.

The Lecture Activity part of the tool codes with respect to activities and expectations of the lecturer: what they are doing during their presentation and what they inherently expect the students do. The Student Engagement part of the tool records how students engage with these activities. Students are observed to determine what effect the lecture activities have on them.

The main coding categories for the LA part are geared towards identifying the levels of ‘interactivity’ in the lectures. It can be noted that lectures in the School of Physics at The University of Sydney are fairly ‘standard’ in that lecturers give a PowerPoint presentation of one hour, lecture notes are shared and lecturers aim to cover content in similar amounts of time.

All physics lectures at the University of Sydney are recorded and made available for download and streaming for enrolled students. In 2011, the audio was available and in

2012, a visual component was also added, meaning that the students could access the slides as well as any video the lecturer recorded during the lecture hour. Analysis of the hit rate of each lecture shows that a minimal number of students used this service. In 2011, on average, between 3 and 7 students accessed each audio lecture and in 2012, between 7 and 10 students accessed the slide-shows per lecture. These data indicate that the dominant channel for delivery of the physics content occurred face-to-face during lectures.

The SE part of the tool involved directly observing students behaviour in lectures. The lectures from 2011 and 2012 were analysed with regards to the Lecture Activity and in 2012, ethics approval (Appendix E) was sought to observe the lectures to record Student Engagement. Although, due to logistical reasons, the LASE was technically used asynchronously, there is no special reason for this to occur, that is, the LA and SE part of the tool may be used together or separately.

Development of LA

Lecture activity was observed through the researcher acting as a non-participant observer. Recordings of lectures were made through the School of Physics recording system (Lectopia in 2011, Echo in 2012). Lecturers were not aware that the coding was occurring until after they had delivered both years of lectures. Permission was sought and received at this time from the lecturers. Mp3 files were downloaded and imported into the software program NVivo where they were analysed. Further analysis and statistical testing occurred in SPSS. In total, there were ten lectures in four streams and therefore approximately 40 hours of recordings. The audio was automatically programmed to cover the full hour, although Usyd classes generally begin at five past the hour and finish five to the hour to give students enough time to move between classes, resulting in a total of 50 minutes lecture time. No section of the lecture was coded more than once, meaning all lectures were coded for a total of 60 minutes, including the five minutes before and after when the recording was still running. Slides were provided and used if there was any uncertainty in coding.

There was little ambiguity in the coding selection and the categories are relatively self explanatory. The categories are explained below:

Transmission-Style (TS): The lecturer is addressing the students directly and does not expect students to play a significant role in leading the discussion (while students are always encouraged to ask questions, this coding category indicates the lecturer is in a mode where they do not explicitly set time aside for questions or directly request students' involvement in the lecture).

Demonstration (D): The lecturer is performing a Demonstration but does not ask students to predict or discuss the Demonstration. The Demonstration is explained by the lecturer.

Interactivity (I): The lecturer communicated an expectation that students will be the principle participants in the lecture. This includes allocating a period of time in which students are thinking about and communicating their opinions about content or demonstrations shown in class. This may occur on an individual level or in pairs or groups.

Exercise (EX): Time that is specifically allocated to the completion of the Interactive Exercises.

Administrative (AD): The lecturer (or other) is providing information about administrative details. This predominately occurred in the first lecture and was included to account for a large portion of the class not fitting into other categories.

Dead Time (DT): Time before and after the official start and end of the lecture. The lecturer is not speaking and is not attempting to garner the attention of students. Although this should be approximately 10 minutes for all lectures, the exact amount would vary, and therefore this variation was considered significant enough to include in the coding.

Quiz (TCS): Time that is allocated to the completion of the TCS. This occurred only in lecture 10.

The categories for coding were determined after a discussion with a physics education researcher external to the institution, and based on the observation of previous mechanics lectures in the Regular Physics course in the Mechanics module. A-priori coding categories included TS, D, I and EX, whilst the rest were a result of generative coding.

To best reflect the type of activity present, coding did not occur at units of time significantly less than 15-20 seconds. For example, explanations that could be classified as TS but which occurred at the end of a demonstration were coded as part of a demonstration unless they segued into transmission style teaching as indicated by this time period. Another example would be if an individual student asks a question during a TS phase. If the question is short (less than 15 seconds) and the lecturer answers without expecting feedback or involvement from the rest of the class, then the question is not coded separately as Interactivity. Individual questions did not amount to any considerable amount of time in this course.

Figure 5-5 NVivo screen capture for Lecture Activity coding (Lecture 1, Stream 1, 2011). Time period of coding section (bottom), matches audio excerpt (top).

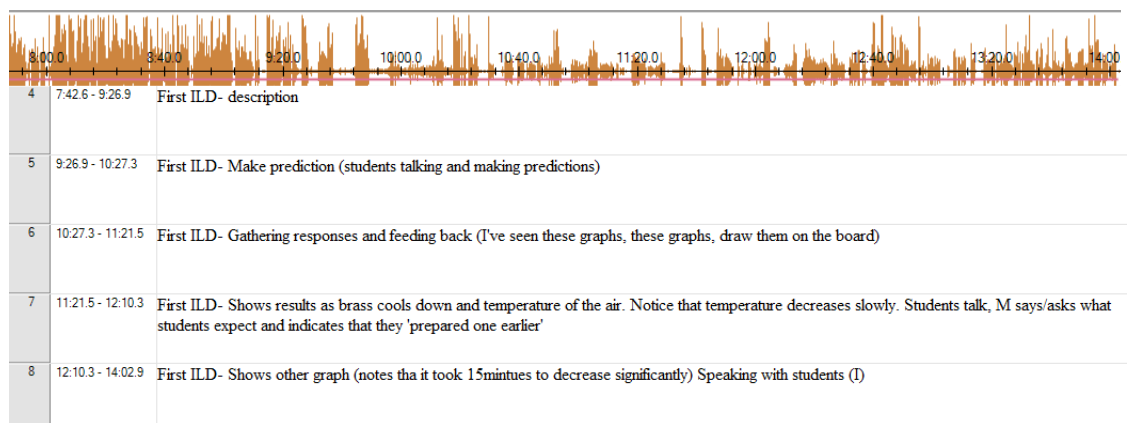


Figure 5-5, a screen capture of the coding in NVivo, shows an example of what the coding looked like. The coding occurred with respect to time periods measured in min:sec:00 format, although this precision was not necessary and fractions of sections

were rounded to the nearest second. Any salient information was also noted within the software program as field notes.

Although coding categories imply similar activities were going on, there are also differences between the four streams that are not captured by this classification. These will be discussed further with respect to specific results in Chapter 8.

Development of SE

The planning and design stage of the Student Engagement aspect of the LASE occurred during the last two lectures of the mechanics module which preceded the thermodynamics module in 2012. This exercise involved the same student cohort that was used for subsequent observations, but both the topic and the lecturer were different.

For the first lecture, two researchers made general notes in the absence of any guidelines and with no collaboration. An internal report developed to describe the construction of the SE may be found in Appendix F. Results were shared and along with reference to literature, the researchers then agreed upon the structure of the SE part of the LASE (Figure 5-6 and Appendix G for full template).

Figure 5-6 Part of Student Engagement template

Date/time:		Number of students:			
Stream/Lecturer:		Lecture No.			
Time period	Activity	Student Observation			
		Paying attention	Not paying attention	Writing	Other

Key aspects of the design that were emphasised included the ability for one researcher to collect as much useful information as possible without needing to perform any recording and for the collection to be completed independently.

The agreed method involved the following instructions:

Find a covert place at the back of the lecture theatre

Select ten students on the basis of position (and peer group diversity) as well as visibility

Allocate students with Unique ID (Numbering one through ten, anticlockwise around lecture theatre)

At periods of 10 minutes (or when distinct and notable activities are taking place, i.e., the ILDs), starting at number 1, fill in the LASE form, starting with lecture activity taking place and then recording what individual students were doing during the observation period.

Field notes should be made at the beginning and throughout the lecture to record salient events.

Coder reliability was confirmed during the second lecture. However, the specific approach was designed to limit subjectivity and therefore be predominantly carried out by only one researcher. Elaboration and justifications for certain characteristics of the SE are provided below. Information and images of the two lecture theatres used for the thermodynamics module and the SE may be found in Figure 5-7.

Limited number of students observed: Only 10 students (between 10-20% of lecture attendance) were directly observed. Due to the SE being intended for common usage, the unfeasibility of attaining ethics for recording lectures meant that this was the most appropriate viable alternative. Supplementary notes were taken when this observation was not satisfactorily representative of the lecture room at this time.

Selected lectures only: Each different ‘type’ of lecture was observed. Not all lectures were observed but care was taken to observe salient lectures: the first, the lectures with and without ILDs and Exercises, and a lecture with known high levels of Demonstrations.

Individual tracing: Students were allocated a unique ID within each lecture to ascertain instances of repeated behaviour. Students were not tracked across lectures.

Attempts at representation: Students from all physical locations were selected and students which were ‘interacting’ were avoided such that behaviours were not linked.

Irregular time intervals: At times, it was necessary to alter the regular time intervals of observation to capture behaviours during a distinct type of lecture activity. For example, the in-class demonstrations.

Alternative ILD sheet: because of the nature of this type of ILD instruction. A slightly different sheet was used for ILD lectures (Appendix H).

Specificity: Further specificity in coding was not sought due to the objectives of this project. The resources needed to substantiate subjective stances such as ‘did the teacher allow for discussion’, was outside the scope of this particular project, although it would be very useful if these or other aspects were added onto this prototype version.

Figure 5-7 Slade lecture theatre (top) and Physics LT2 (bottom). Both lecture theatres have 150pax capacity.



5.2.4 Lecture evaluations

There were three different evaluation surveys through which students could report their experiences. The Physics Lecture Evaluation is the existing evaluation form that is completed after all modules in all physics units in the School of Physics. This evaluation has existed within the School for several years. The Physics Lecture Evaluation form includes Likert questions addressing the lecture content, pace and lecturer performance, and additional free response questions about general attitudes towards any aspect of the course. The school's administration collates the information as a way of providing feedback to lecturers and for internal records of teaching and learning. To this evaluation, an additional evaluation form was added: to the streams which partook in the ILD program, an ILD specific form was added, and to the others, a form which addressed the Interactive Exercises. See Appendix I for these forms.

5.2.5 Interviews

Interviews were conducted on two separate occasions to provide elaboration on the results of almost all tools mentioned in this section. The interviews were conducted in semester two in both 2011 and 2012 with ten students in total. They were semi-structured in nature and reflective: students provided insight into the course, the module, the exam, what they remembered of the exercises and ILDs and spoke generally about university physics. Some guiding questions for the 2011 and 2012 interviews are provided in Appendix J.

5.3 Student Learning Outcomes

5.3.1 Thermal concepts survey

The Thermal Concepts Survey (TCS) was one method that was used to ascertain the status and development of student understanding of thermodynamics concepts (Appendix K). The TCS is a validated tool¹⁰ amalgamated and amended from existing thermodynamics concept inventories (Wattanakasiwich, Talaeb, Sharma, & Johnston, 2013). The tool was used due to its matching the thermal concepts coverage in the Usyd module. The test is split into two parts. Part I is considered conceptual thermodynamics knowledge and can be completed without prior physics instruction whilst part II is considered more specialised knowledge (Table 5-4).

Topics		Item
Part I	Temperature and heat transfer	1, 2, 3, 4
		5, 6, 7
	Ideal gas law	Isobaric process 8, 9, 10, 11, 12
		Adiabatic process 13, 14, 15, 16
Part II	The 1 st law of thermodynamics	Adiabatic process 17, 18, 19
		Isobaric process 20, 21
		Isothermal process 22, 23
		Isochoric process 24
		Cyclic process 26, 27, 28, 29, 30, 31
		P-V diagram 25, 32, 33, 34, 35

Table 5-4 Content of TCS (Part I and Part II)

¹⁰ Including content and construct validity and item analysis (Item Difficulty, Point Biserial and Discrimination) as well as the whole test measures KR-20 and Ferguson's Delta

This distinction is made because part two cannot be attempted without some instruction on the terminology, physical principles and representations used. That is, it is not necessarily a ‘conceptual test’ in that students are able to make assumptions based on their intuitive understanding, as with the FCI. As such, only part one was issued as a pre-test, while both part one and part two were issued as post tests. Although this somewhat contaminates the standard form of the pre- and post-test assessment method, it was deemed necessary since students would not have covered any of the content of part two in high school and the lecturers and researchers involved in the study deemed it unfair and inappropriate as part of the content analysis process. Part one was therefore considered on pre- and post-test gains testing while the full test, parts one and two, for the post-test, were considered for comparisons of means between the different groups. All administrations of the TCS were in pen and paper form.

5.3.2 Normalized gain and the Hake Plot

The measure used for determining improvements in the TCS is the ‘normalized gain’ measure. For whole group scores, the average gain is calculated using Equation 1.

$$\frac{(post \% - pre \%)}{(100\% - pre \%)}$$

Equation 1. Normalized gain

5.3.3 Final exam

The final exam was an additional measure intended to gauge student understanding, between the four streams. Section 4.4.2 displays the description of stylistic features of the Usyd Physics exam, notably, the absence of multiple-choice questions. Each result in the two years of the implementation involves quoting student averages from both the total exam mark and the marks attained for the three thermodynamics questions so summaries of the content of these papers will be provided below (Table 5-5 and

Table 5-6). The full 2011 and 2012 examination papers may be found in Supplementary Materials.

Question	Description	Marks
1	Angular velocity, mass and kinetic energy (mechanics)	5 each
2	Centripetal force and acceleration (mechanics)	
3	Rotational motion and kinetic energy (mechanics)	
4	Temperature and thermometers (Thermodynamics)	10 each
5	Frequency of waves, graphing waves (oscillations and waves)	
6	Standing waves in open pipes- instruments (oscillations and waves)	
7	Motion in a straight line, inclines, force diagrams (mechanics)	
8	Collisions, momentum, kinetic energy and equations of motion (mechanics)	
9	Ideal gas and thermodynamics processes (thermodynamics)	
10	Kinetic theory, pressure, radiative heat transfer (thermodynamics)	
11	Simple harmonic motion (oscillations and waves and mechanics)	
12	Doppler effect (oscillations and waves)	

Table 5-5 Questions in the 2011 final exam

Question	Description	Marks
1	Angular velocity and centripetal forces (mechanics)	5
2	Centripetal force and acceleration (mechanics)	
3	Energy, momentum and impulse (mechanics)	
4	Kinetic theory and internal energy of ideal gas (Thermodynamics)	10
5	Standing waves in tubes (oscillations and waves)	
6	Standing waves on strings (oscillations and waves)	
7	Frictional forces and Newton's third law (mechanics)	
8	Torques and angular and linear acceleration (mechanics)	
9	Ideal gas and thermodynamic processes (thermodynamics)	
10	The second law of thermodynamics and heat engines (thermodynamics)	
11	Simple harmonic motion (oscillations and waves and mechanics)	
12	Simple harmonic motion, springs and graphing (oscillations and waves)	

Table 5-6 Questions in the 2012 final exam

6 Introduction to Part One: Active Learning Experiment

This part of the thesis will report on the implementation of an Active Learning program in first year Physics at The University of Sydney.

Study One, the first version of the experiment, took place in Semester one, April 2011, with first year Physics students in the Regular course, which consisted of four streams. One of the lecturers, Staff-1 was a pedagogical researcher. The other two (Staff-2 and Staff-3) volunteered to take part out of goodwill. Staff-2 was assisted by Staff-1 in the implementation of the ILDs but only in the experiment lectures.

Study Two, the second iteration of the experiment, took place in semester one, April (and May) 2012, with first year Physics students in the Regular course, which again consisted of the four streams. The same three staff were involved in this iteration, although several aspects of the implementation were improved, including the sample allocations and pre- and post- test matching.

7 Study One 2011

7.1 Aim

There were several aims of the experiment, all of which related to the main research question of characterising the first year thermodynamics lectures with respect to learning outcomes, student attitudes and experiences during an Active Learning implementation. The individual aims are made explicit below:

1. To determine the overall learning gains of students during the thermodynamics module as measured by the pre- and post- TCS part I.
2. To determine whether there was a difference in learning outcomes as measured by the TCS (part I and II), the thermodynamics questions on the final exam, and the overall final exam score.
3. To examine student attitudes towards the two methods of IE through the student evaluation surveys and interviews.
4. To characterise the lectures with respect to the interactivity present in the lecture streams throughout the thermodynamics module as measured by the LA part of the LASE tool.

7.2 Sample- allocation of streams

Students enrolling in the Regular course in first year Physics are fairly similar in terms of their physics background and performance in high school. Therefore, since characterisation of the four streams was not possible prior to allocation due to delays in the retrieval/permission of demographic information, it was hoped that the administrative allocation of students to the four streams would be akin to random selection. The measures used to ascertain homogeneity of samples were the following:

Student high school leaving marks (ATAR), Student high school Physics marks (NSW HSC only), degrees enrolled in and gender.

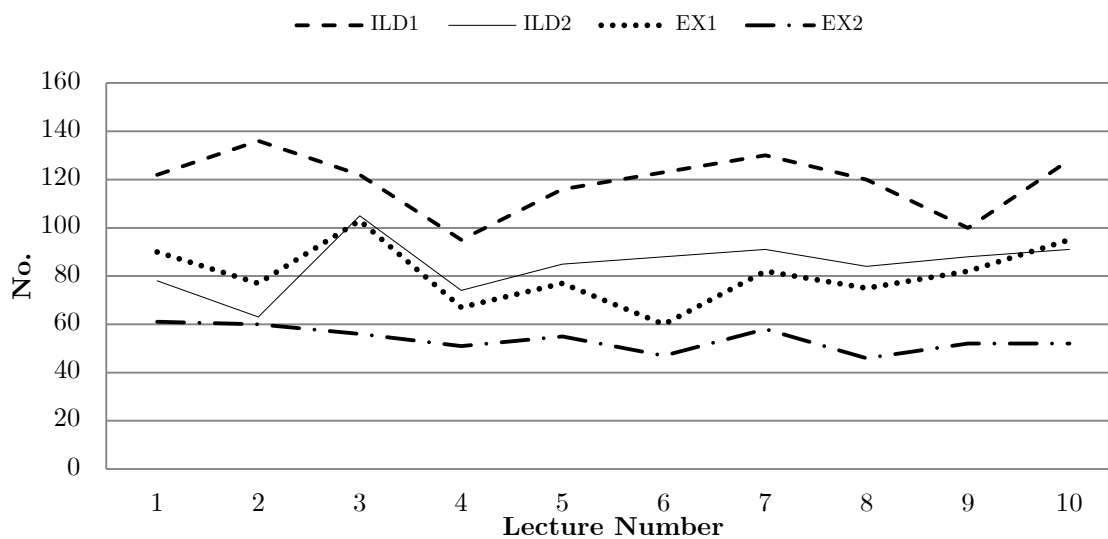
7.2.1 Numbers

Students were counted at each lecture and attendance throughout the course was recorded (Table 7-1 and Figure 7-1). Attendance remained relatively constant throughout the module.

Lecture	1	2	3	4	5	6	7	8	9	10
ILD1	122	136	122	95	116	123	130	120	100	128
ILD2	78	63	105	74	85	88	91	84	88	91
EX1	90	77	103	67	77	60	82	75	82	95
EX2	61	60	56	51	55	47	58	46	52	52

Table 7-1 Lecture attendance for the four streams

Figure 7-1 Lecture attendance for the four streams



To ascertain how many and which students were attending the lectures, student IDs were collected through the ‘lecture sheets’¹¹, during the ‘experiment lectures’¹². There were two measures that provided utility when considering numbers (Table 7-2). The ‘potential number’ of students in each stream is the maximum number of unique

¹¹ ILD or Exercise sheets which had student Identification requests on them

¹² Experiment Lectures were lectures which were part of the experiment; whether they were ILD or Exercise lectures.

students experiencing the thermodynamics module as measured by attendance at the experiment lectures (including the TCS). This measure aims to indicate the total number of students participating in the program, regardless of the level of participation. For example, if one student attended one experiment lecture and only that lecture, but another student attended a completely different experiment lecture (and only that lecture), they were both counted as part of the ‘maximum number’ measure for that particular stream. It is thus an over-estimation of the number of students in each stream but reflects the largest possible number of students exposed to the course.

Stream	Codename	Potential No.	Full participants	Retention
Stream 1	ILD1	156	114	0.73
Stream 2	ILD2	123	76	0.62
Stream 3	EX1	119	82	0.69
Stream 4	EX2	70	54	0.77

Table 7-2 Sample size and retention

The second measure represented the section of the sample deemed to have participated sufficiently in the program to be considered in the statistical analyses. This measure, the number of ‘full participants’, was represented by students who had attended at least three of the four experiment lectures in one single stream. It is intended as illustration of attendance only. For the analysis, this figure will be slightly different depending on the presentation of TCS or final exam data, as not all students that were full participants completed both. The retention column is included to indicate how many students, as a proportion of total students that attended the streams, continued to attend the lectures. This figure represents the lowest possible retention rate, since the potential number is an overestimation. Lastly, most students stayed in their allocated stream. However, the sixteen students that switched between streams were disregarded.

7.2.2 Student high school marks and physics marks

Student ATAR and HSC Physics marks (Section 4.1.3) were used, where available, to characterise and establish homogeneity across the four streams. These data were available for between 61-67% of the streams. There were no statistically significant difference between the students in the streams in relation to their ATAR or high school Physics marks as determined by one-way ANOVA ($F(3,219) = 2.570, p = .055$) and ($F(3,206) = 0.664, p = 0.575$) respectively. Means and standard deviations for each group in relation to the ATAR and Physics marks are provided in Table 7-3 below.

	High school Physics			ATAR		
	N	Mean	Std. Deviation	N	Mean	Std. Deviation
ILD1	77	82.40	10.80	80	92.02	4.60
ILD2	49	84.08	6.39	53	91.71	5.24
EX1	51	82.55	6.03	57	90.45	6.00
EX2	33	81.76	5.16	33	89.37	5.16

Table 7-3 Final High School (ATAR) and High School Physics Marks. These were not available for part of the sample for a wide range of reasons including for students who took a year off or have arrived from other states or countries

7.2.3 Degrees enrolled in

The degrees that students in the different streams were enrolled in formed part of the characterisation/description of the sample. Most of the students in first year Physics are Engineers. The Bachelor of Science students make up the next largest group followed by the Bachelor of Medical Sciences students (for which 2011 was a year where taking first year Physics was compulsory). Figure 7-2 shows the percentage of students enrolled in the three main degrees. The sample size used was the potential number.

Figure 7-2 Degrees enrolled in sample

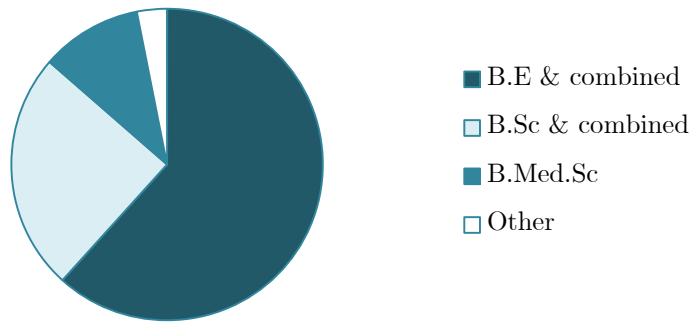
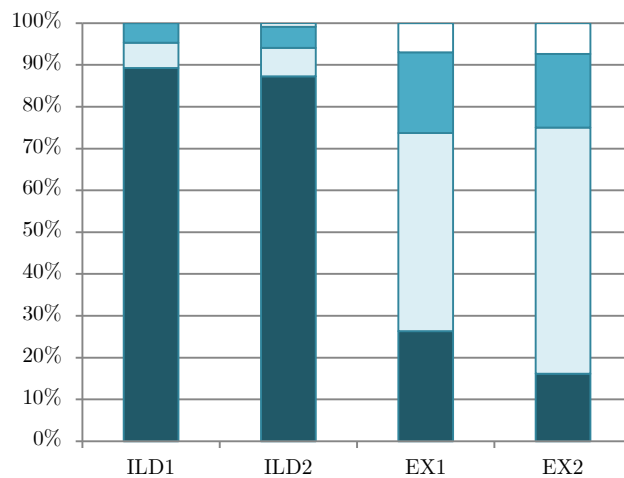


Figure 7-3 Degrees enrolled in by stream



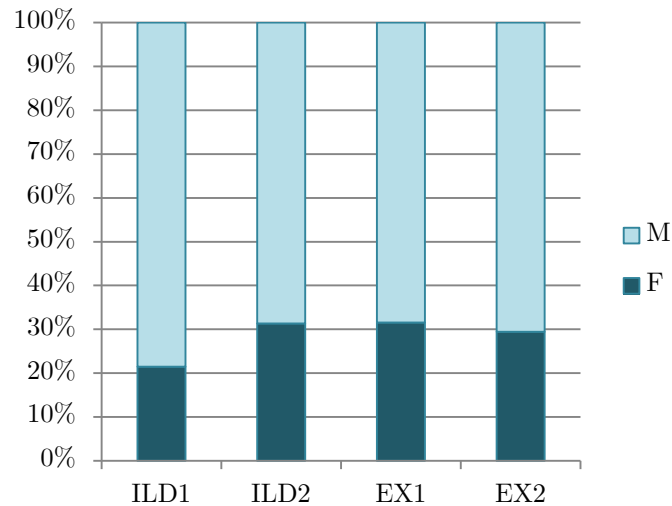
When the separate streams are considered, the allotment/allocation is somewhat more disproportionate with respect to the four streams. Figure 7-3 shows that ILD1 and ILD2 consist of Bachelor of Engineering students while EX1 and EX2 have a more diverse sample predominantly consisting of Bachelor of Science and Bachelor of Medical Science students. Again, student numbers were from the potential sample and thus only percentages are shown.

7.2.4 Gender

In Regular Physics at Usyd, there is a disparity with regards to gender with 69% males to 31% female. However, this average takes into account a higher proportion of males in Engineering degrees (approximately 80%) and a much lower proportion in the Medical Sciences degree (approximately 40%). More females are enrolled in the Bachelor of Medical Sciences degree while more males enrol in Engineering degrees.

Given the difference in degree distribution, it is not surprising to see minor discrepancies in gender across the streams, given certain timetabling restrictions lead to allocation to a particular stream for different degree programs (Figure 7-4).

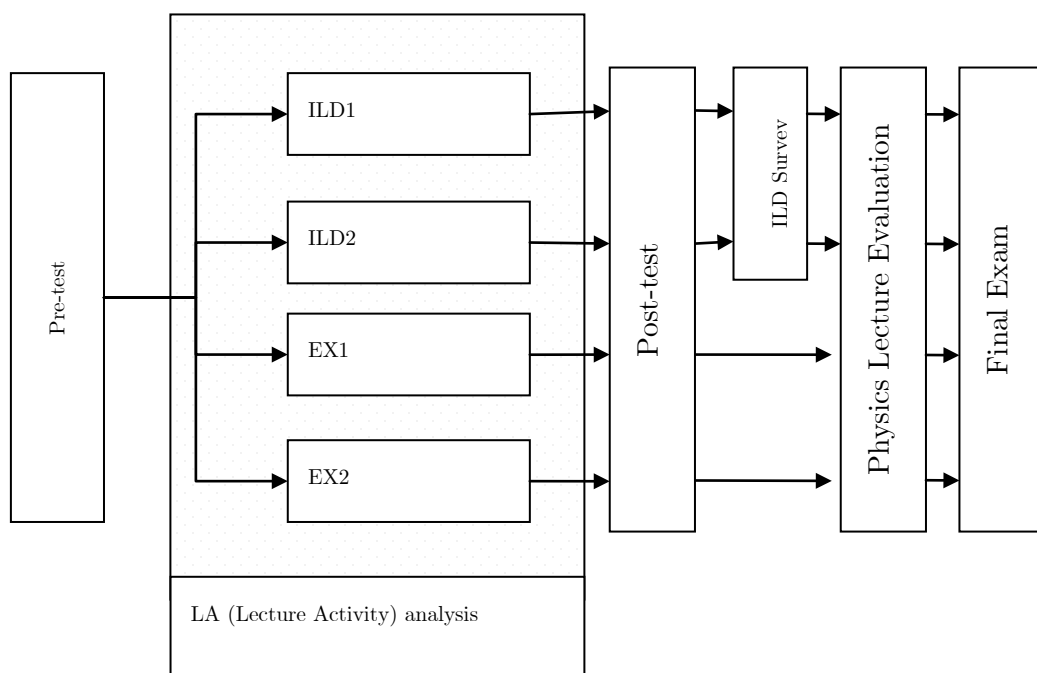
Figure 7-4 Proportions of males and females by stream



7.3 Method

As described in Section 4.6, two of the four streams experienced ILDs while the other two experienced the Exercises. A flow chart of the method is shown in Figure 7-5.

Figure 7-5 Flow chart of 2011 Implementation. No identification was taken from the pre-test administration.



7.4 Results

7.4.1 Overall learning gains

The overall learning gain of the cohort was determined through the use of the normalized gain measure, using average scores of the total number of students who took the pre- and post- tests. It is noted that not all students taking these tests would have experienced the thermodynamics module, that is, the pre- group and post- groups are not matched. This issue is one that was resolved for Study Two. Both pre- and post- samples were normally distributed and a gain between the average pre-scores ($M= 8.96$, $SD=2.47$) and post-scores ($M= 10.97$, $SD=3.16$) was found to be 0.29 (Table 7-4).

	Pre test (/16)	post test (/16)
Number	528	362
Mean	8.96	10.97
St. Deviation	2.47	3.16
Gain	0.29	

Table 7-4 Overall scores and learning gains on TCS (Part I)

7.4.2 Differences in learning outcomes

Next are the comparisons across the individual four streams using post-scores on the full TCS (part I and II), marks on the individual thermodynamics questions in the final exam and overall final exam score (Table 7-5).

An independent samples t-test shows that there was no difference in means between the treatment ($M= 19.54$, $SD=3.96$) and control groups ($M= 19.53$, $SD=4.20$), $t(282)=0.007$, $p=.995$ for the TCS post-test. An ANOVA showed that there were no significant differences in means between the four individual streams, $F(3,280)=0.079$, $p=.971$ on the TCS. An independent samples t-test shows that there was also no difference in means between the treatment and control groups for each individual thermodynamics question (Q4, Q9, Q10), $t_4(320)=0.270$, $p=.767$, $t_9(320)=1.292$, $p=.197$, $t_{10}(320)=-1.082$, $p=.280$ respectively. An ANOVA also indicates that there was no difference in means between the four streams on the thermodynamics questions in the final exam. An independent t-test shows that for the final exam mark, there was no difference in

the means between the treatment ($M= 49.69$, $SD=14.79$) and control groups ($M= 46.57$, $SD=15.46$), $t(320)= 1.830$, $p=.068$. An ANOVA shows that there was no significant difference in means between the four individual streams for the final exam scores.

Post test (/35)				Final exam								
N	Mean	St. Dev.	N	Q4 (/5)		Q9 (/10)		Q10 (/10)		Total (/90)		
				Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	
				ILD1	98	19.59	3.86	113	2.85	0.94	4.98	2.89
ILD2	66	19.45	4.13	76	2.66	0.95	4.96	2.99	2.57	2.20	50.37	14.60
EX1	74	19.66	4.29	81	2.75	0.84	4.53	2.78	2.46	2.28	46.23	15.37
EX2	46	19.33	4.11	52	2.73	0.95	4.59	2.73	2.85	2.57	47.10	15.72
TOTAL	284	19.54	4.06	322	2.76	0.92	4.80	2.86	2.45	2.25	48.40	15.12

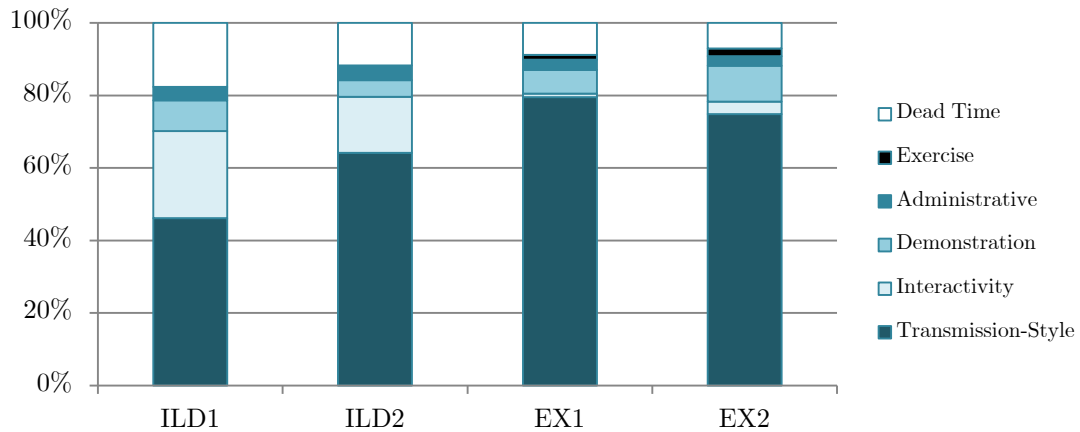
Table 7-5 Post-test and Final Exam scores (including all thermodynamics questions) for the four streams

7.4.3 Other results

This section of the results will characterise the lectures, particularly with respect to the level of interactivity for both the ILDs and the Exercises, as measured by the Lecture Activity part of the LASE tool. The experience of the Interactive Engagement implementation by the students is reported, as measured by the Physics Lecture Evaluations, the ILD and IE evaluation and the student interviews.

The overall breakdown of each stream's time allocation for the different lecture activities as an average across the whole course (excluding lecture 10 which consisted of the completion of the quiz) is shown in Figure 7-6.

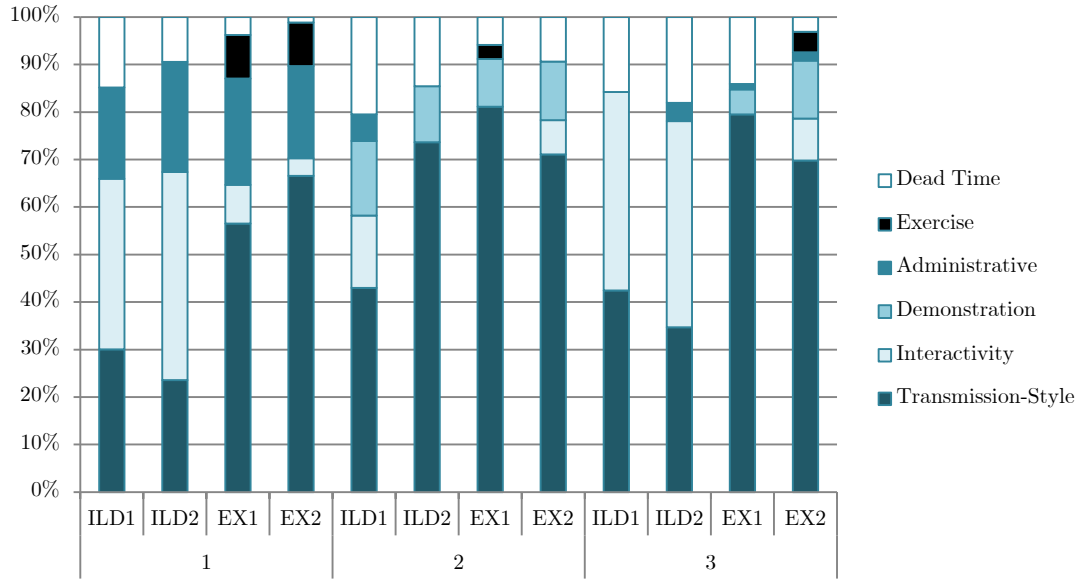
Figure 7-6 Lecture Activity coding by Stream



On average ILD1 exhibited the highest proportion of Interactivity (I) teaching, followed by ILD2, EX2 and lastly EX1.

Since there was a wide variability in the time periods coded to any of the categories, it may be more illustrative to show a selection of three distinctive lectures. Figure 7-7 shows a break down for lectures one, two and three; lectures one and three were experiment lectures and lecture 2 was not. Lecture one was the first lecture and therefore exhibits a significant amount of ‘Administrative’ coding. ‘Dead Time’ in this case represents the time at the beginning and end of the lecture. Lecture two contained equal amounts of Demonstrations across the streams. Of the four streams in this non-experiment lecture, both Staff-1 and Staff-3 produced more Interactivity when compared to Staff-2. The results show that Staff-2 produced almost identical lectures for the two streams they were responsible for (one ILD, one non-ILD) during the non-experiment lectures.

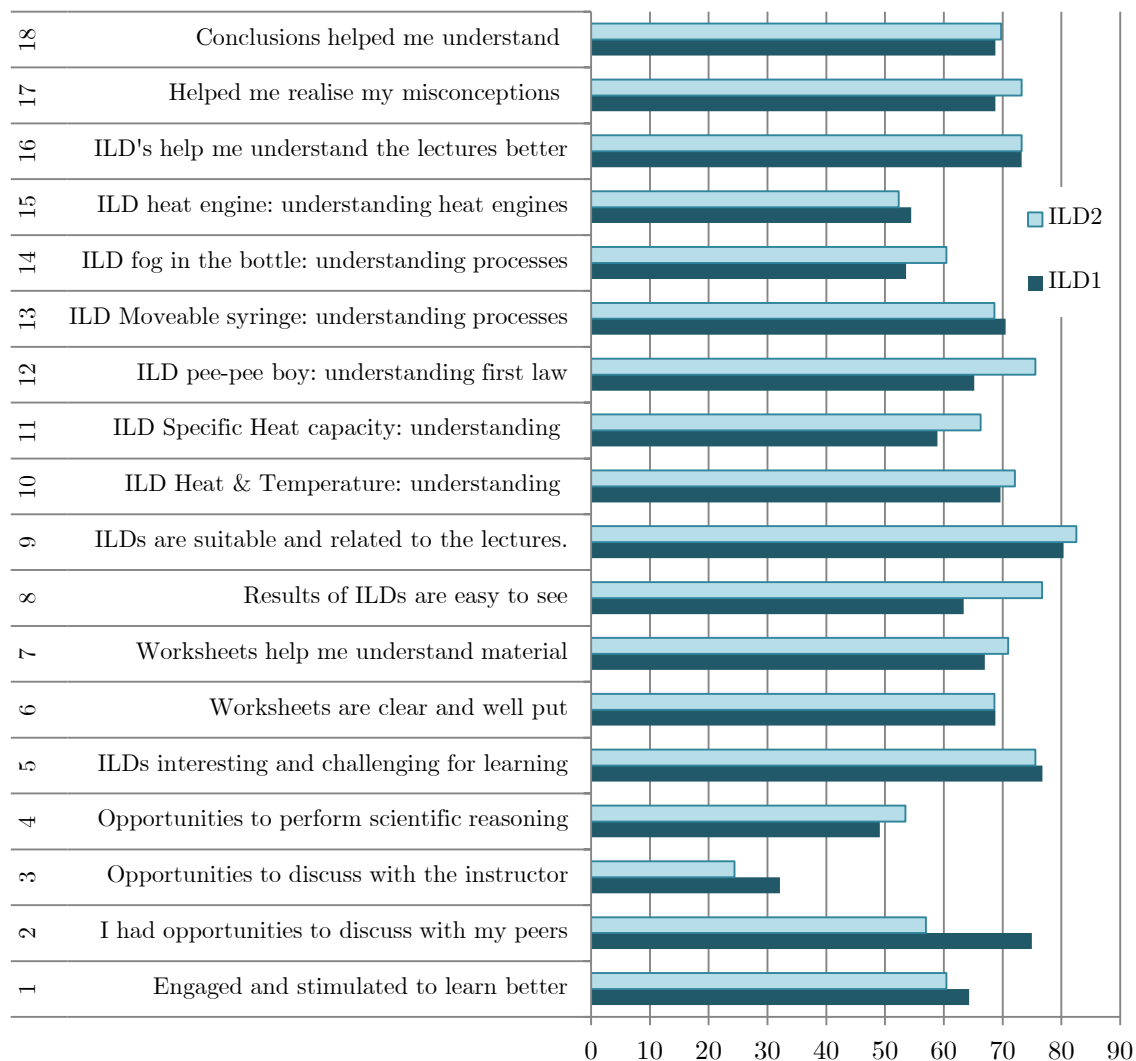
Figure 7-7 Lecture Activity coding for the four streams and for the first three lectures. Each lecture is one hour in total



Student evaluations of the course showed that students were very satisfied with all aspects of the course but that they held reservations about their understanding of thermodynamics. All lecturers were judged to be of excellent quality. The lecture evaluation forms have a tradition of privacy and it was not deemed necessary to disclose individual, lecturer-based quantitative statistics beyond these insights.

Further surveys were deployed to gather students' thoughts on the IE techniques used in the thermal Physics modules, both the ILDs and the Interactive Exercises. With respect to the former, the ILD survey was administered to streams one and two ($N=112$, $N=86$).

Figure 7-8 Results from ILD Survey for ILD1 and ILD2. Percentages represent the combined upper two scores on a 5 point Likert scale. Questions have been summarised. See Appendix I for details.



In general (Figure 7-8), the students attitudes were overwhelmingly positive in regards to the ILD experience, with ratings of ‘strongly agree’ or ‘agree’ for over 70% of the sample for the following items: ‘ILDs are interesting and challenging for learning’, ‘suitable and related to the lectures’, ‘ILDs helped me understand the lectures better’, ‘making predictions beforehand helped me realise my misconceptions about thermodynamics’ and ‘the conclusion after each ILD made me understand the concepts involved’. The two lowest scoring items were ‘I had opportunities to discuss my opinions with the instructor’ and ‘I had opportunities to perform scientific reasoning’, with only approximately 25-30% and 50% respectively selecting the ‘agree’ and

‘strongly agree’ categories. There was alignment between the two streams for most of the items but notably, on two items, the responses from the students exhibited significant variation. The first item was the item which stated ‘I had opportunities to discuss with my peers’ which secured 73% of ILD1 in the top two categories but only 58% of ILD2. The second item which saw variation in student responses was ‘results of the ILDs are easy to see’, with 62% of students in ILD1 agreeing or strongly agreeing and 78% from ILD2. The items that referred to individual ILDs (10-14) were neither very high nor very low scoring. The phrasing of the question followed the structure ‘ILD ‘X’ : helps me understand the concepts related to ‘x’ better’ and so were a more targeted form of the general item which covered learning quality as a whole. The general understanding question (18) scored much higher than any of the individual questions. In order from highest (70%) to lowest (50%) for individual ILDs were: Moveable syringe helping with understanding of isobaric process, heat and temperature with the understanding of heat transfer and thermal equilibrium, pee-pee boy with understanding of the first law of thermodynamics, specific heat capacity with the understanding of the same, fog in the bottle with the understanding of adiabatic processes and finally, heat engine with understanding of the same.

The differences between the way students answered these surveys in each of the two ILD streams was not significant. There was a slightly more positive response from ILD1 students regarding questions two and three, which concerned ‘opportunities to discuss’ with the lecturer and peers, and there was a slightly more positive response from ILD2 students with the understanding of two ILDs (see questions eight and 11 from Figure 8-11).

In the next section (Q19-Q22), students were asked to select their most and least favourite ILD and provide reasons as well as list the ILD that they understood the most and least, also with reasons. Most students reported that they liked the pee-pee boy ILD the most. The heat engine ILD was the one that students reported to have liked the least. In terms of understanding, most students reported to have understood the pee-pee boy the most and the fog in a bottle or heat engine the least.

In their justifications of these selections, students responded by explaining that the most easily understood demonstrations were preferred and the preferred demonstrations were ‘fun’ or ‘interesting’. See comments below (the demonstration students are referring to is in parentheses).

“interesting, clearly demonstrated principle” (for pee-pee boy)

“The thermodynamics concept was easy to understand and it was easy to listen and watch because it was entertaining” (pee-pee boy)

“It was good to be able to see a temp change, it helped me understand” (heat and temperature)

“Very well explained after attempting to hypothesize the reason. Made a lot of sense about the expansion of the air and the resulting change of pressure” (moveable syringe)

“ILD was paced well and demonstrations clearly related to topic. Also cleared a lot of misconception”

“It was unexpected” (fog in a bottle)

“Still unsure how it works” (fog in a bottle)

“I have seen the similar experiment before” (heat and temperature)

Overall, comments about the ILDs were positive and strongly linked to students understanding the concepts more fully, seeing a different perspective and tying in with the objectives of the course.

In 2011, the Exercise Evaluation form was not yet constructed; however, the standard Physics Lecture Evaluation form was used as a vehicle to garner attitudes towards the

Exercises through the inclusion of an additional single open ended question about the exercises.

Please provide your opinion(s) about the Interactive Exercises you completed throughout the course

For the EX4 stream, 18 of the 50 returned evaluation sheets contained comments for the question related to the Exercises. Of these 18, 12 were positive or very positive about the exercises and even though none were negative, six did not mention the activities at all, either commenting on the fact they appreciated that they encouraged lecture attendance or included positive comments about the lecturer. For the EX3 stream, out of the 80 evaluation sheets that were returned, 37 contained comments for the question related to the exercises. 25 were positive, six did not comment directly about the exercises and six were negative. Of those negative six, all but one (“not really useful”) were negative only due to administrative issues. Examples are included below to illustrate.

Examples of positive, negative and neutral comments:

“I think that they're a good incentive to analyse the content without worry of the consequence.”

“it was a great experience to test myself about this topic. And since the questions covered was about this real life examples, it was more interesting to answer and read the feedback”

“Interesting and useful”

“Interactive Exercises was a great idea to keep up with the workload and have some practical questions”

“Useful in confirming understanding of course content”

“it was sort of distracting trying to do it but also listening to the lecturer”

“I thought it was pretty average. It didn't really help that much, I didn't know whether I got it right or not. Despite this, they helped me think about the relevance of the concepts.”

Student interviews were conducted in Semester 2, 2011 after the course was completed. An email was sent to all students requesting volunteers for a research project and of the five that replied only two were students which took part of the Regular course in Semester one. Both of these students were part of the non-ILD (Interactive Exercise) streams so no elaboration of opinions of the ILDs was possible. Students were not directly asked their opinions about specific parts of the intervention so that their reactions reflected their organic memory of the experience. This resulted in little being said about thermodynamics learning or about the intervention. Since so little was said, all references to the thermal Physics modules or the exercises is provided below in full.

On impressions on the Semester one course:

S1: I think the thermal physics part was what I probably did best at last semester and um... I think that was partially because of the bonus two marks and I attended the most lectures for that module but also the lecturer was really good and he... I mean he really explained things well.

On what they remember about the exercises:

S1: I can't remember specific details but I do remember sometimes I thought that the exercises wasn't that relevant to that particular lecture. Sometimes it was...

H: Would you have preferred it to be relevant?

S1: I suppose it could have been a bit more, its more useful that way because you might remember the content of the lecture more if you have to um... do an exercise like that... yeah... I don't really know what to think of those. Sometimes I thought they were... yeah... sometimes not that relevant to the material so I don't know how beneficial they were... I mean I think it just would have been more helpful if you just got a typical like a Mastering Physics or typical sort of exam question, not too hard but you know that sort of thing, that sort of question might be...

On explaining how an 'Eski'¹³ works

S1: OK, well, so presumably the cans of drink will be at a higher temperature than um the inside of the eski so as soon as you put them in and close the lid they'll start transferring heat energy into the eski into those icepacks and eventually the temperature of the cans of drink and the temperature of the ice packs and the inside of the eski will increase and decrease respectively to the point where they will reach thermal equilibrium.

H: so how do you think energy is transferred in this case

S1: how is it transferred...? Do you mean on a molecular level?

H: Yeah, what is actually happening

S1: oh, well, um... the, the molecules of the cans of drink are they're moving...uh.... faster than the well, first the container that they're in so they will increase the internal energy of that material and then the ...uh... molecules inside the can the material they'll be vibrating I

¹³ The 'Eski' is a thermally insulated portable container used to store or transport food and drink. Eski's are the generic term used for these containers but the name reflects a brand, rather than the object itself.

suppose faster than the molecules of the air and the icepacks next to them so they'll transfer the energy to those molecules.

H: how do they do that?

S1: I don't know... I suppose it's like an abacus like situation

H: so one kind of bumps into the other...

S1: yeah, and travels that way.....

H: and then the whole eski over time?

S1: well it's designed so that it doesn't lose heat very quickly but eventually it's gonna lose some energy over time so after a while um after a long time the inside of the eski will reach the same temperature or close to the same tempereare as the outside...

H: so it will lose energy

S1: um... yeah. It will lose energy. But it won't... yes... it will lose entropy. It'll go into the surroundings so entropy will still increase. And the second law of thermodynamics won't be violated.

On impressions about Semester one course:

S2: I did find the thermal physics pretty interesting, I did do some reading about um... uh... some of the internet in my free time but nothing that would be too relevant to my course, just some things that I felt... do you want me to talk about this...?

H: Yeah

S2: I don't know if you have heard of, oh, you probably heave heard of something like this, I think it was called uh... it was a thought

experiment called 'Maxwell's Demon', so if I remember correctly, it was sort of a box and its uh... divided in two by some sort of a wall and there's a little... in one chamber there's a gas of some temperature and the other chamber is colder and there's a gap in the wall separating the two chambers and a little demon and somehow he's able to ...um... only allow molecules of a certain speed to pass through so the idea is that um... if you could do that... the uh... if you could make the entropy of the system involving the box of hot molecules uh... decrease or something like that its supposed to be in violation of the second law but then um... someone said uh... for him to do that he would actually have to use energy... yeah... so

On the exercises:

S2: They were a little bit distracting cause we weren't really given time to do it so either you are paying attention to the lecturer or trying to do it... I thought they were pretty... they weren't too complicated... you didn't need to think too hard about it... they were pretty easy to fill out... it helps you think about it.

T: Did you... um... were you encouraged to turn up to those lectures because of those bonus marks that were attached to those exercises?

S2: Yeah, I go to all of my lectures anyway but I guess it does, it's more of an incentive.

On explaining how an Eski works:

S: Well, the heat flows from warm to cold and the cans are warmer than the ice so the heat flows out of them into the ice until they reach the same temperature like so the ice warms up while the cans cool down

until they become the same temperature and then they slowly they'll slowly interacting with the air outside because it's not completely um... um.... it's not uh... completely closed system so um.... um... heat does slowly seep in to the eski and it slowly all warms up until it's the same temperature as the air outside.

7.5 Discussion

Overall, the normalized gain for the 2011 cohort on the thermodynamics module as measured by the TCS was 0.29. Hake's measure of normalized gain allows some inferences to be made about the degree of student success at the completion of a course. His large study indicates that in mechanics, a gain of about 0.23 is considered normal for 'traditional' lectures. There exist very few studies that use normalized gain in thermodynamics courses at the tertiary level, particularly that compare 'traditional' with Interactive Engagement methods, so it is difficult to be conclusive about whether the overall gain of 0.29 is a low, medium or high gain. For example, a study of thermal concepts in a first year Engineering course reports gains of up to 0.9 for individual questions and 0.4 on a conceptual survey after implementing 'inquiry based' learning. However, by their own account, they use surveys that are not validated or consistent (Prince, Vigeant, & Nottis, 2009). In 2012, the same authors constructed and validated a thermal concepts survey, predominantly on heat and temperature (similar to Part I of our TCS) and showed very mild gains of 0.10 (Prince, Vigeant, & Nottis, 2012), citing the inherent conceptual difficulty of concept surveys as the reason for the very slight gain. Meltzer, in his teams' extensive work on thermodynamics, also includes an analysis of the introduction of Active Learning methods. However, these results are mostly qualitative, not pre- and post- and overall inconclusive, showing little improvement in student understanding. Given the vast data on mechanics, an overall gain of 0.29 can be therefore tentatively declared as medium to high. A more thorough analysis of normalized gain was performed in Study Two, where pre-test scores for individual students were collected.

Students performed satisfactorily –and consistently –in most measures of learning outcomes; the TCS, final exam and Q4 on the final exam saw scores averaging around 55% on each. However, students were less successful with Q9, scoring on average 48%, and a concerning 25% on Q10, which was the lowest scoring question in the exam. This suggests several important issues. Firstly, one measure of student achievement may not be sufficient in concluding students are proficient in thermodynamics concepts. Secondly, thermodynamics is still a very troublesome topic in first year Physics. The ability to apply thermodynamics to everyday situations was also not particularly sophisticated after the course, with one student explaining that a cool Esky will become warmer over time by losing energy and another saying that heat will flow into the system because it is not ‘a completely closed’ system. This supports previous research showing that students have trouble applying their thermodynamics knowledge to real world situations, particularly if they apply of the ‘heat as substance’ view.

The comparisons between streams showed that there were no differences in means for any of the measured learning outcomes. One weakness of the 2011 implementation was that the streams could not be satisfactorily assumed as identical. Although the streams were identical with respect to ATAR and physics background, only 60% of the sample was accounted for. This may have had an effect on the improvements on the pre- and post- tests and the overall learning outcomes, since students with missing scores are students who have completed high school in other states or countries and thus represent a highly variable sample. These issues are to be rectified in Study Two by ensuring samples are identical with respect to pre-test scores instead.

In terms of the analyses of the course, several general conclusions can be made. Firstly, it was clear that the introduction of the ILDs in Streams one and two increased the level that students were physically ‘engaging’ with the lecturer and demonstration. A comparison between the two ILD streams shows that ILD1 exhibited twice as much Interactivity as ILD2, 23% versus 11%. Further analysis shows that the difference manifested itself in both how much time was spent on interactivity-based activity during the ILD program and also, how much persisted in the non-experimental

lectures. For example, recall that the item on the ILD evaluation: ‘I had opportunities to discuss with my peers’ was rated significantly lower for ILD2 compared to ILD1. That is, Staff-2 both spent less time allowing ‘interaction’ to occur during the ILDs, but also did not engage in any ‘Interactive’ teaching during the remaining lectures. This can be clearly seen with reference to the Lecture Activity coding of EX1 which was the other stream taken by Staff-2, where less than two minutes of Interactivity during the nine one-hour lectures took place. Therefore, even with only three different staff, there is a significant difference in how they choose to divide lecture time for different activities, despite similar lecture notes and identical curricula.

Students provided some insight into how these differences, and the program in general, were perceived through the evaluation surveys and interviews. Overall, students were very positive about both the ILDs and the Interactive Exercises. ILDs have known to produce positive attitudinal gains amongst students and as such, this finding is not incredibly surprising. Students appreciate “clearly seeing” the concepts in a way that was considered “entertaining”. However, it was found that students also appreciated the opportunity to make predictions beforehand, as seen in comments such as: “very well explained after attempting to hypothesize the reason” and “it was unexpected”, “also cleared a lot of misconception”.

What was most surprising was that the students, without coaxing beyond the presence of a single optional question on the lecture evaluation form, were overwhelmingly supportive of the Interactive Exercises. Particularly striking was students’ appreciation that the Exercises were low stakes (marks were only allocated for completion and feedback was provided in a timely fashion), were based on everyday occurrences, were interesting and were a way of bringing together the various concepts in the course. The majority of negative comments referred to logistical issues. This feedback confirms that the Exercises were indeed ‘context-rich problems’ and a form of Interactive engagement: students recognised them as a distinct activity, separate from the lectures, and engaged in ‘Active Learning’, despite not necessarily discussing them with peers or the lecturer.

The findings related to student engagement are expanded on to include these other important factors in Study Two. That is, more analysis will be conducted to appropriately consider 'hands on' as well as 'minds on' Active Learning, specifically addressing questions around how the students respond to different types of lecture activity, what do students' think about these differences and do different types of lecture have any effect on student learning outcomes. These findings will occur in the context of the amended research methods, particularly the control of student backgrounds (degrees) and pre-test scores for Study Two.

8 Study Two 2012

8.1 Aim

The aims of Study Two extend those in Study One and are as follows:

1. To determine the overall learning gains of students during the thermodynamics module as measured by the pre- and post- TCS part I
2. To determine whether there was a difference in learning outcomes for students using the measures of TCS gains
3. To explore whether there were differences in final scores: post-test, in thermodynamics questions in the final exam and overall final exam score
4. To examine student attitudes towards the two methods of IE through student evaluation surveys and interviews
5. To characterise the lectures with respect to the interactivity present in the lecture streams and the degree to which students are engaging throughout the thermodynamics module as measured by the full LASE protocol

8.2 Sample- allocation of streams

In Study Two, after students had been administratively allocated to streams, student demographics were acquired and revealed similar imbalances to Study One (Engineers versus Science/Medical Science degrees). Given this information was provided a-priori,

the three staff teaching the course voluntarily switched streams in order to have the appropriate distributions of Engineer's and Science students across the streams.

8.2.1 Numbers

Students were counted at each lecture and attendance throughout the course was recorded (Table 8-1). Attendance remained relatively constant throughout the module.

Stream no.	Lect. Attend.	1	2	3	4	5	6	7	8	9	10
Stream 4	ILD1	59	65	71	56	??	??	56	??	59	69
Stream 2	ILD2	87	??	99	105	85	92	105	??	84	116
Stream 3	EX1	83	72	92	78	70	73	82	??	77	88
Stream 1	EX2	98	91	106	92	96	87	92	??	100	106

Table 8-1 Lecture attendance for the four streams. Some data are missing due to faulty counting equipment.

The coding of the lecture streams retained consistency with 2011, naming in relation to lecturer and treatment (ILD or EX). Therefore, ILD1 was the stream taught by Staff-1 and included the ILD in both years. ILD2 and EX1 were the streams taught by Staff-2, indicating the respective implementations and EX2 was the stream taught by Staff-3. This was considered the best way to represent this information. However, it must be noted that the time and day of the lectures was different in streams of the same name in different years.

The same measures of sample size were considered for the 2012 implementation, although in this year, additional sample number information also existed for the pre-TCS. Therefore, for the gain measurements, the sample number reflected students who completed both the pre- and post- TCS as well as attended three of four experiment lectures. For comparison of other measures (full post-test, thermodynamics questions and final exam), the sample size was different and reflected the students who were assigned to the streams and completed each measure.

Codename	Potential no.	Full participants	Retention
ILD1	81	65	0.80
ILD2	129	88	0.68
EX1	105	84	0.80
EX2	127	94	0.74

Table 8-2 Sample size and retention

8.2.2 Homogenous sample

Due to the issues discussed in 2011 with ATAR and Physics marks, the samples were further characterised by their TCS pre-test scores in 2012. There were no statistically significant differences in the pre-test scores between streams (ANOVA, $F(3,387)=1.679$, $p=.171$). This is also the case for gain measurements where the full-participant subsample was used (Table 8-3).

	N	Average	St. Dev
ILD1	68	9.24	3.27
ILD2	112	8.41	3.29
EX1	96	9.21	2.78
EX2	115	9.06	3.27

Table 8-3 Pre-test scores of four streams

8.2.3 Degrees enrolled in

Given a knowledge of the imbalances in degrees across streams in 2011, corrections occurring in 2012 resulted in a more even allocation between ILD and EX streams. To begin with, the 2012 data show that there was a significant change in the students taking Regular Physics with respect to degree. There were a much high proportion of B.E students and a much lower proportion of students in Medical Science degrees and the 'other' category Figure 8-1.

Figure 8-1 Degrees enrolled by sample

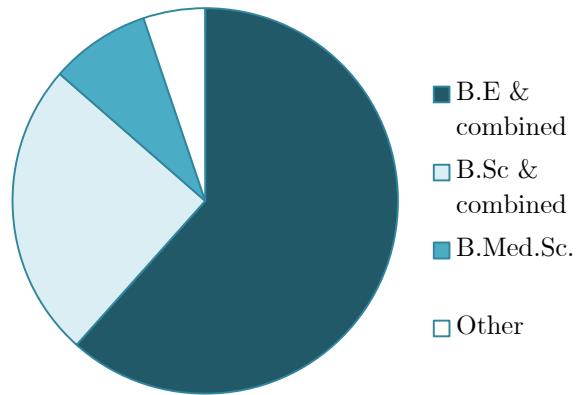
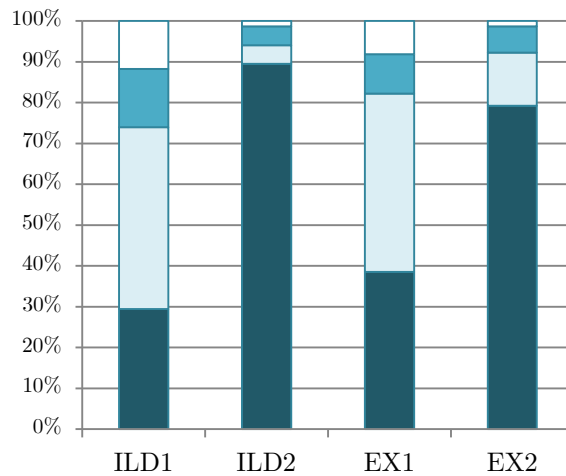


Figure 8-2 shows that ILD2 and EX2 consist of Bachelor of Engineering students while ILD1 and EX1 have a more diverse sample predominantly consisting of Bachelor of Science and Bachelor of Medical Science students.

Figure 8-2 Degrees enrolled by stream

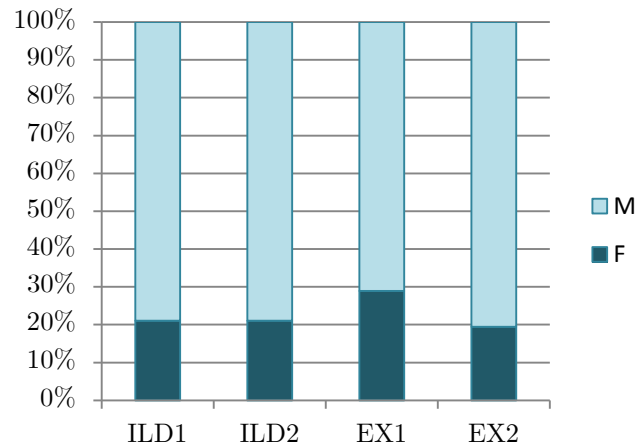


8.2.4 Gender

In 2012, the proportions of females to males in each stream were even more similar than 2011, however, there was a decline in the overall proportion of females, from 31% to 27% across the Regular group overall. This change and the decrease in Medical

Science students can be attributed to the abolition of Physics pre-requisite for the Medical Sciences degrees, resulting in many students opting out of Physics, including many of the females this degree attracts.

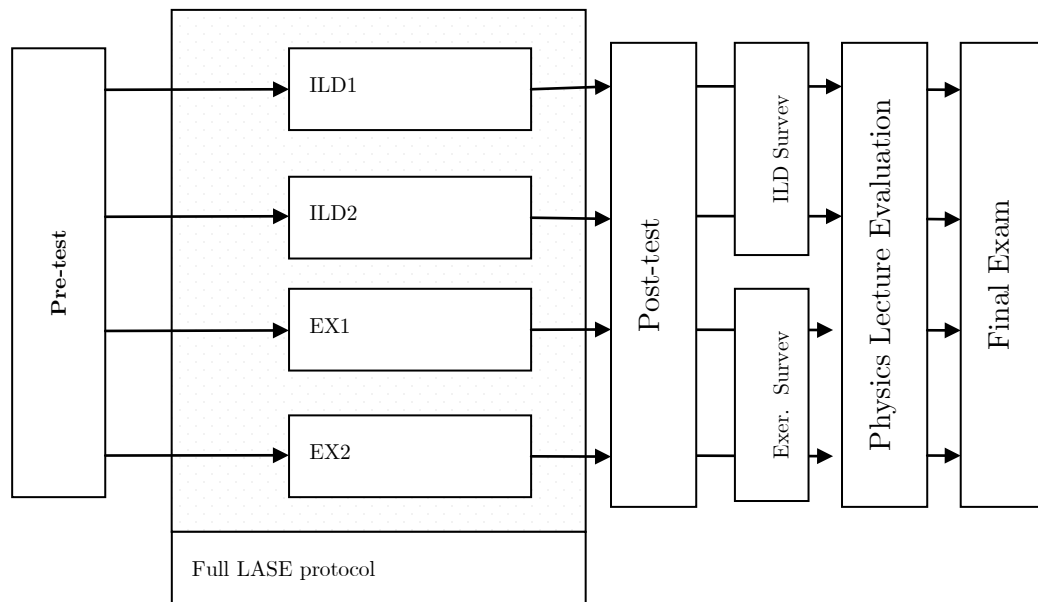
Figure 8-3 Proportions of males and females by stream



8.3 Method

A flow chart of the improved method is shown in Figure 8-4.

Figure 8-4 Flow chart of 2012 Implementation.



8.4 Results

8.4.1 Learning outcomes- overall

The overall gains were calculated in the same manner as in 2011, with the full sample for pre- and post- tests, with the post scores being out of 16. The sample size for the pre-test was lower due to logistical issues at the time of administration which made it difficult to capture as many students as in the previous year.

The overall cohort gain of 0.28 was effectively identical to 2011. Differences between the streams and increases in this value are seen when considering full-participants (Table 8-4).

	Pre /16	Post /16
N	391	379
Mean	8.94	10.96
St Dev	3.03	2.45
Gain	0.28	

Table 8-4 Overall scores and learning gains on TCS (Part I)

8.4.2 Learning outcomes- gains on TCS with full participants

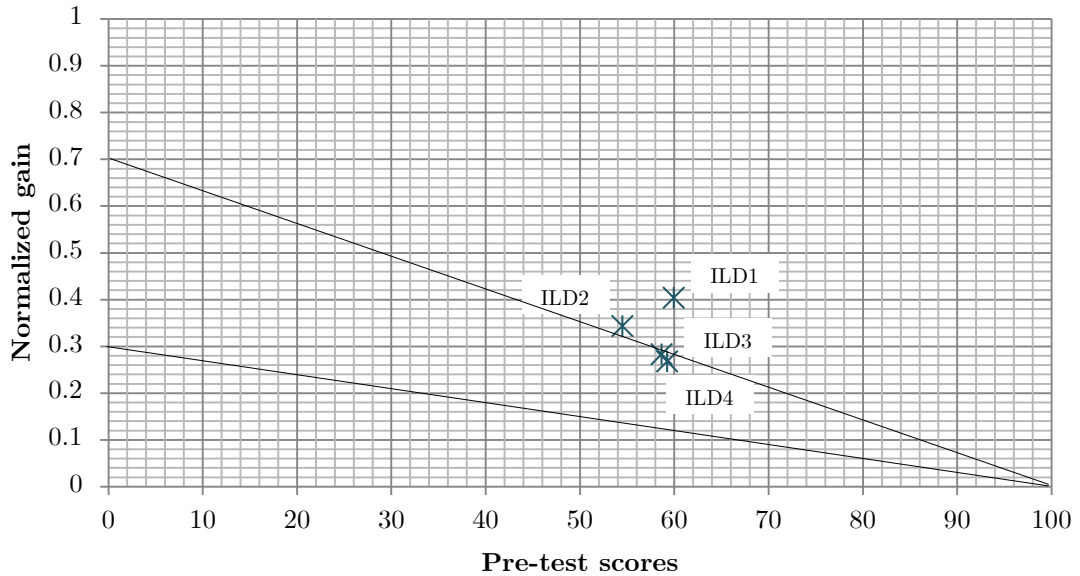
The full participant sample for the whole cohort and the full participant subsamples were all normally distributed with respect to pre- and post- scores. The overall gain and the gains for individual streams are provided in Table 8-5 below. These gains were averaged for students who had completed both the pre- and post test and were full participants, hence the sample number is decreased overall from the overall gain, and the overall gain different from Table 8-4.

	N	Pre-test /16		Post- test /16		Gains (part only)	I
		Mean	St. Dev.	Mean	St. Dev		
ILD1	34	9.59	3.53	12.17	2.18	0.40	0.35
ILD2	60	8.72	3.41	11.21	2.20	0.34	
EX1	55	9.38	2.70	11.25	2.31	0.28	0.26
EX2	63	9.48	2.53	11.22	2.17	0.27	
Overall	212	9.25	3.01	11.38	2.23	0.31	

Table 8-5 Pre- and Post-test scores for the four streams, and normalized gain measures

ILD1 shows the largest gain, followed by ILD2 then EX1 and EX2. These results can be put on a Hake plot, to determine relative gains with respect to pre-test scores (Figure 8-5).

Figure 8-5 Pre-test scores vs. Normalized gain for the four streams. Lines demarcate areas of Hake's Low, Medium and High Gain areas (1998)



The pre-test scores have been changed to percentages here and when placing boundaries at 0.3 and 0.7 on the normalized gain axis to indicate areas of medium and high gains as described by Hake (1998). ILD1 is the most conspicuous extrusion.

8.4.3 Learning outcomes- other measures

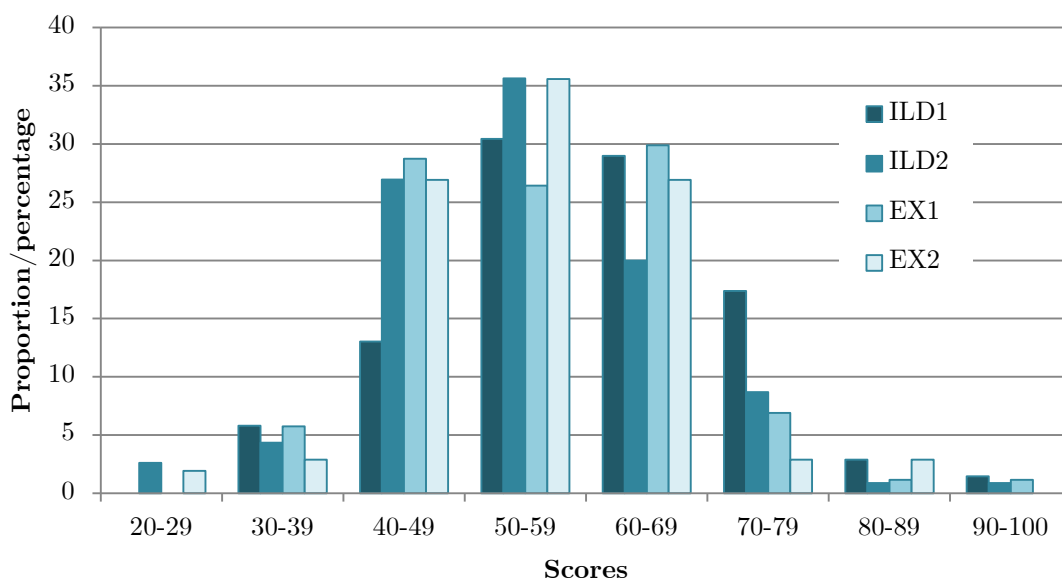
Next were the comparisons across streams using the remaining measures: TCS post-scores, marks on thermodynamics questions in final exam, and total mark in the final exam. An ANOVA (equal variances not assumed) on the post-test (Part I and II) scores shows that the means between streams were significantly different, $F(3, 371)=3.001$, $p=.032$. There was also a difference in means between the streams for the final exam mark, $F(3,559)=2.856$, $p=.037$ respectively. For the post-test, ILD1 had the highest mean, whilst on the final exam, EX2's mean was higher (Table 8-6). The difference sample reflects a greater number of students completing that full post-test than the 'full-participant' sample used for the gain analysis.

Stream	Post test (/35)			Final exam									
	N	Mean	St. Dev	N	Q4 (/5)		Q9 (/10)		Q10 (/10)		Total (/90)		
					Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	
4	ILD1	69	20.72	4.31	119	1.58	1.37	3.69	2.86	3.13	2.61	40.34	20.00
2	ILD2	115	18.96	4.14	152	1.68	1.39	3.96	2.72	3.68	2.82	46.36	19.04
3	EX1	87	19.36	3.97	135	1.66	1.36	3.98	2.92	3.97	2.74	44.24	20.06
1	EX2	104	19.23	3.74	154	1.95	1.42	4.05	2.66	3.84	2.71	46.34	17.42
TOTAL		375	19.45	4.06	560	1.73	1.39	3.93	2.78	3.68	2.73	44.56	19.17

Table 8-6 Post-test and Final Exam scores (including all thermodynamics questions) for the four streams

There was also a difference in the distributions of the post-test scores as measured by a Chi-squared test, showing that the differences in means as revealed by the ANOVA was due to a lower percentage of ILD1 scoring in the 40-49 bracket offset by a higher percentage in the 70-79 bracket, $p<.05$ (Figure 8-6).

Figure 8-6 Distributions of scores for the four streams



Explorative tests were done for gender and degree with respect to learning outcomes including post-test, final exam and all questions on the final exam. There was no significant differences between male and female performance on any thermodynamics outcome measures (post-test and thermodynamics questions in the exam). However, an independent t-test indicated that there was a significant difference in scores for Q2 in the exam between females ($M=2.54$, $SD=1.34$) and males ($M=2.94$, $SD=1.45$), conditions $t(556)=2.792$, $p=.005$. This was a question about free-body force diagrams for a swinging pendulum.

Although the possibility of differences in learning outcomes for different degrees was considered, no differences were found in any of the thermodynamics measures. There were, however, only significant differences found in several questions between different degrees and the exam overall with respect to the ‘other’ degree category. When removing differences caused by the degree category ‘other’ (due to its small size) and considering substantive post-hoc tests for individual questions only, two questions emerged as potentially of interest: Question 1 and Question 7 (see Supplementary Materials). An ANOVA (equal variances not assumed) on the question one and

question seven scores shows that the means between Bachelor of Science students and Bachelor Engineering students were significantly different, $F(3, 537)=8.836$, $p<<.050$ and $F(3, 537)=5.827$, $p=.001$. Both of these questions are quantitative in nature and the Engineers outperformed the Science students in both.

8.4.4 Other results

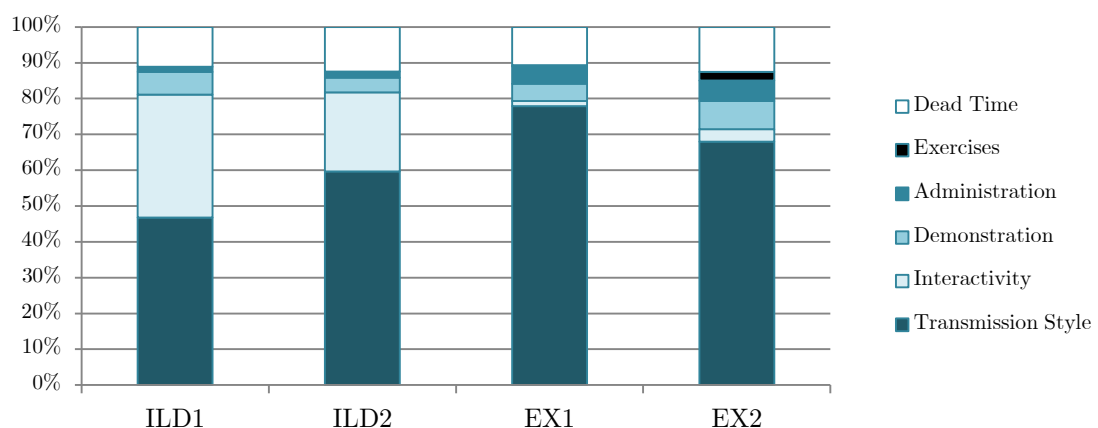
This section of the results will characterise the degree of fidelity of the implementation of the Interactive Engagement techniques, both the ILDs and the Interactive Exercises, as measured by the LASE tool. The experience of the Active Learning implementation by the students is also reported in this section, as measured by the Physics Lecture Evaluations, the ILD and IE evaluation surveys and student interviews.

LASE

The LA part of the LASE was deployed and analysed in the same fashion as in 2011. The overall breakdown of each stream's time allocation of the different lecture activities as an average across the whole course (excluding lecture ten which consisted of the completion of the quiz) is shown in Figure 8-7. Due to bad recording, lectures six and seven were also not included in the average calculation since data could not be gathered for the full hour for all streams. Since these two lectures contain one experiment and one non-experiment lecture, the removal of these two lectures is not expected to alter the average measures significantly.

On average ILD1 exhibited the highest proportion of Interactivity (I) teaching, followed by ILD2, EX2 and lastly EX1.

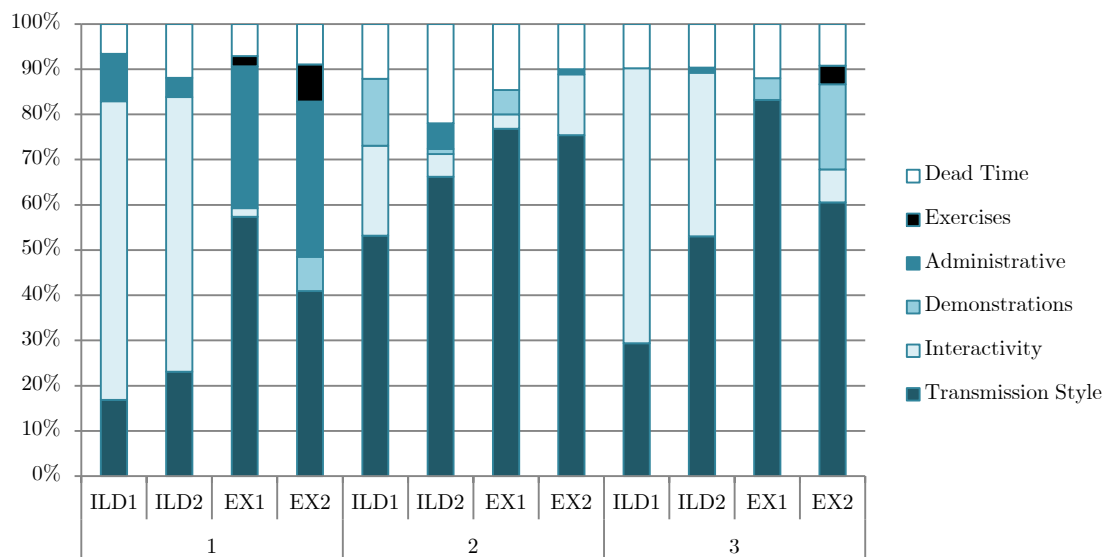
Figure 8-7 Lecture Activity coding by Stream



Data for the first three lectures is provided to illustrate how these average values translated to individual lectures of different types (Figure 8-8); the ‘first’ lecture, the ‘non-experiment’ lecture and the ‘experiment’ lecture (that wasn’t also the first lecture of the module). Lecture 1 naturally presented the most Administrative teaching with ILD1 and ILD2 showing significantly less administrative activities than the other non-ILD streams. This was presumably due to the lecture having the largest suite of ILDs to get through. This assertion is also supported by the very large portion of time (around 70-75%) dedicated to the ILDs themselves. This lecture recorded the minimum time spent on Transmission-Style teaching in the whole module and occurred with ILD1; less than 10 minutes was spent giving direct instruction in this instance. Lecture 2 supports results from 2011 data that shows that in non-experiment lectures, Staff-2 lectured identically between their ILD and Interactive Exercise stream; a claim further substantiated through observations, lecture slides and descriptive field notes. Staff-2 did spend some time on administrative details for the ILD2 stream, presumably to make up for the lack of time in lecture 1 due to time pressures for the ILD program. In contrast, ILD1 still maintained a high level of Interactivity (around 20%- the highest), despite lecture 2 being a non-experiment lecture. Staff-3 also showed a considerable amount of Interactivity (just over 10%) in this lecture, in contrast to lecture 1 where the focus was on administration, demonstrations and giving students time to complete the Interactive Exercises.

In lecture 3, another experiment lecture, several results appear: Firstly, there was almost twice as much Interactivity in ILD1 compared to ILD2, despite both completing the ILD program. This is accounted for in two ways: Staff-1 spent more time on the ILDs, particularly in providing more time for student discussion, and Staff-1 also included Interactivity in addition to the ILDs in the form of clicker questions and Peer Instruction. An example can be seen from the coding excerpt in Table 8-7. It is also evident that Staff-3 in EX2 provided explicit time for the completion of the exercises in Lecture 3 whereas the students in EX1 did not receive this time. EX2 also spent more time on demonstrations.

Figure 8-8 Lecture Activity coding for the four streams and for the first three lectures. Each lecture is one hour in total



	ILD1 (min:sec)	ILD2 (min:sec)
First ILD	9:16	6:56
Second ILD	6:39	5:36
Third ILD	7:02	7:27
Other	7:54	0:00
Total	30:51	19:59

Table 8-7 Breakdown of activities coded as ‘Interactivity’ during lecture 7

The LASE has the potential for development. One issue identified within this project was the overgeneralisation of categories described. The 2011 data were used to delve further into the coding categories in 2012. Particularly interesting was how each lecturer approached worked examples. Worked examples, or ‘problems’ as the School of Physics commonly refers to them, are usually presented during lecture time at the discretion of the lecturer. In this particular course, several worked examples were common across the four streams. However, there was a difference in the examples selected and the number that could be significant. Almost all examples were included in the lecture notes along with solutions. See Table 8-8 for details about which content the worked examples were based on for each stream and how many were present across the course.

Figure 8-9 A worked example presented in all four streams. **ISEE** refers to a heuristic offered to students to aid with development of good problem solving techniques. It stands for ‘Identify, Set-up, Execute, Evaluate’.

A surveyor uses a steel measuring tape that is exactly 50.000m at a temperature of 20°C. What is the length on a hot summer day when the temperature is 35°C?

Solution: (ISEE)

a) $L_0=50.000\text{m}$ $\Delta T= (35-20) \text{ }^\circ\text{C} = 15^\circ\text{C}$ $\alpha= 1.2\times 10^{-5}$

$$L= L_0 (1+ \alpha \Delta T) = 50.009 \text{ m}$$

EX2 went through the most examples. One of these examples is provided for illustration in Figure 8-9.

ILD1	ILD2	EX1	EX2
Coffee cup and systems	Coffee cup and systems	Coffee cup and systems	Coffee cup and systems
Skin as a thermometer	Skin as a thermometer	Skin as a thermometer	Skin as thermometer
Length expansion	Length expansion	Length expansion	Length expansion
Specific heat	Specific heat	Naked person radiation	Conductivity
Coffee cup entropy	Coffee cup entropy	Ideal gas container	Radiation
Ideal gas in cylinder	Ideal gas in cylinder	Specific heat	Temperature in radiative heat transfer
		Coffee cup entropy	Specific heat
		Ideal gas in cylinder	Magdeburg plates
			Coffee cup entropy
			Ideal gas in cylinder
			Heat engines

Table 8-8 List of worked examples in the four streams.

In General, little time was spent on these examples (<1-3minutes). Commonly, an explanation of the problem would be offered, then a conceptual discussion of the underlying physics, then a brief explanation of the maths (or reference to the solution). Across the four streams, the most time was spent on the ‘coffee cup entropy’ example and the ‘ideal gas in cylinder’ example. The coffee cup entropy example was the longest and was done by all four streams and all lecturers (Figure 8-10). Some similarities and differences between how lecturers approached this example are provided to demonstrate differences within the Transmission-Style category in the LASE. Although it is difficult to quantify or qualify how lecturers are different, this certainly helps.

The coffee cup example was as follows:

Figure 8-10 The coffee cup example common to all four streams. Of all examples, lecturers from all streams spent the most amount of time on this example in lecture time.

A mug of coffee cools from 100°C to room temperature 20°C . The mass of the coffee is $m=0.25\text{kg}$ and its specific heat capacity may be assumed to be equal to that of water, $c=4190\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$. What is the change in entropy of the coffee, of the surroundings and change in entropy of coffee plus surroundings?

Staff-2 spent the most amount of time on this example, writing much of the mathematics on the board. Staff-1 and Staff-3 spent less time on this example. Each lecturer chose to focus on different aspects of the example. Staff-1 highlighted the conceptual aspects of the question, with strong links to the coffee cup and what was happening. Staff-2 focused on boundaries and applications of the theory, whilst Staff-3 favoured a walkthrough of the question which stemmed from an initial ‘guess’ of what the ultimate answer would be. Staff-1 and Staff-3 both asked students for input; Staff-1 gave students time to speak with each other and Staff-3 took a vote about whether the entropy would increase, decrease or stay the same. This is but one example of how one type of coding, representing ‘Transmission-Style’ teaching, displayed a fair amount of heterogeneity (Table 8-9).

	Staff-1	Staff-2	Staff-3
Time spent on problem (Min:sec)	6:35	10:15	3:39
Brief explanation of approach	Lecturer M introduces the problem, talks about it conceptually, skips over the maths then gives students 30s to talk about it. After this, goes through the maths (on the slide).	Introduces question, introduces variables then, on the board, goes through the steps of the working out, including integral, emphasising units and boundaries of systems.	Introduces question then asks what students would expect the entropy change to be for each part (positive, negative, zero) then briefly shows working on slide.
Working out	On slide	On board, working out as you go	On Slide
Interactivity	Yes 30s discussion	No	Yes, positive, negative or zero question
Selected quotes	“Now in terms of conceptually, the coffee is cooling ...when we look at the two together it should be greater than zero. Now the coffee itself. we used our equation for entropy and we do the integral...we plug the numbers in and we get a negative value. I'll give you two seconds to talk about it....”	" So we should look at the net change, the total change in entropy is $33\text{J}\cdot\text{K}^{-1}$ so it's positive value... it's consistent with second law...because I put my boundary right...the new boundary makes the whole system an isolated system...”	"A mug of coffee at a particular temperature is cooling down and you are asked to find the change in entropy of the coffee and the coffee and air. Do we expect the entropy change for the air to be positive or negative? What about for the coffee? So we can go ahead and ...calculate quantitatively what is going on....”
Student questions?	no	no	no

Table 8-9 A description of how each different lecturer presented the 'coffee cup' example

The Student Engagement part of the LASE (5.2.3) helps illuminate the other side of this equation; what the students were doing during these lecture driven activities. The SE was deployed in lectures two, three, five and seven, meaning they covered two experiment lectures and two non-experiment lectures. All streams were observed. The primary quantitative measure within the data collection is the proportion of the students ‘engaged’. Students were ‘engaged’ if their attention was focused and they were fully participating in the activity that the lecturer was assigning. Other categories included ‘distracted’ and ‘writing’. Ten students were observed each time period and there were five periods that were observed across four lectures in total. Proportions expressed as percentages could be expressed for an individual time period or as an average. Statistical analyses were not deemed appropriate with the size of the subsamples when comparing across lecturers, streams or certain activities. Qualitative data included all other field notes which were directed at: general observations, what students were doing when they were either paying attention or not, late arrivals/early

departures, use of technology in lectures, materials brought to lectures and any noteworthy events.

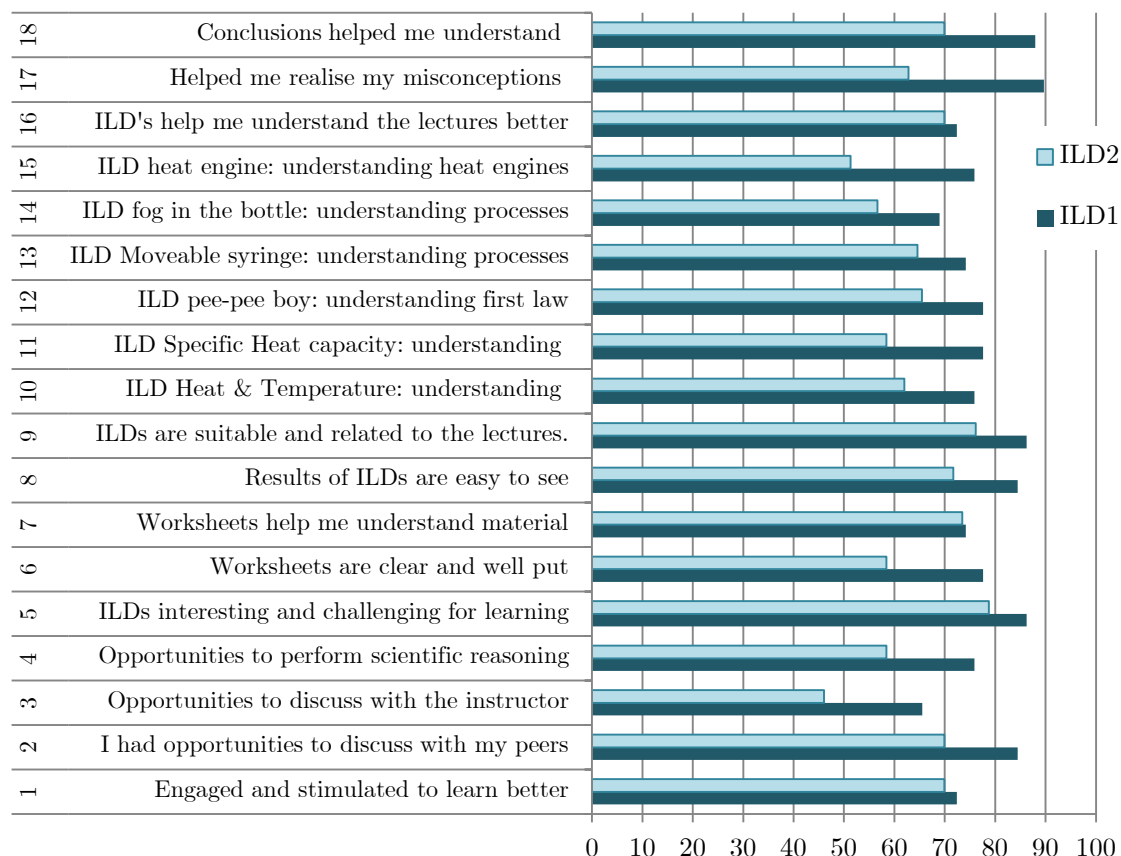
Generally, students were not persistently distracted (playing on their phones, speaking to their neighbours or sleeping/daydreaming). Overall, nine out of ten students were engaged as an average. Full engagement (100%) occurred at least once for all lecturers and for all types of activities, from Transmission-Style teaching to Interactive teaching. For example, 100% of students were engaged in the following situations: with Staff-3 during Transmission-Style teaching in lecture 3, with Staff-2 during a demonstration in lecture 5 and with Staff-1 during an introduction in lecture 5. The lowest levels of engagement occurred across similar situations: 50% during Transmission-Style lecturing in lecture 5 with Staff-3, 60% during Transmission-Style teaching with Staff-2 in lecture 7 and 30% for Interaction teaching (buzz questions) with Staff-1. That is, it was not straightforward to make conclusions about which activities, lectures or lecturers were more successful in engaging the students. However, given the LA and field note data, some more specific conclusions may be reached. Firstly, very few students were taking notes during the lecture- with the exception of the ILD or IE program and when staff wrote on the board. That is, students were not writing down their own notes or thoughts throughout the lecture and only copied derivations wholesale when the lecturer was writing them up as they went. This was also the case with students with laptops. Secondly, although it is often reported that students tend to lose interest and become distracted when given the opportunity to have discussions with friends during ILDs, this was controlled quite heavily and effectively by Staff-1 and Staff-2. If students were seen to be off task, Peer Instruction was halted, and if students took longer than expected to settle back into listening, they were very quickly reprimanded. Conversely, Staff-3, who displayed more tolerance and patience, often waited the longest to remind students that they were not to be talking when he was talking unless they had a question to ask. It is safe to say in this case that lecturer disposition was also an important factor in 'engagement'. A final observation was the comparison between the ILD and EX implementations. More targeted field notes were taken during the ILD implementation, to account for how students were taking to the

ILD activities- particularly during the different stages of ILDs. During the observations, records show up to ten students did not partake in the Peer Instruction part of the ILD program for ILD2, while ILD1 show that of the 10 students that were observed, the most that did not take part in discussion with peers when asked was four.

Evaluations

In 2012, further surveys were deployed to gather student's thoughts on the IE techniques used in the thermodynamics modules; both the ILDs and the Exercises. With respect to the former, the ILD survey was administered to ILD1 and ILD2 ($N=58$, $N=113$) as it was in 2011.

Figure 8-11 Results from ILD Survey for ILD1 and ILD2. Percentages represent the combined upper two scores on a 5 point Likert scale. Questions have been summarised. See Appendix I for details.



As with the 2011 implementation, the 2012 evaluations indicate that the ILD experience was overwhelmingly positive for the students (Figure 8-11). Unlike the 2011 implementation, the 2012 implementation shows large disparities between the two ILD streams. Supporting evidence from the LASE, student responses on the ILD evaluation show that there were considerable logistical or administrative differences between ILD1 and ILD2. For example, only 70% of students in ILD2 stated that they ‘agree’ or ‘strongly agree’ with the statement that they had opportunities to discuss with their peers, compared to 85% of ILD1. More telling was that less than half of students in ILD2 stated they had opportunities to speak with the lecturer compared to 65% of ILD1. Finally, students in ILD2 also rated this stream lower on ‘clear and well put’ and ‘easy to see’ when compared to the students in ILD1.

Such logistical and administrative differences seem to manifest themselves in differences in terms of student attitudes toward understanding. For example, students in ILD1 consistently rated the ‘understanding’ questions much higher than students in ILD2. The specific heat capacity and heat engine understanding between the two streams showed the largest disparity with only 50% of ILD2 saying that they understood heat engines better after the demonstration whilst 75% of ILD1 students responding in the affirmative for this demonstration. Perhaps the most surprising result was related to questions 17 and 18, which asked students to comment on the effectiveness of making predictions before the demonstrations and commenting on whether the conclusions reached after the demonstration helped them understand the content better. Only 60-70% of ILD2 students agreed with this statement, yet this agreement occurred for around 90% of ILD1 students for both questions.

Students expanded on these selections by providing comments. Unlike the standard Physics Lecture Evaluations, most students provided written feedback to support their Likert selections. In terms of general attitudes towards the ILDs:

“It got me to think about the multiple processes, as well as providing a good laugh to break up the lecture”

“My predictions were correct! Also, it was really interesting and I understood the concept well”

“Thermal physics has been one of the best classes I've been to, the lecturer is very easy to understand, maybe going a little slower with ILD's, but otherwise all very helpful.”

The following quotation was from a student in ILD2:

“Be careful not to explain too briefly before doing the demonstration, if the theory is missed the prac makes no sense”

This attitude was common amongst students in ILD2. When asked about the reasons why they listed their least favourite ILD or the one that they understood the least, students remarked that the ILD was discussed too briefly, the demonstration did not make sense, it wasn't well explained, it was too complicated and it was unclear: “Very brief, unclear explanation then quick demonstration and move on”. Whereas responses from ILD1 were more focused on personal tastes or whether or not the ILD was exciting or not, e.g. for the heat engine demonstration: “No other reason, than I already understood this” and “Interesting but less fun”

When students remarked positively, students from both streams stated that the ILDs were easy to understand, they (the results) were unexpected, the concepts were clear, the students were happy to see their prediction right or wrong, the ILDs were relevant, made sense, evoked curiosity and were fun and exciting.

In 2012, the Exercise Evaluation form was deployed to both EX streams to garner more direct and specific attitudes towards the exercises. In terms of logistics, students on average took about 8 minutes to complete the exercises. They also reported to have completed 2.6 exercises and accessed 1.2 solutions from the online resources on average. The results from students' responses are presented in Table 8-10.

Interesting	Clear	Related to study	Deeper understanding	Completed independently	Completed with effort
42.11%	59.21%	72.37%	38.16%	64.47%	72.37%

Table 8-10 Percentage of students selecting the highest two levels on a five point Likert scale

Most of the comments related to the logistics of the exercises, such as the bonus marks and where to access solutions. Some remarked that they needed to contain more calculations.

Student interviews were conducted in Semester 2, 2012 after the course was completed. Students were directly recruited by the researcher in the form of an announcement made during tutorials. In total, five students volunteered to be interviewed.

The more comprehensive explanations firstly enabled some insight in to where lectures fit into the ‘grand scheme of things’ for students. In general, there was the attitude that lectures and tutorials were the primary and most efficient aspect of the course in terms of learning.

“the lectures I went to every lecture and that really helped and all the in class exercises were really good because they made sure you were up to date with everything.” (S1)

“I think the lectures were probably the most helpful thing.. tutorials were good as well but it sort of depended on who you were with...” (S2)

“I believe there are times when one person sees a problem, they won't be able to see the whole aspect of a problem but if you introduce a third party to a problem they might be able to see aspects you weren't able to see. And I think that's what the workshop actually brings to the whole table.” (S3)

Although students spoke favourably about the Workshop Tutorials, they also explained that their success was contingent on a number of factors.

“... so if you were in a group and if you were the person who sort of knew the most and you still didn't know something it sort of was like... you had to ask the tutor.. and the tutor would tell you but you sort of liked working it out amongst yourselves.. a lot of the time people wouldn't ask... I think that's sort of a problem. But when you are with someone that's like 'oh yeah, I know that' and they teach you and you know the next question and you teach everyone that I think that that was very helpful so it's good to work with others but it sort of depends on who you end up with.” (S1)

“I think it's more like if the person doesn't understand physics and they're trying to explain the problem to another person just based on... because they have a solution... probably it's not going to help the student learn much at all.” (S2)

“I remember during that period we have group... two of the people they discussed privately what they discuss and they only two people trying to solve the problem.” (S3)

“If the solution is being presented then you lost the chance.. you lost the opportunity to think about the problem then if we not be able.. if we are not being able to think about the problems that we are dealing with properly then how can we solve another similar type of problem?” (S5)

Students generally considered the lab work to be comprehensive and enjoyable but tedious; they were critical of the lack of complementarity between the lecture course and the laboratory program:

“The labs are good but at the same time I think we were more focusing on getting techniques right rather than the actual concepts so it was good practice but it didn't really teach me about the course itself.. (the actual concept) yeah, the concept” (S1)

“The labs seem a little bit disconnected (laughs)... yeah. At times I do feel like the checkpoint techniques is a bit slow because trying to get through each checkpoint that means um... if we stay on one checkpoint for too long we probably wouldn't be able to finish a whole lab. Um... I think it's a good learning experience just doing the lab to get hands on physics rather than just like imagine all the time.” (S2)

“Yeah it's better but I don't like the lab manuals... they have so much information that you have to read through... and sometimes you don't really need it for what you are learning and it's too much” (S4)

Students were also unsure of the benefit of the assignments; although they appreciated that they provide practice for problem solving skills.

“Mastering Physics, it was just something that I just wanted to get over and done with.. I wasn't used to it. I found it redundant... and a lot of people just didn't really work through the answers, they just copy and pasted into google and found an answer.” (S1)

“Yeah... um... I also think that the mastering physics....if I can say something negative about that... yeah... um... people just look up the answers on the internet... I hear it so much” (S2)

“It's supposed to help and if people are using it like they're supposed to it would but people just dont (yeah). I think it's because it's marked... they just wanna get it done and get it all right (S3)

“I don't really feel like Mastering Physics helps to improve the understanding of concepts as much as the technique of solving problems.”
(S5)

In terms of students' attitudes towards specific characteristics in lectures, whilst most mentioned the demonstrations, one student also appreciated the unit overview that each lecturer provided:

“ I think in lectures (Staff-2) would do this thing where he had a mind map and he would go through what we looked at in all the lectures before and I would be like 'yep I remember doing that I remember doing that' and I think that was really helpful” (S1)

The students were able to provide elaboration on the LASE results which indicated that during the lecture, there were no strong indicators of activities that were guaranteed to engage. They also highlighted the importance of lecturer disposition.

“Um... I think that a lot of the time I was pretty engaged.. I had some stuff going on so I was tired so sometimes when it was at a bad time of the day it would be less so but most of the time it was good and (Staff-2) does a lot of board work so he writes up equations and I think that's really good it gets people really involved and people ask questions so...yeah...” (S1)

In other words, students appreciated a change of pace and the opportunity to ‘engage’ with the material, even if it was just copying off the board.

“To be honest, last semester in thermodynamics I ... the lecturer was very soft toned and um.. if feels like someone is telling you a bedtime story... it's like into a lecture, like probably 20 or 30 minutes and I'm like (pretends to sleep, laughs)” (S3)

When asked what a lecturer could do to guarantee or facilitate student engagement, one student remarked:

“Well if he's doing an experiment he'll ask us like 'why it happened like that' and 'can you explain that' and that forces us to think about it rather than he just explains that to us...” (S2)

Which was a theme echoed from the comments about the tutorial also; students appreciated ‘working it out for themselves’ (as long as the material was not too difficult), rather than the demonstrators providing them with the answers:

“But for the lecture slides, probably it's not a good idea... um... to just have the slides there for students to have it cause in a way... I think it's normal for people to actually ... cause they think it's there... they probably don't pay much attention to the lectures” (S1)

“I think it's important for the lecture to engage the student and they just kept going through the things on their own. I know they're a nice person but if you're not engaging your student and just talking by yourself they will never learn anything unless... I spoke to other students and they feel the same way... but .. you know I understand that they... the lecturers have their limitations as well! (Laughs)” (S2)

In terms of the ILD activities themselves, as with most evaluation surveys, students are quick to point out that the demonstrations are the ‘best bits’. However, it is too crude to accept these statements wholesale. That is, often students say they enjoy the demonstrations the most because they stood out the most; they were the most explicit and easily communicated and compartmentalised activity. During these interviews, students were further questioned for details.

S3: Like the demos were really good

H: So can you tell me a bit more about them

S3: The models were really easy to understand and they were pretty good and sometimes going to the lectures to just see the demo that some friend told me that was really really useful to really understand that concepts

Students also articulated why or if the ILDs were different to ‘regular’ Demonstrations.

“Um... the ones that... well definitely the ones that made you think of course were a lot more helpful because they develop your sense of understanding and you think of a question but the ones that they just show at the front they were also really good because it’s... sometimes it was fun so it's a good way to remember a concept and yeah... so like... both were pretty good but in terms of probably learning... the ones that they gave us... that we had to make predictions were probably more useful.” (S1)

“They're (regular Demonstrations) probably not really directly like not really um... a method for teaching but really its the questions that we kind of think about why things are the way they are that makes us...

helps us relate a concept we've learned but there's still quite a distinction between contextually seeing things and seeing things. They (ILDs/demonstrations) do that –different levels of impact.” (S2)

“OK, well last semester I found the Demonstration questions in the tutorials really helpful. Because it was really easy to actually see what was going on and yeah.” (S3)

“Yeah and I think that's um.. actually really good because it means everyone is really focused and um... yeah... it's um, a lot easier to concentrate that way and follow what's going on and stuff” (S4)

One student also highlighted the risk of losing interest because of the freedom to speak with peers that the ILDs allow:

“Um, just if we are given too much time to ourselves to think about things or too much time to discuss with our neighbour and that sort of thing it's sort of off-putting a little bit. It makes us drift and talk about other things” (S2)

8.5 Discussion

The second iteration of this study, in 2012, saw the same overall course gains than 2011. However, due to improvements in research design, a more appropriate measure of gain was employed to determine if there were any differences between the four streams. Using the normalized gain measurement, ILD1 showed the most gain, 0.40, followed ILD2 with 0.34 and EX1 and EX2 with gains of 0.28 and 0.27 respectively. According to the thresholds indicated on Hake plots, the gain for ILD1 is considered ‘very high’ although the other three gains are also in the ‘high’ area. Although there was no statistically significant difference in means in the pre-test scores, the post-test scores

did differ (Table 8-6). There was also a difference in the distribution of the scores, with ILD1 having a higher proportion of students in the 70-79% bracket and a much lower proportion in the 40-49% bracket.

Extensive exploration was conducted to account for this outstanding result. The first assertion is that increasing interactivity results in increases in learning gains. However, if this was the case, ILD2 should have seen similar gains to ILD1. There are two reasons that may explain this, according to the data presented above in quantitative and qualitative analyses:

1. The ‘pedagogical researcher effect’: This effect postulates that a gain in one implementation of ILDs and not the other was due to the lecturer with a background in PER or pedagogical research being able to implement the IE technique more successfully. A more successful implementation involved a greater amount of ‘Interactive’ time and a greater quality of time spent on ILDs. These results, as measured by the LASE and the student evaluations, show that, firstly, ILD1 implemented more ‘Interactive teaching’. Interactive teaching occurred in the non-experiment lectures as well as the lectures when the ILDs were taking place. That is, ILD1 featured more time spent on the ILDs themselves when compared with ILD2 but also encouraged interactivity in other teaching. The quality of the interactive time on the ILDs was gauged through student evaluation forms, which indicated that students believed there was not enough time for discussion in ILD2 and that the activities seemed ‘rushed’. Students in ILD1 also reported more positively on seemingly unrelated measures. For example, ILD1 students scored higher on whether the questions were ‘clear and well put’. They also scored higher on understanding of several concepts: heat and temperature, the first law of thermodynamics, thermal processes

and heat engines; the latter attracting over 20% more students in the affirmative for understanding. Most significantly, however, was the improvement in perception of general outcomes: the perceptions of ILD1 students overwhelmingly surpassed those of ILD2 when asked whether ‘making predictions beforehand helped me realise my misconceptions’ and ‘the conclusion after each ILD made me understand the concept better’. This indicates that the vast majority of students in ILD1 (around 90%) agreed that the ILD specific activities of prediction and recording lead to greater understanding. The differences in the lecturer approach to the ILDs also manifested itself in the Student Engagement analysis, where there were a markedly lower proportion of students ‘participating’ in the ILDs, particularly in the Peer Instruction portion. Such data supports the assertion that the way a lecturer implements an IE technique is not necessarily uniform and that this has real and significant implications for supporters of IE techniques. That is, many different types of lecturers will attempt to introduce new techniques in their teaching but unless these techniques are implemented as intended, Active Learning is not guaranteed. This may be an important finding for supporting the reporting of and justifying null results in the literature (Georgiou & Sharma, 2012). It is also an important finding for course designers and instructors: a particular activity may not be consumed in the way it is intended. Student interviews revealed that this was already the case in other aspects of the course: if tutorials groups weren’t appropriate, learning was not facilitated and it was easy to bypass the ‘Just in time’ teaching built into the online Mastering Physics assignments by looking up the answers online.

2. The ‘Engineers’ effect: that Engineer’s may not be as open to participating to Active Learning environments as students in

other degree programs are. The first explanation does not fully explain why there was no difference in learning outcomes in 2011. One suggestion, that there was not a sufficiently homogenous sample to begin with, is an option. It may also be the case the all lecturers needed to sufficiently familiarise themselves with the IE techniques used. There is evidence to indicate instead that engineers might be less receptive to the ILD techniques. For example, when considering attendance, in 2011 the stream with the most engineers displayed the sharpest decline in attendance for non-experiment lectures (these were the lectures with no mark allocation). When considering the attendances as recorded by the Exercise and ILD sheets, again, Engineering students were participating less. The exam results also show that Engineering students performed statistically significantly better on calculation or very quantitative questions, supporting the claim that they are less interested in the ‘conceptual’ understanding emphasised by the ILDs and IE techniques in general. Further examination shows that the degree enrolled in does correlate to outcome measures, although none of these measures were thermodynamics-related. Although nothing conclusive can be asserted at this point, the attitude of Engineers versus Science students towards the first year course would be an interesting avenue to pursue in the future.

The other possibility is, of course, that there was no difference in learning outcomes because the improvements in the TCS for ILD1 were not mirrored in any of the other learning outcomes. Indeed, it can be argued that since students received marks for completion rather than individual responses on the TCS, they may not have invested as much effort in completing the test and therefore the final exam is a better measure of learning outcome. A criticism of such a statement might exploit literature on conceptual surveys, which explains that they should not be treated as regular course

assessment but rather, they have a specific purpose which is to clearly and uniquely address known difficulties in thermodynamics. Questions in the final exam will also not necessarily cover all or even most of the content.

There are also improvements that are possible with the LASE that may add detail in the analysis. For example, the Lecture Activity analysis relied on coding of only six categories because this was deemed appropriate for the purposes of determining how much interactivity is driven by lecturers during lectures. However, as the expanded analysis of the Transmission-Style category shows, these categories do not reflect homogenous activities. It is important to stress that without all aspects of the LASE, including field notes, conclusions may be more difficult to substantiate. For example, the finding that Staff-1 drove more Interactivity in their class was substantiated by the Lecture Activity coding, further substantiated through transcription, then triangulated through data from the Student Engagement part of the tool and again supported by evidence from student evaluation and student interviews. In other words, one should always be cautious about any claims being made as a consequence this coding.

Finally, it should also be noted that although the thermodynamics course is by all accounts a successful one when comparing gains with international counterparts and when considering student attitudes, it is still noted that students, on average, are not necessarily performing remarkably. When considering the thermodynamics questions on the final exam, for example, the cohort average was 9.65 ($SD=5.57$) out of a possible 25. Question 10, a thermodynamics question, showed the lowest average marks in the entire exam. Such observations reinforce the need to understand more fully why students find thermodynamics so difficult.

9 Introduction to Part Two: Student Understanding

It is clear from the measurements of learning outcomes from Part One of this project and the literature that there are still some fundamental and robust difficulties experienced by students in thermodynamics. It is also clear that even after standard (or purposely designed) instructional techniques, a very ‘patchy’ and tenuous understanding of thermodynamics is the best that can be achieved for the majority of students. In Part One, student understanding was simply gauged by global quantitative measures; the TCS and final exam marks. These measures were useful in signalling two very broad conclusions: firstly, that intentional instructional changes may improve conceptual understanding (indicated by different gains on the TCS) and secondly, that significant difficulties still exist (indicated by modest achievement on the TCS and sub-par achievement in the final exam). In Part Two, these broad conclusions will be further examined. Chapter 10 will focus on employing existing methods, including item analysis on the TCS and thematic coding on the Interactive Exercises, to provide insights into where these difficulties lay and how universal and resistant they were.

Chapter 11 takes a different approach: Legitimation Code Theory. LCT was utilised to overcome existing limitations in methodologies and as such, the original challenges in working with these methodologies, specifically, SOLO and Phenomenography, are chronicled. The application of Legitimation Code Theory was itself a trial. Through the presentation of the LCT analysis, it will be shown how theoretical, as well as methodological improvements were also achieved. These theoretical aspects are primarily based on foregrounding ‘knowledge’ rather than ‘knowing’ or ‘the knower’ and therefore require adopting a different perspective on student understanding. It will be shown how taking this viewpoint opens up promising avenues when considering not only the development of ways to gauge student understanding, but also on the interplay between student understanding and instructional practice.

10 Student Understanding: Conventional Approaches

As part of an extensive exploratory investigation into student reasoning, several sources of data were accumulated and several methods were utilised to address the question of the persistence of widespread and robust difficulties in student understanding of thermodynamics (Table 10-1). Some margins were determined early on: that the focus should be on conceptual, not mathematical difficulties, and that the difficulties were associated with the explanation of relatively ‘common’ or everyday occurrences. The reasons for these demarcations, should they not be clear, are explicated in (Georgiou, 2009).

Instrument	Sample	Time/Place	Nature
Thermal concepts Survey	First year Physics, thermodynamics module	2011- pre/post 2012- pre/post	Quantitative, Multiple choice
Interactive Exercises (Exercises 2 and 4 not used in analysis)	1 See table Table 4-4 3 First year Physics, thermodynamics module	2011- during lecture course 2012- during lecture course	Short answer responses analysed using LCT
Interviews	10 students (four in 2011 and six in 2012)	2011 and 2012 (after lecture course)	Semi-structured, one-on-one

Table 10-1 Overview of data collected for examination of student understanding

Although student difficulties have been comprehensively covered in topic areas such as mechanics, very few studies report on fundamental thermodynamics concepts at the first year level. The collective data come from diverse samples: diversity which included age, gender, nationality/country of origin, type of educational context, and physics background, and include various methods, ranging from typical multiple-choice-style diagnostic tests to semi-structured extended interviews.

10.1.1 Thermal Concepts Survey

The first and arguably ‘crudest’ source of data of student understanding of thermal concepts is the TCS, which was administered both in 2011 and 2012. A detailed item analysis provides information about which questions were answered most and least correctly, as well as the questions which saw the lowest and highest gains after instruction. In both 2011 and 2012, and as expected with a validated survey, there was general consistency in the way the questions were answered. Figure 10-1 shows the consistency of the responses for 2011 and 2012 for Part I of the TCS. It is also apparent in Figure 10-2 that Part II of the TCS was largely lower scoring.

Figure 10-1 Percentage correct for individual items on Pre-test (Part I only) for 2011 cohort and 2012 cohort

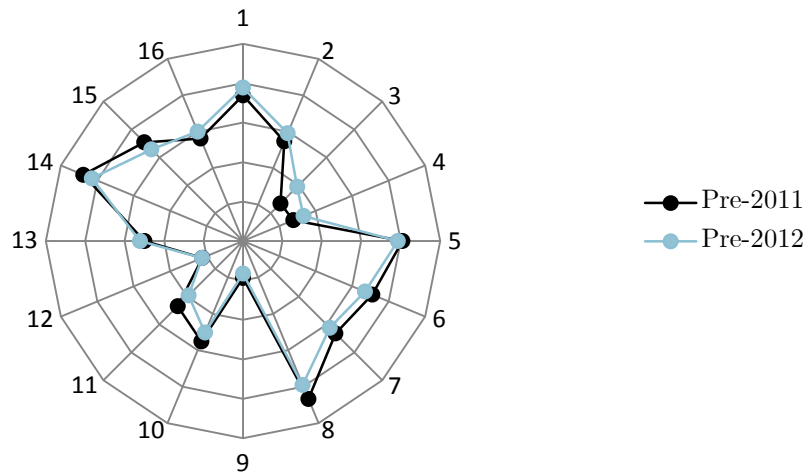
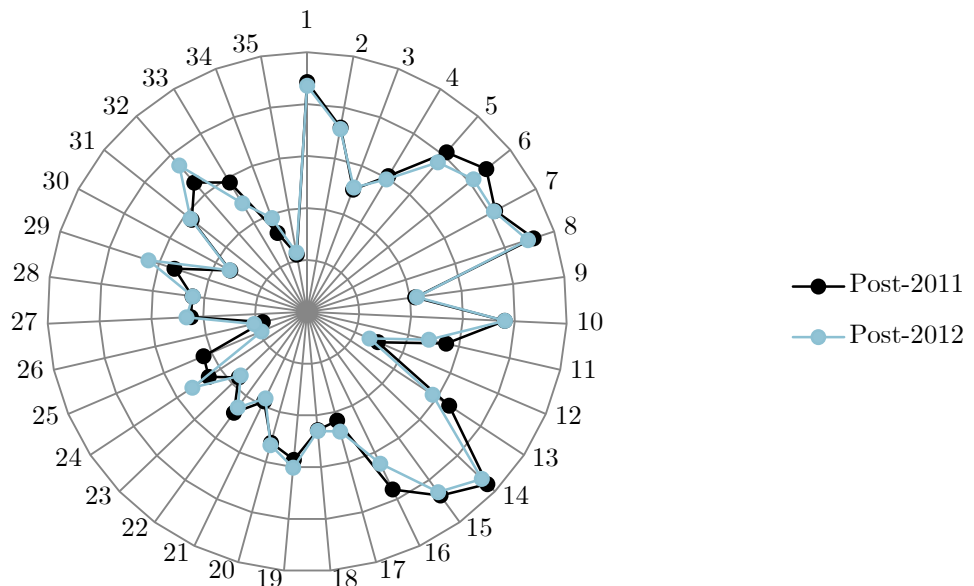


Figure 10-2 Percentage correct for individual items on Post-test (Part I and II) for 2011 and 2012 cohort



Q	Pre-2011	Post-2011	Pre-2012	Post-2012	Gain2011	Gain2012
1	73.86%	88.51%	77.83%	87.08%	0.15	0.09
2	54.73%	72.13%	59.20%	71.58%	0.17	0.12
3	26.89%	50.29%	38.92%	51.16%	0.23	0.12
4	27.65%	60.92%	33.25%	59.43%	0.33	0.26
5	80.87%	81.61%	78.54%	76.49%	0.01	-0.02
6	71.02%	88.22%	66.98%	81.91%	0.17	0.15
7	66.29%	82.18%	62.26%	81.65%	0.16	0.19
8	86.74%	91.67%	79.01%	89.41%	0.05	0.10
9	18.75%	41.95%	16.51%	42.64%	0.23	0.26
10	55.11%	76.15%	50.24%	76.23%	0.21	0.26
11	46.78%	54.89%	39.01%	48.06%	0.08	0.09
12	22.35%	29.60%	22.46%	26.10%	0.07	0.04
13	50.00%	65.52%	52.25%	57.88%	0.16	0.06
14	87.69%	95.98%	82.98%	93.02%	0.08	0.10
15	70.83%	87.36%	65.72%	85.79%	0.17	0.20
16	56.25%	75.86%	60.05%	64.86%	0.20	0.05
17		43.39%		47.80%		
18		45.69%		45.99%		
19		57.18%		60.21%		
20		52.30%		53.23%		
21		38.22%		36.95%		
22		47.99%		45.48%		
23		36.49%		35.40%		
24		45.40%		52.97%		
25		43.39%		19.12%		
26		17.53%		20.93%		
27		44.83%		46.51%		
28		44.54%		44.44%		
29		53.74%		64.25%		
30		33.62%		33.94%		
31		56.90%		57.51%		
32		66.09%		74.87%		
33		58.05%		48.70%		
34		32.47%		38.60%		
35		22.41%		23.24%		

Table 10-2 Percentage correct for individual items on TCS for 2011 and 2012 cohorts. Cells shaded red indicate scores below one standard deviation of mean for that question, and green cells for one standard deviation above. Overall gains are provided for 2011 and 2012 using normalized gain.

Table 10-2 (above) shows the percentage of the whole cohort answering correctly for each item. Items for which the percentage of correct answers sits one standard deviation above or below the mean for that implementation are shaded in green and

red respectively. To avoid ‘clumsy’ communication of this group of questions, they will simply be referred to as ‘poorly answered’ and ‘accurately answered’ questions from this point forward.

10.1.2 Poorly answered questions

In Part I of the pre-test, questions four, nine and 12 were poorly answered and in Part II it was questions 26, 30 and 35 that were poorly answered. The latter group of questions had to do with: Q26: work done by a gas on the environment during a process shown on a P-V graph; Q30: heat transfer for a process on a P-V graph; and, Q35: work done during a process on a P-V graph (see Appendix K). These questions were graphical and mathematical in nature and were therefore not considered to be within the margins previously specified for the project. The questions from Part I are expanded on in more detail below.

Question four was based around latent heat and phase change (Figure 10-3). A scientifically consistent answer to this question would involve the understanding that for a substance to change state, heat transfer to or from a substance is required. The table in Figure 10-3 shows that initially, most students indicated that both water and ice would lose the same amount of heat when cooled to reach the same sub-zero temperature. The results are remarkably similar for the 2011 and 2012 cohorts. Although the majority of students reassessed their answer for the post-test (to a final 60%), 22% still indicated that the amount of heat transfer from the water and ice would be the same because the temperature was the same. Reassuringly, a healthy fraction of students who indicated that the temperature of water could not be at 0°C deserted this idea in the post-test.

Figure 10-3 Question four of the TCS with pre- and post- test scores

Question 4: If 100g of ice at 0°C and 100g of water at 0°C are put into a freezer, which has a temperature below 0°C . After waiting until their temperature equals to the freezer temperature, which one will eventually lose the greatest amount of heat?

	2012-pre	2012-post
ice	7%	7%
water	33%	60%
same because T same	37%	22%
no answer because ice has no heat	1%	2%
no answer because water cannot be at $T=0^{\circ}\text{C}$	17%	9%
Total (N)	424	387

Question nine was based on the pressure of an ideal gas (Figure 10-4). A scientifically consistent answer to this question would involve the understanding that the system is at mechanical equilibrium with its surroundings and since the piston in the cylinder is frictionless, the pressure of the gas will always be equal to atmospheric pressure. The table in Figure 10-4 shows that, initially, an overwhelming majority of students (57%) indicated that the pressure would increase. About half of the students abandoned this conception after instruction for the scientifically correct response of ‘no change’, meaning that the percentage of students selecting the correct answer rose from 17% to 43%.

Figure 10-4 Question nine of the TCS with pre- and post- test scores

Question 9: (Image of syringe in water baths excluded here-see Appendix K) A syringe that contains an ideal gas and has a frictionless piston of mass M is moved from a beaker of cold water to a beaker of hot water. How does the gas pressure change?

	2012-pre	2012-post
Increase	242 (57%)	149 (27%)
Decrease	81 (19%)	72 (19%)
No change	70 (17%)	165 (43%)
Total (N)	393	386

The selection, ‘decrease’ remained steady with 19% of students making the selection both pre- and post-. Interestingly, the gains for this question show some of the greatest disparities when comparing between streams, with the ILD streams (first two), showing higher gains than the non-ILD streams (Table 10-3).

Stream	Gain
ILD1	0.38
ILD2	0.50
EX1	0.22
EX2	0.16

Table 10-3 Gains for the four streams for Question 9

Question 12 was based on the same physical principle as question nine but featured different quantities of the same gas at different temperatures rather than different volumes (Figure 10-5). A scientifically consistent answer to this question would involve the understanding that regardless of mass and temperature, the pressure of the gas will always be equal to atmospheric pressure because the system is at mechanical equilibrium with its surroundings.

Figure 10-5 Question twelve of the TCS with pre- and post- test scores

Question 12: (Image of gas in cylinder on heat source excluded here-see Appendix K). Three identical cylinders are filled with unknown quantities of ideal gases. The cylinders are closed with identical frictionless pistons of mass M . Cylinder A and B are in thermal equilibrium with the room at 20°C , and cylinder C is kept at a temperature of 80°C . The piston of each cylinder is in mechanical equilibrium with the environment. How does the pressure of hydrogen gas in cylinder B compare with the pressure of hydrogen gas in cylinder C?

	2012-pre	2012-post
Greater	64 (15%)	54 (14%)
Less	229 (54%)	231 (60%)
Same	95 (22%)	101 (26%)
Total (N)	423	387

The table in Figure 10-5 shows that initially, and finally, the majority of the students answered ‘less’ (54% and 60% respectively), confirming the difficulty in understanding the very same pressure concept covered in question nine. The percentage of students selecting the correct response was 22% for the pre-test and only rose to 26% for the post-test. In fact, this question showed the most resilience in student answers of all questions in the TCS. That is, there is very little change in the distribution from pre- to post-test answers. Again, the 2011 data are almost identical.

10.1.3 Accurately answered questions

Accurately answered questions were questions five, eight and 14 from Part I of the TCS. There were no questions in Part II of the TCS-post test that were classified as accurately answered. (That is, all the questions that scored one standard deviation above the average were in part 1). Questions eight and 14 are briefly discussed below (question five will be discussed in the next section).

Question eight was a precursor to question nine and related to the temperature change of a gas in a syringe which was placed in a hot water bath (Figure 10-6). Seventy-nine per-cent of students indicated that they believed the temperature would increase in the pre-test, a figure that rose to 89% for the post-test.

Figure 10-6 Question eight of the TCS

Question 8: (Image of syringe in water baths excluded here-see Appendix K). A syringe that contains an ideal gas and has a frictionless piston of mass M is moved from a beaker of cold water to a beaker of hot water. How does the gas temperature change?

Question fourteen was arguably of a similar nature to question eight (Figure 10-7). The question itself was one of three, which addressed the pressure, volume, and temperature of a gas. Like question eight, it was a question that addressed the most obvious change. In question 14, that most obvious change was associated with pressure, while with question eight, it was temperature. Unsurprisingly, therefore, there was a similar pattern in the way students answered this question when compared to question eight: 83% of students answered correctly in the pre-test with an increase to 93% for the post-test.

Figure 10-7 Question fourteen of the TCS

Question 14: (Image of cylinder with piston, showing masses being added is excluded here- see Appendix K). An ideal gas is contained in a cylinder with a tightly-fitting piston so that no gas escapes. Several small masses are on the piston. (Neglect friction between the piston and the cylinder walls.) The cylinder is placed in an insulating jacket. A large number of masses are quickly added to the piston. How does the pressure of the gas change?

10.2 Questions five and six from TCS & Interactive Exercise One: Thermal conductivity

Questions five and six of the TCS were related to Interactive Exercise One and will be discussed together with this Exercise to explicate ideas about thermal conductivity (Figure 10-8). Chronologically, Interactive Exercise One was implemented both before as well as throughout studies one and two, and as such, some of the responses are considered triangulatory while the others are instead complementary. In the TCS, students answered these two questions quite well, with around 70% answering correctly in the pre-test and up to 90% of students answering correctly in the post test.

Figure 10-8 Questions five and six of the TCS

<p>Question 5: Jan announced that she does not like sitting on the metal chairs in the room because “when touching it, they are colder than the plastic ones.”</p> <p>Question 6: Kim picks up two rulers, a metal one and a wooden one. He announced that the metal one feels colder than the wooden one.</p>
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Figure 10-9 Interactive Exercise One. Actual exercise included space for students' answers (Appendix B)

Interactive Exercise 1			
Instructor:		Name:	
Lecture:		SID:	

Answer the review question below and return at the end of the lecture. No marks are allocated for the content of your answer, only for attempting the question (attending the lecture). Make sure you spell your name correctly and provide correct SID.

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.

Heat transfer, Cold transfer, Temperature, Heat, Conductivity, Insulation,

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:

Group	Year	Institution	Course/degree	Student background	No.	Contact
US	2010	Curry College, Massachusetts,	Algebra-based first year Physics	Mostly no high school Physics	16	Jerry Touger
SGPRE	2010	Sydney Girls High school,	Yr 8 (age:13/14) before and after	No formal thermal physics instruction, high socio- economic status school. Girls only.	57	Jeff Stanger
SGPOST	2010	NSW, Australia	completion of thermal physics coverage.		60	
MSW8	2010	Muswellbrook High School, NSW, Australia	Yr 8 (age:13/14)	Co-Ed regional school students before thermal physics instruction	28	Andrew Roberts
MSW12	2010		Yr12 Physics class (age:17/18)	Co-Ed regional school students studying HSC Physics course	10	
LDN13	2010	St Philomena's Catholic High school for Girls,	Yr 13 (age:17/18) final year (A-level) Physics	Girls only. Students have relatively strong backgrounds in science	6	Julie Di Rocco
LDN11	2010	Surrey, England.	Yr 11 (age 15/16) triple science, GSCE		29	
CT1maj	2010	University of Cape Town, South Africa	First year mainstream Physics (1004W)	Students have physics background and intend to continue toward a Physics major	65	Andy Buffler
CT3rd	2010		Third year mainstream Physics (3021F)	Students who have performed well enough in second year to proceed to third	16	
CT2nd	2010		Second year mainstream Physics (2014)	Students who have performed well enough in first year to proceed to second	20	
CT1nov	2010		First year introductory course for non-majors	Students have diverse backgrounds. Mainly, students do not have a strong background in physics or science	77	
SydMast	2009	University of Sydney, NSW, Australia	Master of Education	Post graduate students in education	16	
SydPri	2009		First year Primary Education	Students mainly without HSC Physics studying to be primary school teachers	63	
SydAdv	2009		First year Physics Advanced	First year Physics students likely to major that performed well in the HSC or Physics	51	
SydReg	2009		First year Physics regular	First year Physics students that could possibly major in Physics or Engineering students	345	
SydFund	2009		First year Physics students Fundamentals	First year Physics students who did not complete Physics at high school and will most likely not be Physics majors	139	
Greek	2010	University of Athens, Greece	Third year nursing students		65	Anna Kozak
Polish	2010	Zespol skol Zawodowych, Zgorzelec, Poland	High school students	17/18 year olds in math at a technical college (part of high school)	57	
EX1-11	2011	University of Sydney, NSW, Australia	First year Physics regular	First year Physics students that could possibly major in Physics or Engineering students	90	
EX2-11	2011				61	
EX1-12	2012				83	
EX2-12	2012				98	

Table 10-4 Sample description for Interactive Exercise One

Interactive Exercise One is considered a context-rich problem and provided in full in Figure 10-9. The various samples and years that this question was administered to can be found in Table 10-4 (above)

The data consisted of categorical data (the selection of concept, which will be referred to as the students' 'concept-choice') and qualitative data which were coded (thematically) for most of the sample.

The question is effectively presented as a single question with two parts and based on the ideas behind questions five and six in the TCS: the 'feeling' of coldness when touching objects made of different materials in thermal equilibrium. In both parts of the question, a scientifically consistent answer 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 part a) the situation involves bathroom or kitchen tiles and bedroom carpets. In part b) the two objects are plastic and glass bottles in a self-serve refrigerator. A suitable response then for part a) would be: 'the tiles feel colder because heat is transferred at a faster rate from the feet to the tiles than from the feet to the carpet. The tiles and the carpet are both actually at the same temperature'.

The analysis of this question was multifaceted. Firstly there was the characterisation of the students' concept-choice across samples; secondly, there were also their justifications for this concept-choice which were coded using thematic coding; and lastly, the analysis is further enriched by having two analogous problems (with respect to the physics involved), masked behind different surface features, which allowed comparisons between the two.

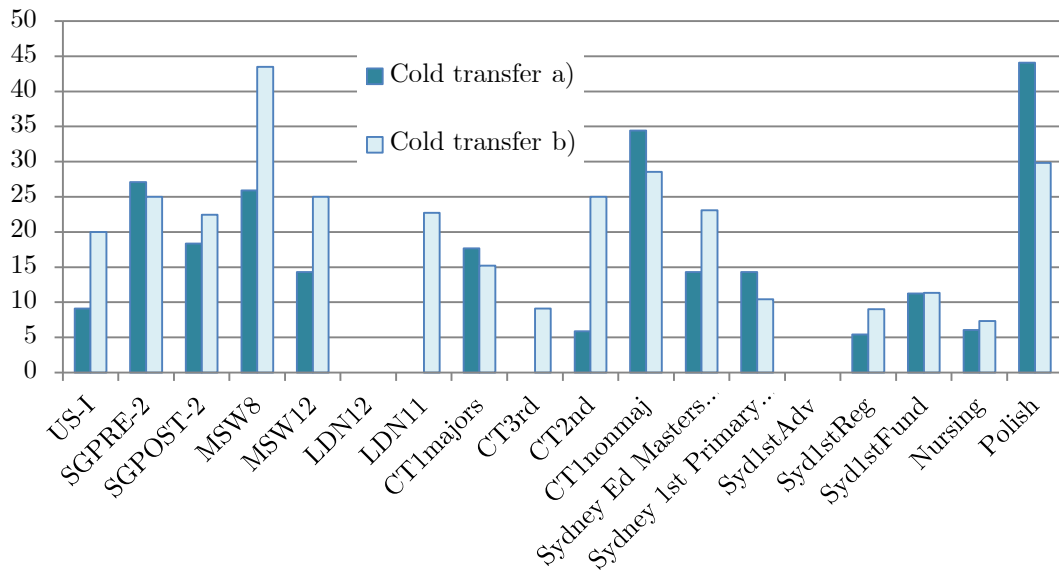
10.2.1 Concept-choices and explanations

The concept-choice of the student is most informative when coupled with coding of their responses. However, there were also some interesting ‘at-a-glance’ findings regarding the choice of the concept alone.

Firstly, in all samples, some concept-choices were clearly more favoured than others. This result was achieved by simply counting the concept-choices in NVivo for all groups. ‘temperature’ and ‘heat’, typically the concepts mentioned first and most in thermodynamics up to the junior high school level, were the least popular across the sample. Concept-choice ‘heat’ was selected in 6.6% of responses across both parts of the question and ‘temperature’, 5.7% ($N=1625$).

‘Cold transfer’ was the next most popular concept-choice, but, unlike ‘heat’ and ‘temperature’, it varied widely in its use across different samples. The notion that ‘cold’ as opposed to ‘heat’ can be transferred is reported widely as an alternative conception. The reason that it is ‘alternative’ is that there is no physically distinct entity known as ‘cold’, there are simply varying degrees of heat transfer or states of matter that are described by temperature. The concept-choice query for part a) and part b) for the concept-choice ‘cold transfer’ show that the prevalence of the concept as a real concept is high in a number of the various groups sampled, particularly amongst the younger novice groups (e.g., the year 8 science students from a rural NSW school, MSW8, and the first year Cape Town group, CT1nonmaj). The selection of the concept was absent in the English senior Physics class from London and the Advanced first year Physics group from Sydney. That is, none of the students in either sample selected ‘cold transfer’ for either part of the question (Figure 10-10).

Figure 10-10 Proportion of selected samples making the ‘concept-choice’: cold transfer



Many of the groups of students also favoured the selection ‘cold transfer’ for the first and not the second part of the question. For CT3rd and LDN11 groups, none made the selection in the first part of the question but a non-trivial amount did in the second. For groups such as the MSW8, MSW12 and CT2nd groups, there was a significant increase in the selection of the concept for part b) of the question when compared to part a).

The justifications of cold transfer in the students’ explanations were also fairly varied. Below is a selection taken from the explanations attached to the concept-choice ‘cold transfer’. The groups they belong to are indicated beside them (see Table 10-4):

“It is cold transfer because the tile is made up of stone, as we know that usually the stone is cold therefore it release the cold that is why it is cold transfer” (SydReg)

“Carpet is well insulated and has additional padding under it so that the carpet will not pick up the cold transfer from the flooring beneath it.” (US)

“Personally, I find that cold transfer is most associated with the scenario because the surface of the glass is able to stay cool even in rather uncomfortably hot weather.” (SGPRE)

“As she steps onto the tiles that are cold, the cold transfers from the tiles over to her feet while stealing the warmth from Rebecca's foot” (MSW8)

“Her body temperature is higher (warm). So when she goes to the bathroom without shoes she feels the cold because there is a temperature difference. The cold goes to the warm so the process is cold transfer” (SydReg)

“Conductivity is the transfer of thermal energy through contact. It is not restricted to heat transfer, but also cold transfer. So the cold tiles transfer their thermal energy, which in the case is very low to Rebecca's feet” (SydReg)

These excerpts highlight the diversity of views represented by the ‘alternative conception’ of cold transfer. In fact, excerpt five actually blends the ‘cold transfer’ concept with the ‘scientifically consistent’ concept of heat transfer, while excerpt six actually states the first law of thermodynamics, albeit in an irregular form: ‘the cold goes to the warm’. The use of cold and heat transfer interchangeably brings into question the significance of the ‘alternative conception’ of cold transfer and confirms the variability of the conception.

Further examination was conducted into the combinations of concept-choices between part a) and part b), particularly with respect to ‘matched’ choices. This was achieved using the matrix-coding function in NVivo and checking the concept choices for a select sample in the data (Figure 10-11).

Figure 10-11 Screenshot of coding in NVivo. The Matrix-coding function allows for matching of certain concept-choice selections. This one shows the ‘heat transfer’ selection for part a) of the question (labelled Q1) and ‘Insulation’ for part b) (labelled Q2). One example of the 136 matches is shown below (6.008).

	A : Case:Q2 C...	B : Case:Q2 C...	C : Case:Q2 C...	D : Case:Q2 C...	E : Case:Q2 Concept = Insulation
1 : Case:Q1 concept = Unassigned	12	0	14	9	14
2 : Case:Q1 concept = Not Applicable	0	0	0	0	0
3 : Case:Q1 concept = Conductivity	9	0	73	14	45
4 : Case:Q1 concept = Heat transfer	27	0	85	59	136
5 : Case:Q1 concept = Insulation	12	0	54	24	46
6 : Case:Q1 concept = Temperature	6	0	16	3	16
7 : Case:Q1 concept = Heat	3	0	7	0	9
8 : Case:Q1 concept = Cold transfer	5	0	29	4	43

<Internals\Greeks> - § 13 references coded [33.29% Coverage]

Reference 1 - 2.82% Coverage

6.008

Q1 concept

Heat transfer

Q1 Explanations

Differences in temperature of the body and floor tiles, heat transfers from feet to the tiles, as a result her feet gets colder

Q2 concept

Insulation

Q2 Explanations

In the container, glass bottle freezes easier therefore is harder to warm up unless she have sore throat and cold?!!

About one quarter of the responses exhibited ‘matched’ concept-choices: the same concept-choice for part a) and part b). Of these, ‘conductivity’ in both parts was the most popular of the matched concept-choices at 8% of all responses. ‘Heat transfer’ was next at 6%, followed by ‘insulation’ (5%), ‘cold transfer’ (3%), ‘temperature’ (1%) and less than 1% for ‘heat’.

The majority of responses, however, included the selection of two different concepts. The two most popular choices for the two questions overall were ‘conductivity’ (21.7%) and ‘insulation’ (24.0%).

The concept choice-response nexus is examined more carefully in a subsample (Table 10-5).

Concept-choice	Part a)			Part b)		
	Total Number making concept-choice	Percentage of total number coded to Fully Consistent node	Equivalent Number	Total Number making concept-choice	Percentage of total number Coded to Fully Consistent node	Equivalent Number
Conductivity	121	28%	34	188	20%	38
Heat Transfer	278	11.5%	32	82	28%	23
Insulation	105	7%	7	192	6%	12
Temperature	24	4%	1	32	6%	2
Heat	14	21.5%	3	5	20%	1
Cold Transfer	31	3%	1	42	2.5%	1
Other	24	25%	6	57	12%	7
Total	598			598		

Table 10-5 Comparison of concept-choice with successful response. Table adapted from (Georgiou & Sharma, 2011)

Results from the 2009 implementation (approximately $N=600$, first year Regular students) shows that students' justifications of certain concept-choices are more successful than others. That is, there is some pattern when considering which choices and for which question, a) or b), led to more successful answers. For example, the concept-choice of 'conductivity' was more successful and there was no difference in both the frequency of the choice between the two parts of the question or the proportion of successful justifications. Although the most successful choice when considering justifications, 'conductivity' was slightly more successful in part a) compared to part b), whereas 'heat transfer' was far more successful in part b). Even though 278 students chose 'heat transfer' for part a) compared with only 82 for part b), only 11.5% of those in part a) were successful in their justifications while more than double that figure (28%) were successful in part b).

11 Case study with LCT analysis

11.1 On a personal note

Thus far, the study of student understanding has reported on the TCS to identify patterns of student responses that indicate difficulties, it has looked to the ‘normalized gain’ and other measures to show that some ideas are more flexible than others, and it has combined TCS findings with short answer responses that reveal further details of particular student difficulties.

To provide the reader with some context, these aspects of the project were complete within the first half of the doctoral program. However, despite the diverse methodological practices that were utilised, many fundamental questions remained:

- Why do students think in the ways that they do?
- Why is it difficult for student understanding to be developed in the area of thermodynamics?
- Why is there not a more coherent way to approach these issues?

It was at this time that I took a course (recommended to me by a colleague) that was to cover concepts in Legitimation Code Theory and was given by the theory’s author. I was convinced that this approach could prove valuable to research in science education. In the later part of my project, therefore, I engaged in a comprehensive case study involving the use of LCT in analysing student responses. The success of this application rested on several key elements; the utility of the approach as determined by the constructive description of student understanding, the ease of communicability of the approach, the implications for instruction, and the potential for further work, particularly in addressing social and linguistic features of science education, hitherto underdeveloped.

11.2 The question

Of the four exercises that were considered for comprehensive qualitative analysis, Interactive Exercise three was deemed the most appropriate. The second was graphical and as such, was outside the scope of the project whilst the fourth produced fairly narrow and homogenous responses. Of the remaining two, the responses from Interactive Exercise Three were more diverse in content and left a stronger impression on the students; reports from students indicate Interactive Exercise Three was thought provoking, interesting, and was based on concepts they were introduced to primarily in the first year course.

Figure 11-1 Interactive Exercise Three

Interactive Exercise 3

Instructor:		Name:	
Lecture:		SID:	

Answer the review question below and return at the end of the lecture. No marks are allocated for the content of your answer, only for attempting the question (attending the lecture). Make sure you spell your name correctly and/or provide correct SID.

1. On a warm summer day a large cylinder of compressed gas (propane or butane) was used to supply several large gas burners at a cookout (the valve was open to release the gas). After a while, frost formed on the outside of the tank. In a few sentences, **explain at least one mechanism** associated with the frost formation.

Interactive Exercise Three is a context rich problem (Figure 11-1). For this reason, Interactive Exercise Three would not be considered a 'suitable' exam question since there is no 'precise' answer and therefore it is difficult to assign objective marks to student responses. The physics behind this scenario is as follows: the cylinder contains liquid fuel (propane or butane) and vapour fuel. As the gas exits the cylinder to supply the burners, some of the liquid fuel inside the cylinder evaporates to maintain constant vapour pressure (the same pressure that the vapour was at before it was released).

Evaporation requires an energy input, and this is achieved through heat transfer first from the cylinder walls to the liquid, then from the air outside of the cylinder to the cylinder walls. Air contains water molecules and the heat transfer from the air is significant enough to result in the water molecules condensing and freezing onto the outside of the cylinder.

One unforeseen complication with this question is that it assumes knowledge of the workings of a gas cylinder; that it contains both liquid and gas. If this assumption is not taken into account, a scientifically consistent response could proceed as follows: an expanding gas does work and therefore requires heat transfer to it. The subsequent heat transfer from the cylinder and consequently the surrounding air results in the condensation of the water molecules in the air and their ultimate freezing. Strictly speaking, it is more important that students apply scientific reasoning consistently rather than understand the precise workings of the cylinder.

In these responses, because the question asks for ‘at least one mechanism’ it is expected that students will reveal both *which* concepts were deemed most relevant and an explanation of how those concepts applied to the provided scenario. The fact that the question assumed knowledge of the working of a gas cylinder that some students had and others didn’t, combined with the requirement to explain ‘at least one mechanism’ meant that there was an extensive range of physics content presented in the responses. The diversity in responses thus provided us with rich insights into student reasoning.

11.3 Sample

The data used were the 2011 data from the Active Learning implementation and occurred in the non-ILD streams (EX1 and EX2) ($N=133$).

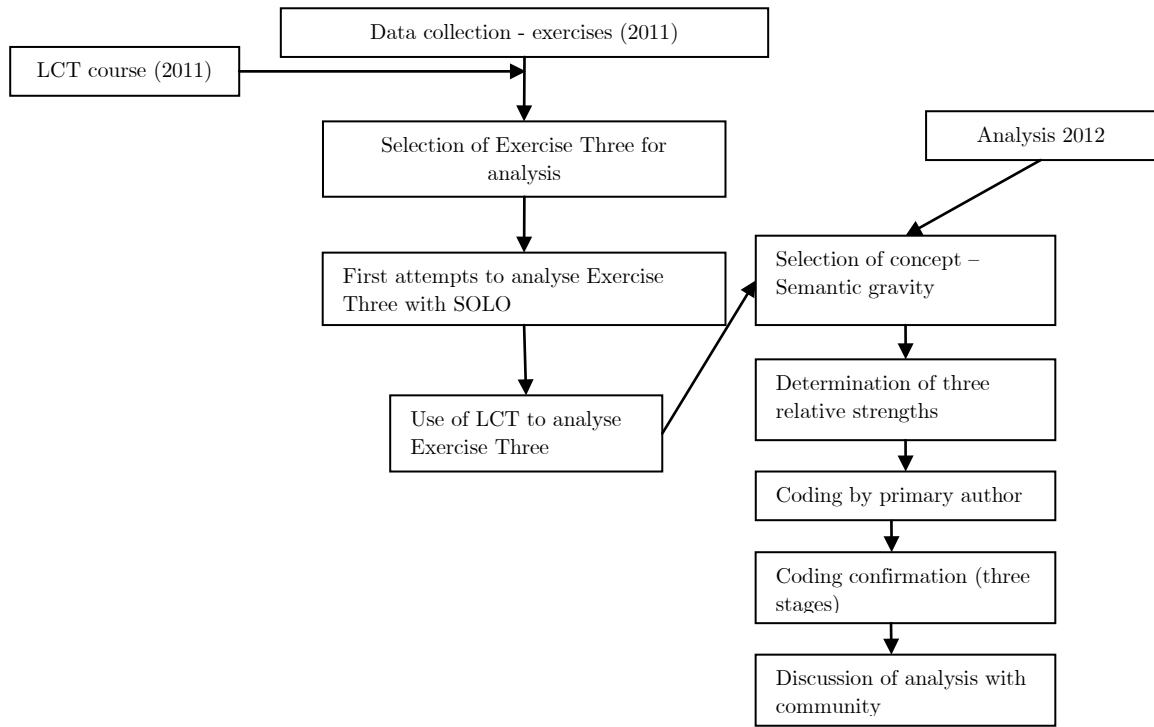
The students in this sample are mainly Bachelors of Science, Medical Science or Engineering, with very similar ATARs ($M=93$, $SD=5$), placing them in the top 10 per cent of the state. The question was administered at the beginning of selected lecture

classes and collected at the end. Lecture observations indicate that the students completed the question largely autonomously and reported to invest a serious effort in completing them, taking approximately 10 minutes to write their responses. The average length was three to four sentences with some use of equations and limited use of diagrams.

11.4 The analysis

The application of LCT in the context of physics teaching and learning was completely original and therefore required comprehensive collaboration. Figure 11-2 shows an outline of the analysis, which began with the data collection in 2011 and was developed over the better part of two years. Initially, after Interactive Exercise Three was selected as the question of interest, an analysis with existing methods (SOLO, phenomenography) was sought, to provide a baseline for the LCT analysis through either triangulation or comparison. The selection of the concept of semantic gravity occurred after consultation primarily with experts in LCT, whilst the coding was mainly achieved through collaboration with PER experts. The analysis was presented to both a scientific and LCT audience, at two separate symposia, to confirm the validity of the approach.

Figure 11-2 Outline of Interactive Exercise Three analysis



11.4.1 Previous Attempts at analysis: SOLO, phenomenography

Before LCT was applied, the responses were provided to two PER experts at the University of Sydney (S1 and S2) who were asked to utilise the Structure of Learning Outcomes (SOLO) framework (Georgiou and Sharma, 2010, Biggs and Collis, 1982, Boulton-Lewis, 1994, Lake, 1999). Both S1 and S2 had prior experience with this type of coding before and both had also published papers using phenomenography. S1 and S2 coded with respect to the different levels of quality in the SOLO framework (as determined by the relational structure of the responses). In doing so, the following issues emerged:

- S1 and S2 produced highly conflicting analyses: only 14% of coding were agreed on between the two coders. In 32% of responses, the disagreement was within one SOLO level, 35% of the coding of responses were two levels apart, and the

remainder were four levels apart and ambiguous due to the inability of one or other of the coders to assign to one level without ambiguity.

- S1 and S2 both adapted the criteria slightly in an effort to suit the data. S1 and S2 both agreed that there was no ‘extended-abstract’ level and both offered different ways of applying the criteria to the data
- Both S1 and S2 reported they were not confident in their final codings.

Despite S1 and S2 having extensive experience with the relevant methodologies and with the physics, the use of SOLO was deemed unsuccessful in this case. S1 made additional comments regarding a possible phenomenographic application. Some of the suggestions for phenomenographic categories are provided below and although these do not qualify as a comprehensive approach, they are useful as preliminary insights.

look at the logical structures

various physical principles evoked

nature of assumptions used (explicit and implicit)

Applicability of principles to the situation

Failure to localise effects (e.g. gas cools on expansion so cylinder cools).

Argument from label (e.g. endothermic process).

Incorrect logic. (Probably the commonest mistake is to correctly quote the ideal gas law and then assert or imply that P is proportional to T .)

Coherent arguments spoiled by incorrect usage of technical terms (e.g. “heat” instead of “temperature”; first law named as second law).

The attempts to apply SOLO and phenomenography by S1 and S2 highlight the difficulty in coding a context-rich problem, and also provide some justification for the desire to attempt subsequent analysis using LCT. The phenomenographic suggestions were integrated into the LCT approach and will be discussed later.

11.4.2 LCT analysis

The LCT dimension of Semantics was an obvious choice for the analysis of Interactive Exercise Three. Semantics involves both ‘semantic gravity’ and ‘semantic density’, however, time allowed only for the development of the former.

Once the concept of semantic gravity was deemed most appropriate for this analysis, several stages were traversed as part of the coding and analysis. First, discussions around the themes of the student responses took place. The primary author collated the ideas from S1 and S2 and then conferred with one other researcher (S3) familiar with both the physics in the question and LCT to confirm the validity of the selection of three relative strengths of semantic gravity. Coding was subsequently conducted mainly by the primary researcher. Validity, calibration and confirmation of coding were achieved through the following three stages:

- Coding with S1 and S2: a formal meeting took place with S1 and S2, discussing the new framework and the concept of semantic gravity. Explanations of the semantic gravity strengths were provided and S1 and S2 independently coded in accordance with these guidelines.
- Collaboration with S3: S3 was provided with the same framework and student responses and was asked to consider some exemplars in an effort to reach validity. Some minor changes were made, and the external language of description, the tool through which the concept is operationalised, was produced.
- Meeting with SUPER: A meeting took place with the PER group at the University of Sydney (SUPER) and validation of coding took place through confirmatory means (each group was assigned to different selections).

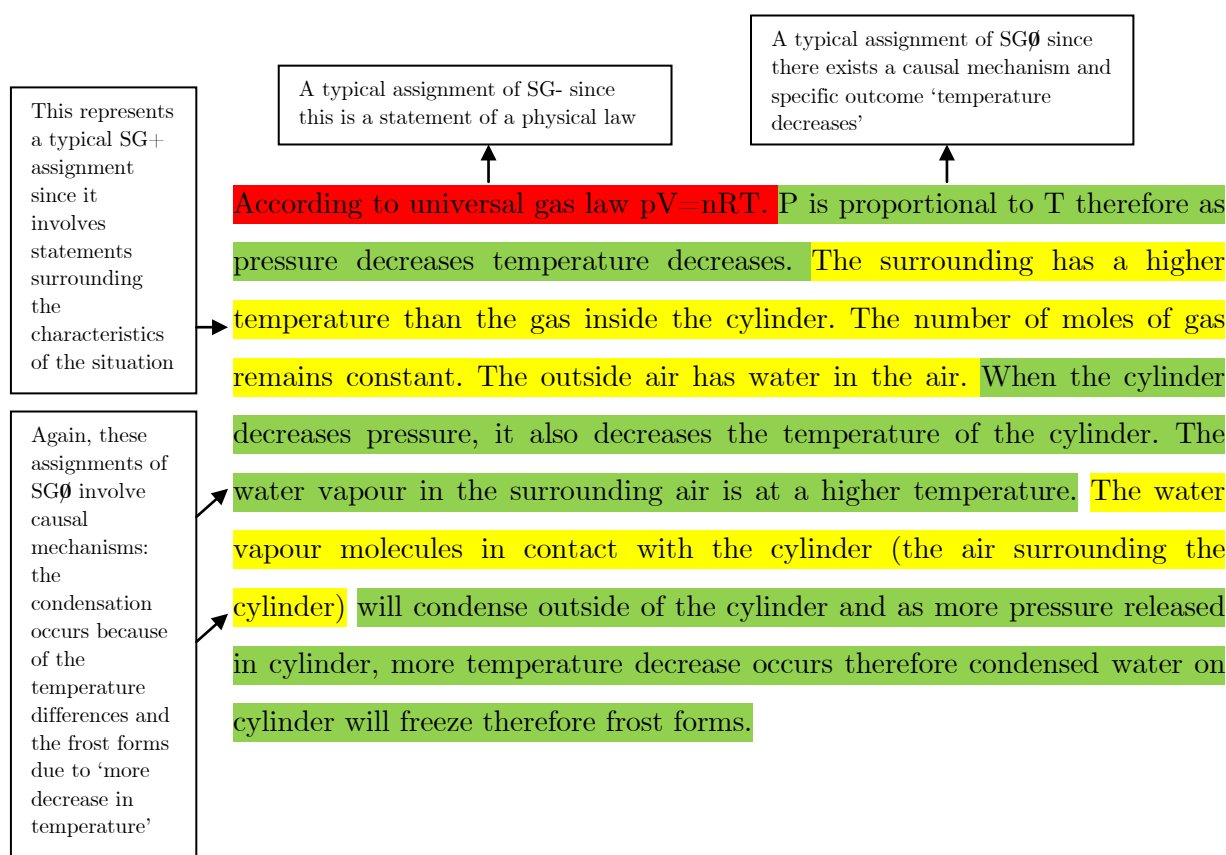
The following external language of description resulted (Table 11-1). Overall, an inter-coder reliability of 90% was reached. The analysis was then presented at a science symposium and an LCT roundtable, both held at the University of Sydney.

Semantic Gravity	Coding categories	Description of coded content	Examples of student responses (all reproduced exactly with grammatical and spelling errors)	
Weaker	SG-	Student is describing a physical principle, law, theory, or concept in a general enough way that it means something without reference to a specific situation	i An expanding gas absorbs energy	
			ii As the state changes from liquid to gas; heat absorbed from surrounding	
			iii $E=mc\Delta T$	
			iv The gas undergoes an adiabatic process	
			v Thermal equilibrium	
			vi the second law of thermodynamics	
			vii $PV=nRT$	
			viii The first law of thermodynamics	
			ix the mechanism is pressure	
			x The ideal gas law	
	SG \emptyset	Student is describing the object(s) but making reference to a physical process(es)- either explicitly or implicitly providing some explanation or embedding some cause. Often, the intermediate level 'links' the SG- with the SG+ levels	i therefore it absorbs the heat from the surroundings, decreasing the temperature	
			ii P stays the same. V decreases and therefore temperature decreases	
			iii this causes the heat in the surrounding the cylinder to drop	
			iv so heat flows into the surface, cooling the gas	
			v it is expanding because the pressure outside the cylinder is less than inside	
			vii and so the expanding gas removes heat from the nozzle of the cylinder	
			viii work is done by the system- it loses energy in the form of heat	
			ix in this situation, heat leaves the tank as the gas is released	
			SG+	Student makes a reference to the object, it's characteristics or rephrases or extends upon the question (or the language in the question)
	ii When gas is released it meets a cool surface			
	iii so it sticks to the wall of the tank			
	iv there is a greater density of gas in the cylinder at the start			
	v the formation of frost was a direct result of the gas leaving the cylinder			
	vi frost formed			
	vii propane and butane are gases at room temperature			
	viii As gas is released the volume of gas decreases			
	Stronger			ix The pressure in the tank decreases, however, the volume remains constant

Table 11-1 External language of description (description of coding with examples)

Table 11-1 describes three levels which represent relative strengths of semantic gravity. The most abstract level (SG-) contained general principles used to justify the reasoning made in the response. The most concrete level (SG+) contained descriptions of the objects in the question, including tautology or repetition. The intermediate level (SG \emptyset) existed between SG- and SG+ and contains the causative reasoning of the student, often linking the abstract to the concrete. One example is provided below to show to how some typical assignments were made (Figure 11-3).

Figure 11-3 Example of annotated and coded excerpt. Semantic gravity strengths are provided. Red indicates SG-, green indicates SG \emptyset and yellow indicates SG+.



Of the statements that were difficult to code, 'therefore frost forms on the surface of the cylinder' was the most controversial. It was unclear whether this statement represented stronger semantic gravity (SG+) or slightly weaker (SG \emptyset). In the example above, the assignment to SG \emptyset was retained due to the explicit reference to the continued temperature difference and the explanation of the water vapour in the surrounding air. In the example below (Figure 11-4), however, the same statement was coded to the stronger

level, due to a causal mechanism being absent and because this phrase formed part of the question. That is, the student was not explaining why the frost was formed, but making a causal statement regarding another mechanism and simply adding the statement subsequently.

Figure 11-4 Example of coded excerpt

Ideal gas law $pV=nRT$. As the gas supply is used up, P decreases. As n, R and V are constant, T must decrease. Hence frost is formed on the outside of the tank.

Although the responses were coded into categories of distinct levels of relative semantic gravity, this does not indicate the responses within the categories are homogenous. For example, the sections coded to the SG- category are all general principles, but some are clearly more general than others [e.g., (viii) (the first law of thermodynamics) compared to (iii) ($E=mc\Delta T$)]. An excerpt containing several coding examples is provided below to show a greater spectrum of responses (Figure 11-5).

Figure 11-5 Example of exemplar coded excerpts containing the range of different combinations of semantic gravity assignments

<p>The release of the compressed gas allowed for an expansion of volume and the mechanical energy is turned into heat when first opened. Therefore, the temperature is changes greatly due to the shift of molecules into a greater space is reduced</p>
<p>$pV=nRT$. When the valve is open, the cylinder is pushing the gas out. Its volume does not change, but the number of moles of the gas n decreases. To counter the change, the temperature must go up. Since energy cannot be created it needs to be transferred from the outside of the cylinder to the inside. A rapid decrease in temperature outside cause water vapour in the air to freeze, forming frost on the wall of the cylinder.</p>
<p>Heat transfer: The gas in the cylinder is cold and it makes the cylinder surface much colder than the normal air temperature. Water vapour particles lose energy due to drop in temperature, so it sticks to the wall of the tank.</p>
<p>Because the frost has formed by heat transferred in the summer day, the temperature increases</p>
<p>Since its hot (summer) outside the cylinder a difference in temperature causes a layer of frost to be formed on the outside of the tank.</p>
<p>It takes heat to release the gas; therefore it absorbs the heat from the surroundings, decreasing the temperature. $pV=nRT$. P stays the same, k and n stay the same. V decreases and therefore temperature decreases.</p>
<p>$TV^{\gamma-1}=\text{constant}$. Assume that this is an adiabatic process</p>

11.5 Results and discussion

The results will be presented to highlight the way in which the use of the framework resulted in novel insights into student understanding. Firstly, an overview of the coding will be presented in terms of the semantic gravity present; next, the findings will be situated amongst the existing research on conceptions through the introduced concept of ‘emergent conceptions’; lastly, an illustration of how the LCT concept of semantic gravity was able to reveal details about how and why students approach a problem in physics in a particular way will be discussed through what is termed as ‘The Icarus Effect’. This section will conclude with a discussion around the implications for instruction.

11.5.1 Semantic gravity in responses

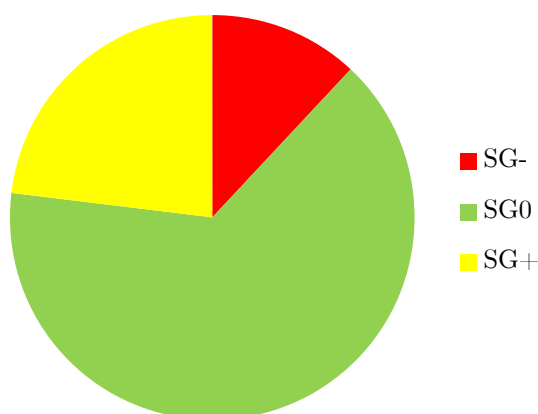
As Table 11-2 shows, students’ responses involved a combination of some or all of the three relative levels of semantic gravity. The number of coding references was determined by simply counting the occurrences of each type of level or combinations of levels in a response. For example, there was only one ‘single level’ SG+ assignment, and 26 ‘two level’ SG \emptyset , SG- assignments, meaning that these responses only contained SG \emptyset and SG+ coding.

	Coding present	No. of coding references
Single levels	SG \emptyset	15
	SG+	1
	SG-	4
Two levels	SG \emptyset / SG-	26
	SG \emptyset / SG+	37
	SG-/ SG+	1
Totals	All three	49
	At least two	113
Total		133

Table 11-2 Employment of different strengths of semantic gravity

It was not common for responses to remain in one particular level and some combinations of semantic gravity levels were more frequent than others, particularly those closer together. Figure 11-6 also shows the proportion in terms of number of words coded.

Figure 11-6 Proportion of words coded in full sample



This implies that most of the responses resided in the SG \emptyset level, indicating that students were attempting to explain either from the ‘top down’ or ‘bottom up’. That is, they would either begin with the particulars of the question, then introduce a slightly more abstracted idea, or, they would employ abstract principles and ‘unpack’ them in the intermediate level by way of explanation. An example is provided below.

Top down: $pV=nRT$. P stays the same, k and n stay the same. V decreases and therefore temperature decreases.

Bottom up: The release of the compressed gas allowed for an expansion of volume and the mechanical energy is turned into heat when first opened.

11.5.2 Augmenting the conceptions research

Of the three identified levels of relative semantic gravity, the SG \emptyset level was where the student provided, implicitly or explicitly, the supposed mechanism which lead to the frost formation. Therefore the ‘conceptions’ identified in the student responses were found to reside in this level. That ‘conceptions’ belong to a particular part of the spectrum of context-dependence is important. It indicates that conceptions are often extracted from more complete explanations, and thus should be considered in this context. For this reason, we shall refer to this/these ‘conceptions’ or supposed mechanism(s) as ‘emergent

conceptions¹⁴. These emergent conceptions are not necessarily wholesale statements from the students; they are ideas put forward by the students in various ways. Some examples are presented in the following list.

- Decrease in pressure leads to decrease in temperature
- Decreased temperature leads to frost forming
- Heat flows from warm to cold
- Increased disorder results in decreased heat which results in decreased temperature
- An expanding gas absorbs heat from surroundings, leading to a decrease in temperature
- Heat transfer from something makes that object colder
- Objects in contact reach thermal equilibrium with each other
- Heat transfer from air results in condensation and freezing
- Decreased order increases entropy and decreases temperature

The figure below (Figure 11-7) shows a coded sample indicating the three levels, SG-, SG \emptyset and SG+ in red, green and yellow respectively, with the emergent conceptions provided.

Figure 11-7 Emergent conceptions: conceptions emerging from SG \emptyset level

<p>The frost formation results because of decrease in the internal pressure, which according to $pV=nRT$ will lead to a decrease in temperature. The mechanism associated is pressure (difference in pressure inside the tank and outside the tank)</p>	<p>Decrease in pressure leads to decrease in temperature</p>
<p>Heat flows from the warm air to the cold so the cold air condenses then freezes as heat flows from it. This mechanism is the first law of thermodynamics which say hot to cold is how heat moves.</p>	<p>Heat flows from warm to cold Heat transfer from air results in condensation and freezing</p>
<p>When the gas is in the cylinder it has high pressure so it has low temperature and when its released the air around condenses due to the temperature change</p>	<p>Decreased temperature leads to frost forming</p>

¹⁴ They ‘emerged’ from the SG \emptyset level

These examples show that the emergent conceptions can occur: anywhere in the explanation, more than once in a single explanation and in the presence of both or one of the other levels.

Some of these emergent conceptions are fairly general, for example, ‘objects in contact reach thermal equilibrium with each other’, while others are more unique to the question asked: ‘decreased temperature leads to frost formation’. There were a small number of SGØ segments that could not be described in this list of emergent conceptions, such as:

“and the mechanical energy is turned into heat when first opened. Therefore, the temperature is changes greatly due to the shift of molecules into a greater space is reduced”.

Many of the emergent conceptions are identified as alternative conceptions (or misconceptions) and catalogued in the extant literature. Take, for example, ‘decrease in pressure leads to decrease in temperature’. This alternative conception has been reported as arising from different contextual situations, in Physics, chemistry and at different levels of study. However, many of the explanations around this conception are actually quite general. For example, the pressure-temperature relationship has been associated with an over-reliance on algorithmic thinking, or inappropriate use of mathematical formula instead of physical reasoning (Boudreaux & Campbell, 2012). Such general findings are extremely important and yet seem destined to exist within the confines of the individual studies. This is presumably because the main research thread in this area revolves around ‘constructivism’ and misconceptions, and therefore defines research in the standard narrative: students have existing ideas, these ideas may be incompatible with scientific ideas and therefore students should be encouraged to move away from inconsistent, naïve ideas to consistent, scientifically consistent ideas.

It is important that these emergent conceptions are not considered in isolation. As discussed in the literature review, students’ ideas are highly dynamic. Boudreaux and Campbell state that “in reporting student difficulties, we do not necessarily imply that student ideas are stable and coherent, as a ‘misconceptions model’ of student reasoning

would suggest.” (p. 710), however it is difficult to see how studies which simply identify students’ ideas can avoid representing them as ‘stable and coherent’.

In these student responses, since the SG+ level contained details about the scenario (cylinder, frost etc.) and the SG- level contained statements of general laws and principles, it is very easy to disregard the importance of these details, however, doing so reduces the qualitative analysis simply to multiple-choice options; the ‘misconceptions model’.

Instead, accepting the idea of emergent conceptions allows us to recognize that ‘explanations’ are supported by students’ linking their ideas to general principles and/or the details of the question. One significant consequence of this recognition is detailed in the next result ‘semantic gravity range’, which will explain how emergent conceptions fit into the global structure of responses and why this is significant for physics knowledge.

In summary, the LCT concept of semantic gravity allows us to describe ‘Emergent conceptions’. By ‘residing’ in the SG \emptyset level, emergent conceptions, otherwise labelled as misconceptions/alternative conceptions or facets cannot easily be misconstrued as isolated and discrete; researchers are forced to consider the context of the student’s response.

11.5.3 Semantic gravity range

The concept of the ‘semantic range’ of students’ responses is identified in order to more easily refer to the number of different relative levels of semantic gravity present. A larger semantic range indicates that a greater number of levels were present in a response whilst a smaller range indicates that only one level was utilised. Most students’ responses (85 %) exhibited a larger semantic range, meaning they employed at least two relative strengths of semantic gravity in their responses. This includes, in approximately equal measures, responses which were coded to both SG- and SG \emptyset and the SG \emptyset and SG+ level. Such structure in responses indicated that students attempted to link general principles or use established physics mechanisms to explain a concrete physical phenomenon.

Although a larger semantic range in student responses seems fairly obvious (or it would to physics instructors and educational researchers), it is a distinct quality in response to a somewhat unique knowledge structure (Lindstrøm, 2012). As mentioned in the literature review (Section 3.5.2), physics exhibits a ‘hierarchical’ knowledge structure, meaning that, units of knowledge are subsumed and integrated within other units of knowledge. This is not necessarily the case in all knowledge structures. For example, amongst literary critical theories, many units of knowledge are incommensurable to one another. They exhibit ‘horizontal’ knowledge structures.

The display of a larger semantic range therefore indicates that students recognise these characteristics of the knowledge structure; that context-dependence is important in explaining physical phenomena; and that tangible experience may be explained through utilisation of physical theories. This context dependency is what Redish draws attention to when he talks about ‘abstract reasoning primitives’ mapping onto ‘concrete facets’ (Figure 3-2). The importance of context-dependency is also therefore implicitly highlighted in diSessa’s p-prims on which Redish bases the ‘mapping’ process. The usefulness of the language of the theoretical framework of LCT is palpable when considering what Redish calls ‘mapping’. It provides a stronger explanatory basis by imposing a definition on ‘concrete’ and ‘abstract’ through the language of description, defining the substance and quantity of ‘mapping’ through the concept of semantic range and allows application to existing research.

An example of an application of the concept of semantic range using this language is the Expert-Novice literature in PER (and science education research). According to the Expert-Novice literature, students begin to develop distinct characteristics as they become more expert learners; they are able to see past the surface features of a question, successfully link theory to example and use the correct terminology. In terms of a sociocultural view of learning, students become further ‘encultured’ into the discipline, in this case, the understanding of thermodynamics and physics in general. The student progressively takes on the characteristics of the expert and this is hopefully facilitated by the educator. This view is a powerful one that has driven the Expert-Novice literature. However, much of the Expert-Novice literature has focused predominantly on content

knowledge, and to a lesser extent ‘approaches to learning’, ‘self-efficacy’ and ‘epistemology’. The recognition that the knowledge structure of physics is distinct has not been explored. Using the concept of semantic range, this dimension of ‘becoming more expert’ or ‘becoming more encultured’ can be more precisely described. The explanation is instead framed as more novice students exhibiting a smaller semantic range, while the more expert students are recognising the need for a larger semantic range. This allows comparisons between groups and over time. It also affords a different way of approaching the problem.

For example, students less exposed to physics, when asked to explain a physics phenomenon, are more likely to give concrete answers or answers resembling opinions, responses that reflect a narrower semantic range. Since Interactive Exercise Three was not an appropriate question to provide to ‘novices’ data were used from Interactive Exercise One to support this assertion. The following responses are from either part of the question and by two different groups; junior high school students, and university students.

Responses from 15-16 year-olds (SGPRE/POST, in Table 10-4)

“Personally, I find that cold transfer is most associated with the scenario because the surface of the glass is able to stay cool even in rather uncomfortably hot weather.”

“I think because the cola was actually the same temperature, but that plastic acts as a sort of insulator so that you can't feel the cold as much”

“Maybe carpet holds more heat because it is layered and tiles are cold because it is smoother? If you are insulating a house or something I'd rather choose carpet than tiles.”

“It just does. The tiles are cold and when she steps on them, the coldness touches her feet.”

“If the temperature was hot, the tiles would be hotter. If the temperature was cold, the tiles would be colder. Don't know why though.”

Responses from first year university Physics students (SydReg 2009, in Table 10-4):

“Heat is transferred from our bodies to the floor more easily when the floor is made of tiles. Tiles are more conductive. The heat on our bodies leave out bodies more easily when we step on tiles compared to stepping on the carpet. Tiles are better conductors”

“Carpeted floor has a higher heat capacity than the tiled floor. Heat is transferred from Rebecca's foot to the tiles more and faster than the heat is transferred from Rebecca's foot to the carpet. Rebecca's foot lost more heat when she walked on the tile floor”

“The conductivity of glass is better than plastic, so the glass get equilibrium with cola faster than plastic”

“The plastic is a better insulator of heat than glass. Since the glass bottle doesn't retain any heat it feels colder than the plastic bottle. Note: Both bottles have coke inside at the same temperature and that the glass bottle reaches a temperature closer to the coke than the plastic bottle”

The responses from the first, younger group were rooted in the details of the question and often included personal feelings. They spoke about objects, whether they were cold or hot, and their personal opinions about what they would do. The second, older group, with more experience in physics, even when not providing the ‘correct’ answer, were attempting to draw on a physical mechanism; they were detached and objective, more likely writing in third person (typical of a scientists’ writing).

Figure 11-8 Examples of different semantic ranges.

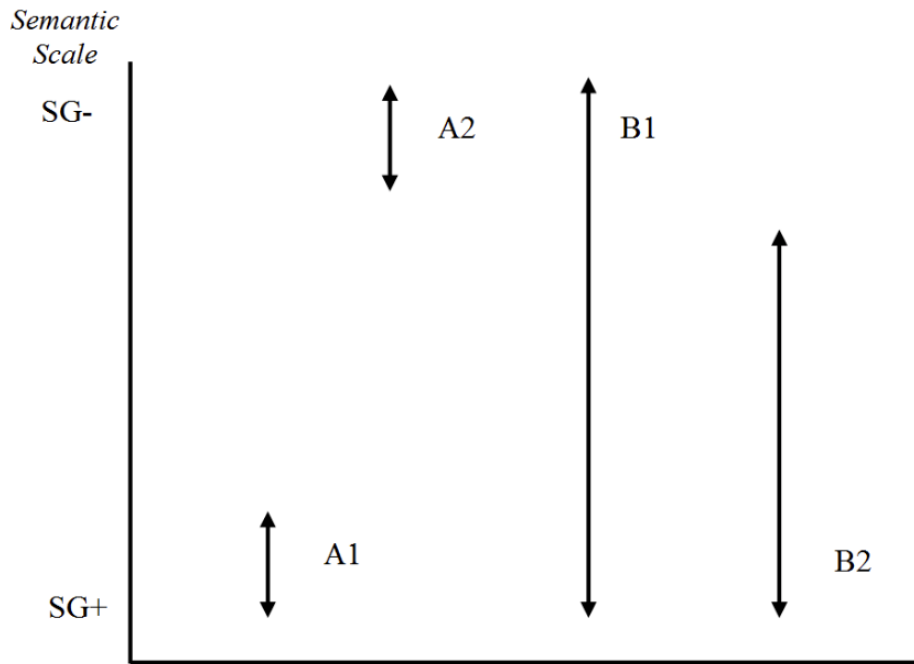


Figure 11-8 presents a visual representation of different relative strengths of semantic gravity and therefore semantic ranges. Students lacking experience in science present a very limited semantic range in explanations, often remaining at the very concrete levels which show stronger semantic gravity (A1). Students with a strong background in physics, although not necessarily successful in the content of their explanations, appreciate that a larger semantic range is necessary (B1, B2), one that reflects the depth of context dependence of the knowledge structure. As such, the analysis makes transparent characteristics that would have been missed in an approach which focused instead on 'content' or 'correctness'. One particular result, outlined in the next section, will show how the semantic range relates to student understanding.

In summary, it is, the *structure* of the response is evidence itself, and is a valuable supplement to analysis of the content. The tangibility of using the concept of semantic range facilitates the production of further questions: how does the semantic range of responses change with different levels of 'expertise' or, as will be discussed later in the results, how does the semantic range relate to the success of a response?

11.5.4 Moving beyond conceptions: The Icarus Effect

For Interactive Exercise Three, analysis shows that the most successful questions, as determined through coding with regards to internal consistency, had characteristic semantic gravity ranges.

There were altogether 17 of the 133 responses coded as ‘Internally consistent’. Coding of these occurred at the same time as coding for the relative levels of semantic gravity. S1, S2 and S3 agreed on the selection of the 17 and a further meeting was convened to discuss the legitimacy of these codings. Agreement again was reached at the 90% level.

The criteria for this coding was based on whether or not one of the mechanisms associated with the frost formation as provided and did not contain contradictions. Responses could be coded as ‘Internally consistent’ even if the students did not include the assumption of the composition of the contents of the gas cylinder. Some examples are provided below for illustration. These excerpts have similar semantic gravity ranges (B2 in Figure 11-8).

The frost forms because work is done as it expands from it liquid form to a gas form. This causes the heat in the surrounding the cylinder to drop condensation. It then freezes in the atmosphere and frost is formed on the tank

As the pressure inside the tank decreases, the gas expands, taking in energy which cools the container (absorbs heat from the container) which in turn does the same to the air around it. In the air, water gives up some of its kinetic energy changing from vapour water ice

The compressed gas in the cylinder is in a liquid state. As the state change from liquid to gas; heat absorbed from the surrounding, thus lowering the temperature of tank to the point where moisture from the atmosphere condenses on the tank, forming frost.

Amongst the most unsuccessful responses were A2, A1 and B1. What this illustrates is that it is ‘where the student’s reach’, rather than, say, what conceptions they betray, that determines how successfully they answer the question. Students that ‘reach too high’ or exhibit responses with weaker semantic gravity (range B1 in Figure 11-8) are more likely to fail to make the appropriate connections in their explanations. An explanation of the nature of the ideal gas equation and the student’s interpretation of it is provided in detail to evidence this assertion.

The ideal gas law (Equation 2) is a general law which applies to an ‘ideal gas’ and like all physical laws, it involves a set of assumptions. Most real gases can be considered as ideal gases and so the ideal gas law can be applied to determine characteristics of interest for gases used in a wide variety of contexts.

$$PV = nRT$$

Where P = pressure, V= volume, n= number of moles of gas,
R= gas constant $8.314 \text{ J}\cdot\text{K}^{-1}\text{mol}^{-1}$, T= temperature

Equation 2 The Ideal gas law

This law can help describe, for example, what might happen if you have a gas confined in a fixed volume and increase the temperature (the pressure will increase), or if you compress a gas at a fixed temperature (the pressure will increase). Although the idea gas law has great explanatory power, it has been reported that students often find the interpretation of this law difficult and are not successful in its application to different circumstances (e.g., Boudreaux & Campbell, 2012).

Most commonly, the law is misunderstood as a two variable equation (similar to Ohm’s Law, $V = IR$ or Newton’s Second Law, $F = ma$). It is therefore assumed that only *one* variable will change in response to another and not realised that the change of more than one variable, unlike the two-variable situation, will not result in predictable outcomes (increases or decreases in the dependent variable), at least without the specific quantitative information.

In the responses analysed for this paper, all uses of the ideal gas law in response to Interactive Exercise Three, implicit or explicit, were scientifically inaccurate either by contradiction, or by failing to account for the three-variable situation. Explicit mention of the ideal gas law occurred in 38 of the 133 responses, while 40 additional responses implied a reference. Although the references were implied, there is little doubt that the students were referring to the ideal gas law (Table 11-3).

	Coded	No. of responses	of examples
Ideal gas equation/law	Red (Abstract)	38	'Due to ideal gas law' 'PV=nRT'
Implied references	Green (Intermediate)	40	'The decrease in pressure within the tank causes a decrease in temperature' 'Since the volume of the gas increased, the temperature decreased' 'However the amount of gas particles in the cylinder decreases causing a decrease in temperature as well'

Table 11-3 Responses explicitly or implicitly employing the use of the idea gas equation

Here is the most common explanation for how the ideal gas law was used to explain the frost formation:

“Due to the pressure decreasing as a result of gas leaving the cylinder, the temperature decreases”

In and of itself, this explanation is a typical example of mistaking a three-variable problem for a two variable problem. It is not inconsistent to state that a decrease in pressure leads to a decrease in pressure without accounting for the other variable(s). However, some responses included a qualification which made such an attempt. For example, some responses stated that the number of molecules remained constant, which although solving the problem of unaccounted-for variables, contradicted the statement that pressure decreased because the gas was let out (lacking a mechanism for replenishment). If both the number of molecules and the pressure decrease, it is necessary to explain that one does so more than the other, to account for the drop in temperature, making this response inconsistent. There was only one student that attempted to quantify the change:

“ $pV=nRT$ $T=PV/nr$. As the gas is released from the cylinder, the pressure and number of molecules decrease. From the modified equation, the numerator decreases faster than the denominator, causing a decrease in temperature.”

In this case, even if we accept that the student had no resources to understand that the cylinder contains a liquid as well as the gas, there is no reason provided for why one variable should change more than the other. Furthermore, mathematically, the statement is inaccurate; an additional decrease in the numerator would actually lead to a higher temperature.

There was also a second solution involving a volume increase:

“ $pV=nRT$ therefore pressure decrease will cause both volume expansion and temperature decrease”

The typical oversight in regards to the three-variable problem resurfaces here; the failure to recognize that an outcome cannot be ascertained when all three variables are changing at the same time. The pressure decrease cannot both result in both volume increasing *and* temperature decreasing.

These examples of students attempting to link changes in pressure, volume and number of molecules to a change in temperature clearly confirm the difficulty of reasoning attached to a three-variable problem. But it suggests more than that. Students were not provided with a question about an ideal gas under certain conditions, a ubiquitous question in first year thermodynamics. They had a choice. This question type does not involve merely providing students with the content and asking them to work through it, it required a decision to be made by the student on which concept(s) they were going to use in their explanations. The question therefore becomes: why did they choose to use the three-variable problem in the first place? They did need to employ SG- reasoning in their responses but in fact accommodated them by making spurious or sometimes unreasonable assertions.

Interview data suggests that students suppressed their intuition to ‘reach higher’ and apply the ideal gas law to the situation. The students’ justifications for these choices were compelling. Six students in total were given the question and asked to provide a verbal explanation. All but one explained the question using the ideal gas law. All students were asked why they drew upon the ideal gas law to provide an explanation for the frost formation.

“Because we saw it a lot”

“Equations are easier and more convenient to use compared to a conceptual understanding.”

“It’s one of the first things you look at when you look at gases and it has a lot of things in it and it uses the word gas in it.”

Students were then prompted to consider alternative explanations:

T: Can you think of another way to explain this?

S: When the gas is expanding... it’s doing work on its surroundings....

T: So if a gas is doing work, how does it do this work?

S: Well.... the work... heat is equal to work.... so if... the energy of the work has to come from somewhere. That comes from the container, so the temperature of the container decreases because the particles of the container are moving slower and gave lower energy.

A second student came to the same conclusion. When arriving at the explanation that an expanding gas requires energy the student commented that:

“I’d say the second one (explanation) was clearer because like you can visualize it better... it’s less abstract”

Although it is possible to use the ideal gas law to explain what is happening with the ‘frosty cylinder’, it is not actually necessary or appropriate in this case. Students were sufficiently enticed by the equation to ‘reach up’ to a higher level of abstraction than

needed and this may be a reflection of student attitudes toward physics or a consequence of the way that physics is taught throughout school and university (general principles first (A2), examples later (A1), and not necessarily with an intermediate link).

In essence, these results show that there was an appropriate semantic range associated with Interactive Exercise Three (see B2, Figure 11-8) and that students that were not successful drew on explanations that were too weak in semantic gravity; figuratively, they flew too close to the sun (A2, B1). It wasn't only that students had problems understanding that three-variable equations could not be manipulated as two variable equations, or that they were unable to successfully use the ideal gas law, it was also that they were compelled to 'reach up' to a more general equation when it wasn't necessary.

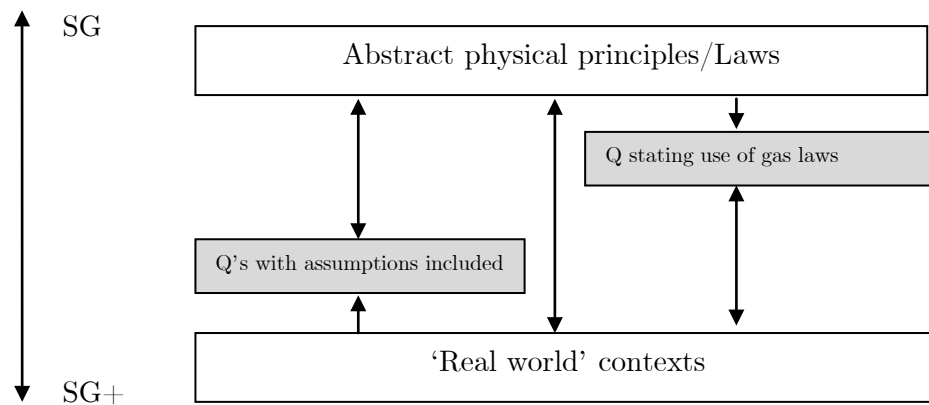
11.6 Implications for instruction

The albeit illustrative analysis presented here suggests that the form taken by knowledge claims may be a significant factor in student achievement in science education. Specifically, it highlights the potential importance of apprenticeship into appreciating the degree of context-dependence of meaning that is appropriate at different stages of the curriculum and for different kind of problems. This in turn has implications for research into issues such as student conceptions.

In terms of instruction, semantic gravity allows for flexibility across different tasks and contexts. There may be cases where a larger or smaller semantic gravity range is more appropriate. It is known, for example, that most physics problems are highly specialised (Teodorescu, Bennhold, Feldman, & Medsker, 2013). In thermodynamics courses students are often provided with 'traditional' questions: 'consider an ideal gas in a cylinder with a frictionless piston...', or 'using Charles's Law, predict ...'. However, Interactive Exercise Three, a 'context-rich' question, requires explanation of a real world phenomenon. Students are expected to reach up the semantic scale from the context-dependent problem to select which (less context-dependent) concept is appropriate and then move down the semantic scale to enact this concept in an explanation of the given scenario. Students find Interactive Exercise Three difficult because, while establishing the strongest semantic gravity setting required (the concrete example), the question does not

indicate its weakest setting; unlike ‘traditional’ questions that remain in a relatively abstract realm (‘consider an ideal gas ...’), the sky could be the limit in terms of how abstract the knowledge is that students are required to demonstrate. The question involves a potentially large gravity range of knowledge.

Figure 11-9 Representation of semantic gravity range of a typical physics question



To illustrate this issue, Figure 11-9 represents how a typical ‘traditional’ physics question weakens semantic gravity by avoiding real or familiar physical situations and drawing on idealisations (e.g., frictionless, massless, no air resistance, ideal gas etc.). This brings them closer in semantic gravity to the abstract principle of scientific knowledge required in a successful answer. Although in a typical undergraduate course students are trained to approach these questions to succeed in their physics study, students’ success or otherwise in this type of task might or might not transfer into other, unfamiliar contexts (Atkinson, Renkl, & Merrill, 2003). Characterisations of physics problems may now be reconsidered in terms of the semantic gravity ranges they demand. ‘Traditional’ problems, which ‘clearly spell the physics out’, ‘predefine variables’ or ‘rob students of an important decision’ (Heller & Heller, 1999) present a narrower and more determined semantic range; the ‘path’ students are expected to take is more clear. ‘Context-rich’ problems present a larger, undefined semantic range; students must make choices about how abstract they will go and justify their choice with strong connections to the concrete. It is unsurprising, then, that students that learn to adapt and succeed with traditional

problems still exhibit significant conceptual misunderstanding, as both Redish and Mazur attest (Section 1). Questions like the frosty cylinder problem may require additional instruction to establish the gravity range appropriate to their solution, either through extensive modelling by teachers or through making the range explicit using concepts like ‘semantic gravity’ as a meta-language in teaching. However, it may be the case that, through such exposure and apprenticeship in the structure of physics knowledge, specifically the semantic gravity range, students may achieve a superior conceptual understanding.

12 Discussion

This project has integrated many existing methods and approaches from science and physics education research –and beyond –to examine the teaching and learning of thermodynamics. The subject area of thermodynamics was chosen primarily due to the paucity of thermal physics concepts covered in the high school curriculum in NSW and the particular difficulties students have when undertaking first year thermodynamics courses. Both the level of education and the subject matter have not been studied as comprehensively as others and many gaps were filled in taking a closer look. However, the findings from the study also extend beyond specific subject matter.

In the area of improving instruction, existing practices, such as the pre- and post-testing methodology and Active Learning approaches were adapted and deployed.

The Active Learning program involved a number of Interactive Engagement methods, most notably, the Interactive Lecture Demonstrations (ILDs). In the first year of the implementation, where lectures with ILDs were compared against lectures with Interactive Exercises, a null result in terms of student outcomes was realised. Student's attitudes towards both the Interactive Exercises and the ILDs were extremely positive, indicating there was utility in both approaches. Methodological improvements and a focus on the characterisation of the lectures were integrated into a second iteration in 2012.

The characterisation of the lectures, particularly in the 2012 implementation using the full LASE, revealed two main results. Firstly, there was a clear difference in the time that students were deemed to be 'interactive' in the lecture between the two streams which experienced the ILD program and the two that had the Exercises. This is not surprising, although the high level of Transmission-Style teaching indicates that this is the most prevalent form of teaching in thermodynamics. Secondly, in 2012, there were more marked differences between streams, even amongst lectures of the same 'type'. That is, both the two ILD and the two Exercise streams displayed different lecture

activity, different student engagement and different learning outcomes. One of the reasons that the 2011 data were not as conclusive as the 2012 was that in 2011, the program was new to all lectures and there was a great deal of support from technical staff and Staff-1 and Researcher B. The higher level of autonomy in 2012 is considered to have produced a more ‘naturalistic’ implementation.

In terms of the Lecture Activity, as measured by the LA, and with respect to the ILD streams, ILD1 was found to exhibit more Interactivity overall compared with ILD2. This difference manifested itself in both the time allocated for interactive activities during the ILDs as well as during the remainder of the lecture program. For example, in the ILD program in lecture seven, ILD1 were given more time to discuss with each other during the prediction phase of the first ILD but were also subject to further class discussions with clickers or engaged in general ‘Peer Instruction’ type questioning outside of the ILD activities. There were also differences amongst the two Exercise, or non-ILD, streams. For instance, Staff-3 had provided more unique time for the completion of the exercises and referenced the Exercises throughout the lecture program. Figure 8-8 shows that in lecture 1 and in lecture 3, Staff-3, in EX2 allowed more time for the completion of the exercises.

Further examination through the evaluation surveys and interviews shows that these differences were consequential for the students. In 2012, the students in the ILD1 stream, which exhibited the most Interactivity, for example, said that they had more time to discuss with their peers and the lecturer and indicated that they understood the concepts better. They also indicated, more so than ILD2, that they were made aware of their ‘misconceptions’. Students in the non-ILD streams indicated that they found the Exercises interesting and used them as a basis for thinking about the thermodynamics concepts. Since Staff-2 in EX1 did not allocate much time for the Exercises, the students in this streams tended to lament that the Exercises were ‘rushed’ and interfered with their paying attention in the lectures.

The observations of differences between streams, together with the student’s reports support the conclusion that these differences influenced student learning outcomes. Using

the Thermal Concepts Survey, it was found in 2012 that ILD1, the stream with the Staff-1, exhibited the highest normalized gain of 0.40, followed closely by ILD2 with a gain of 0.34. The Exercise streams saw gains of 0.28 and 0.27. Staff-1 was the lecturer for ILD1, which also exhibited the most ‘Interactivity’, both during and separate to the ILD program.

In addition to these insights, several pertinent questions emerged. Firstly, despite the medium to high gains, students did not demonstrate consistent, sophisticated understanding of thermodynamics concepts. This was evidenced by the following: relatively lower scores in Part II of the TCS, a 37% average score on the thermodynamics questions in the final exam, and inconsistent explanations of basic thermodynamics concepts in the interviews. Also, historically, the thermodynamics questions are consistently the lowest scoring on the first year Physics exam.

Furthermore, when the study had concluded, the program in its entirety was not retained for the following year (2013), despite both Staff-2 and Staff-3 being allocated the thermodynamics module (Staff-1 was allocated to a different module). Staff-3 showed interest in retaining both the Exercises and the TCS, however, both Staff-2 and the new lecturer allocated to the thermodynamics module did not feel comfortable forgoing one full lecture for its implementation. For equity reasons, the TCS was therefore not administered in 2013. The newer staff member and Staff-2 also did not feel comfortable running the ILDs without support. This indicates that although the lecturers found aspects of the program useful, significant and continued support is necessary to ensure its retention.

Finally, the SE part of the LASE indicated that students *seemed* to be ‘minds on’ during all kinds of lecture activity, meaning that it is difficult to ascertain what is ‘minds on’ simply through observation. For example, the SE showed that there were periods where students were seen to be fully engaged in ‘Transmission-Style’ Lecture Activity whilst also appearing distracted during Interactive Engagement methods. Student interviews indicated that student’s felt that giving them ‘too much’ time would encourage diversion.

These observations may be repositioned as two distinct issues that feature in the PER literature. The first issue is associated with academic reporting and professional communication. Although ‘Active Learning’ and associated terminology (Interactive Engagement, Peer Instruction etc.) are described comprehensively as ‘types’ in the literature, their interpretation into practice is much less scrutinised; the assumption seems to be that the ‘type’ will be translated with sufficient fidelity. Since the implementation of IE methods is highly variable, particularly amongst non-specialists, the reporting of differences in the ways in which IE methods are implemented and received is important. This reporting should also include the reporting of null results; if and when they occur. An implementation that does not achieve a ‘positive’ outcome is no less important, from the point of view of research, as one that does. Characterisations which are occurring through observations and tools like the RTOP are welcomed, though these do not often focus on what the students themselves are doing and are nonetheless not common practice. Clarity is particularly relevant now, considering that many of the more successful IE methods which have been reported to occur in very specific contexts (namely, mechanics first-year calculus-based physics courses in the United States), are being adapted to ever more international contexts. Success across these contexts necessarily requires more meticulous characterisation.

The second issue, which has been discussed in detail in the literature review, involves the inherent limitations in the view held by science and physics education researchers about the nature of conceptions and of conceptual change. Practical and instructional developments have depended primarily on the recognition and analysis of large scale patterns: identifying misconceptions, exploring their characteristics and development, analysing novices and experts to determine conceptions and other general characteristics like motivations and ‘epistemologies’ and considering some social aspects. However, many argue that the utility of these approaches will always be limited if they continue to develop devoid of theoretical grounding. Many researchers, for example, have already accepted that we should move beyond simply identifying and describing alternative conceptions. The direction most are taking is the focus on the individual mind and of ‘knowing’, leaving behind issues surrounding knowledge itself. As Erduran and Scerri put it: “Schwab (1962) argued that expertise in teaching requires both knowledge of a

content of a domain and knowledge about the epistemology of that domain. Teachers develop the necessary capability of transforming subject into teachable content only when they know how the disciplinary knowledge is structured” (2002, p. 22). In the history of the work on conceptions, major advances were made in the presence of deeper theoretical and epistemological discussions. For instance, highlighting the importance of the views of children or students altered both the understanding of and approaches to student understanding. There was also a shift when the ‘social’ aspect of understanding became more prominent. In the current attempt, a shift, instead, to knowledge was proposed, advocating the use of Legitimation Code Theory.

The utility of this approach was explored through the concept of ‘semantic gravity’, or context dependence, which is one of many of the organising principles of knowledge. This concept was used to analyse responses to a context-rich problem, Interactive Exercise Three, and was completed by first year Physics students.

The first step in the analysis identified of the presence of combinations of different strengths of semantic gravity –different semantic ranges –in student responses. The students in the sample had high school backgrounds in physics (but not thermodynamics) and produced answers with a clear structure; they tended towards larger semantic ranges. This suggests that students who learn to ‘play the game’ of physics understand that physics questions usually demand responses which show different degrees of context-dependence; either connecting concepts with weaker semantic gravity to stronger, or through weakening semantic gravity from a very concrete physical situation. Comparisons made between these, more expert, students and students in junior high school (albeit answering a different question-Interactive Exercise One), show that the latter tend to produce responses that have stronger semantic gravity and very small semantic ranges overall. These students, considered ‘novices’, produce responses that communicate opinions or are not significantly abstracted from the physical situation presented in the question.

However, more significantly, when both the structure and content of responses are considered together, in this instance, students employing knowledge with relatively

weaker levels of semantic gravity – signalled by use of the ideal gas law – were more likely to be unsuccessful. This result suggests that there is an appropriate semantic range for success and that students who ‘reach too high’ may struggle to traverse the larger semantic gravity range. Students indicated, during interviews, that knowledge with weaker semantic gravity was attractive, not due to its relevance to the details of the question, but due simply to the fact that it had weaker semantic gravity. Students are tempted by more abstract principles for a variety of reasons and went to extraordinary lengths to make them work; their decisions were skewed by impression of ‘what physics should be’ instead of how best to approach a problem.

It is unsurprising therefore, that ‘alternative conceptions’ were found to reside in the level which was of intermediate semantic gravity; neither the strongest or the weakest. It was in this intermediate level, $SG\emptyset$, where the ‘emergent conceptions’ were found. These emergent conceptions are a shorthand way of communicating the reasoning of the student. For Interactive Exercise Three, it was the mechanism that caused some aspect of the freezing outside of the gas cylinder, such as ‘a decrease in pressure is equal to a decrease in temperature’. The embedding of these conceptions within the greater structure of the student’s response allowed a more functional conceptualisation of ‘alternative conceptions’ as intermediate links between general principles or as abstractions from the situation provided in the question. The functionality manifested itself in both the contextual consideration of the conception, as well as the content of the conception.

The concept of semantic gravity provides a language with which to interpret institutional practice in thermal physics. For example, many thermodynamics questions are based on the ideal gas law. Most of these questions already include various assumptions (e.g., consider a fixed volume cylinder). Effectively, such questions, known as ‘traditional’ questions or problems, are popular (and useful) because there is usually a unique and unambiguous solution that is relatively straightforward to grade. However, researchers note that students’ achievement on ‘traditional’ problems and ‘conceptual’ problems are vastly different. This may be due to the relative weakening of the semantic gravity of expected solutions. That is, the ‘typical physics question’ involves weakening

the relative semantic gravity and removing the need for students to practice this themselves. When discussing the strengths of ‘context-rich’ problems compared to ‘traditional’ ones, this was referred to as ‘robbing’ the students of a valuable decision (Section 3.2.1). Therefore, is it not surprising that there are reports that students are unable to effectively transfer the learning of general principles to other, unfamiliar contexts (Atkinson et al., 2003). This is particularly obvious when considering fundamental understanding, which can remain underdeveloped despite increasing in expertise in physics more generally, such as Meltzer’s study showing basic understanding lacking in third year students (Meltzer, 2004).

Beyond question types, the concept of semantic gravity may also aid in considering the nature of teaching. There have been various arguments for and against the sequencing of thermodynamics concepts (e.g., Herrmann, 2004). In this very specific case regarding the ideal gas law, it is possible to introduce its constituents separately. That is, one could introduce Boyle’s Law, Charles’ Law and Avogadro’s Law, instead of or before the introduction of the complete form of the ideal gas law. This equates to effectively strengthening semantic gravity, or bringing the ‘top down’, and may mean that it may be possible for students to develop more reliable links from the abstract laws to the individual contexts they are studying. Once mastery within this narrower range of semantic gravity is achieved, students can progress to working within a wider semantic range, hopefully, more efficiently. However, it may also be the case that students become dependent on these stronger gravity ‘crutches’. In either case, the identification of this structure in allows for greater understanding of both successful and unsuccessful attempts in teaching these concepts.

In discussing instructional practices, a hypothesis regarding the reported success of the ILDs may be suggested. Namely, that the ILDs develop the links between the stronger and weaker levels of semantic gravity. Rather than being simply ‘hands on’ or ‘minds on’ activities, the ILDs are carefully designed to facilitate ‘movement’ between different strengths of semantic gravity, and the particular concepts are chosen so as to produce the most effective and dependable links. This ‘movement’ has been otherwise named as ‘connectivity’. Buncick et al., explain:

“Connectivity means that the curriculum makes links to students’ concrete experiences, and that course concepts are not taught in isolation but in relation to one another and to everyday physical phenomena in which they play a part. Connectivity is fundamental to both engagement and inclusivity: when students can relate to the material, they are in a position to participate. Conventional teaching (where concepts are too often abstracted from everyday physical phenomena and presented as isolated principles) is more likely to result in a limited dialog between the teacher and a few ‘stars’ who are most comfortable with the abstract language and imagery of the more experienced scientist.(2001, pp. 1237-1238)

A lack of connectivity has been associated, convincingly, with not only student difficulties, but also in with attitudes about physics. Tobias and Hake address the question, ‘what makes science hard’ for science majors and non-majors, citing students who lament that: “I never really knew where we were heading or how much, in the real scheme of things, we had already covered. Each topic the professor discusses feels like it’s being pulled out of a hat” (Hake 1987, p. 162). The opposite should therefore also true: that facilitating the connectivity should encourage deeper understanding of physics (and a better attitude towards it). The concept of semantic gravity is one way of conceptualising ‘connectivity’. It’s operationalisation in analysing demonstrations in particular should prove fruitful, particularly as it is noted that some demonstrations are more effective at encouraging conceptual understanding than others.

The concept of ‘connectivity’ or this ‘movement’ is not only underscored in physics knowledge. Studies using the LCT concept of semantic gravity have resulted in the production of a representation of the changes in the relative strengths of semantic gravity over time (Figure 12-1). This simple representation is known as the ‘semantic wave’.

Figure 12-1 A 'semantic wave'

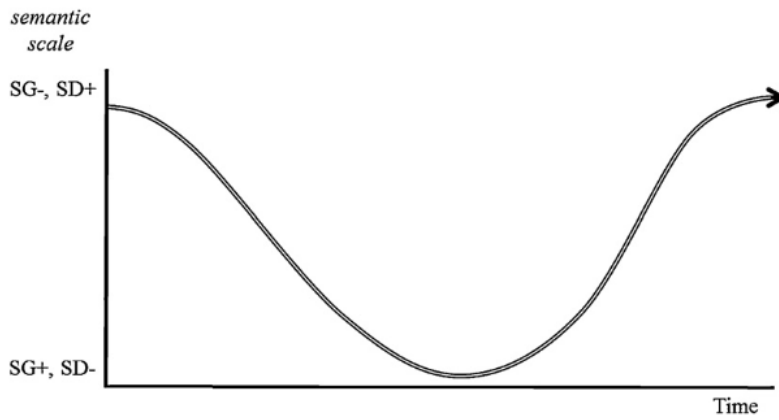
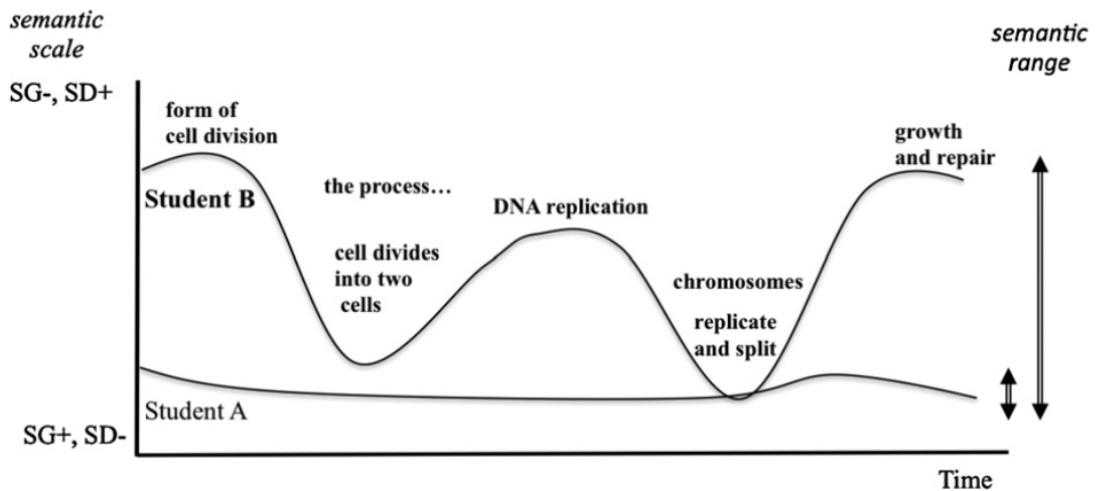


Figure 12-2 shows how the semantic wave may be used to describe practices through the tracing of semantic gravity over time for student's responses to a biology question about cell division (Macnaught, Maton, Martin, & Matruglio, 2013). The larger semantic range reflects a higher scoring response, whilst the smaller range a low scoring response. The authors' analysis is comparable to the expert physics students with their Interactive Exercise Three responses having larger semantic ranges whilst the junior high school students remaining at the SG+ levels with smaller semantic ranges.

Figure 12-2 Different semantic ranges as exhibited by students in Biology (Figure 2, p. 52)



Conclusion

As Redish (2009, p.3) emphasises, how students approach a question is influenced by, amongst other things, their ideas about ‘what kind of knowledge is at play here’. Central to the approach offered by LCT is a relational understanding of practice: student outcomes result from the meeting of their dispositions and the context. In terms of science education research, this is to emphasise student conceptions are student conceptions of something and that something requires analysis. LCT offers a means of analysing not only knowing and knowers but also knowledge, not only ‘teacher’, ‘student’ and ‘milieu’ but also ‘subject matter’. Its concepts can be used to analyse both student conceptions and the knowledge they are expected to learn (as realised in model answers, curriculum, textbooks, etc.), showing the degrees to which they match or clash (see Maton, 2014). This is less a focus on ‘right’ and ‘wrong’, ‘alternative conception’ or ‘misconception’ of content, and more a relational understanding of achievement in terms of the organising principles of student understanding and science knowledge. It thus emphasises that science is more than just its content: it has an architecture, including what form of knowledge is appropriate, such as the gravity range required to adequately explain a particular problem. LCT also has direct and practical implications for teaching and learning, as evidenced by a growing number of pedagogic interventions drawing on the framework.

This project has but briefly illustrated one concept from a multidimensional framework that is rapidly growing as the basis for empirical studies across the disciplinary map. Nonetheless, this example shows that Schwab’s commonplace of ‘subject matter’ does indeed matter, in terms of not only content but also form. This theoretical development is serviced by and services the comprehensive work in PER, including the pre- and post-testing methods and development of instructional practices such as those which encourage Active Learning. LCT offers one way in which we can not only recover ‘knowledge’ for research into science education but also develop a more sophisticated understanding of its role in science education itself.

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Appendices

Appendix A Teacher Survey

Teacher Survey

This survey is intended to gauge the realities of curriculum implementation in the classroom, specifically in the subject of junior science. The results of this survey will not be released to third parties, nor will the identities or personal details of the participants of the survey be disclosed. Your participation in this survey is entirely voluntary and you may, at any time, discontinue the survey with no penalty or explanation. Thank you in advance for your time and interest in this project.

The survey should take approximately 10-15 minutes.

Please return in the postage paid envelope or to the address provided below:

Helen Georgiou
Rm237
A28 Physics Building
University of Sydney
NSW 2006

Please feel free to encourage other secondary science teachers to take part. The permanent link to the online survey is as follows:

<https://spreadsheets.google.com/spreadsheet/viewform?formkey=dEZXTU5ZZ2pIZzRQSmcwNIZyaC1sbVE6MQ>

Demographics

Age group

Please specify your age group by checking a box below

- 21-26
- 27-35
- 36-45
- 45-55
- 56+

Sex

- Male
- Female

School Type

Please specify the type of secondary school you are currently teaching at by checking a box below

- Co-ed public school
- Single sex public school
- Selective government school
- Private school
- Catholic School
- Other religious school
- Other (please state): _____

Teaching years

Please provide the approximate time, in years, that you have been teaching in high school in NSW (full time teaching)

Subjects teaching

Please tick the boxes that correspond to the all the subjects you have taught in your career as a secondary teacher in NSW

- Junior Science
- Physics
- Earth and Environmental Science
- Chemistry
- Biology
- Maths
- Other (please state): _____

Degree type

Please state whether your background was from an Educational Degree (with specialisation), or a subject degree (e.g., BSc) with a Diploma of Education:

Subject Specialisation from University

Please provide the specialisation or major that was awarded to you at University (or equivalent):

More help

Please leave your email below if you would be available for similar voluntary contributions to this project:

Survey Questions

Question 1

Select about four of the following topic areas of junior science (years 7-10) that you instinctively feel you spend the **most time** on during the entire course

- Energy
 - Forces
 - Newton's Laws
 - Electricity
 - Thermal Physics (heat)
 - Elements and compounds
 - Atomic theory
 - Cell theory
 - DNA and genetics
 - Space and related Physics
 - Big Bang
 - Ecosystems
 - Energy Conservation
 - Other (please state):
-

Question 2

Select about four of the following topic areas of junior science (years 7-10) that you instinctively feel you spend the **least time** on during the entire course

- Energy
 - Forces
 - Newton's Laws
 - Electricity
 - Thermal Physics (heat)
 - Elements and compounds
 - Atomic theory
 - Cell theory
 - DNA and genetics
 - Space and related Physics
 - Big Bang
 - Ecosystems
 - Energy Conservation
 - Other (please state):
-

Question 3

Some individual items on the NSW syllabus can be grouped together in an order different to that listed in the document when organising school programs/schemes of work. To what degree do you or your school teach in this way?

- We fully adhere to the syllabus order of topics
 - We mainly adhere to the syllabus order but may change a few topics around only in certain circumstances or only for some subjects
 - We only loosely adhere to the syllabus order; our schemes of work are designed specifically to avoid linear progression
 - This doesn't apply to us as a department; each teacher chooses to do things his/her way
 - Other (please state):
-

Question 4

The document tries to give equal weighting to all the different disciplines of science (physics/chemistry/biology). Do you feel it has achieved this?

- Yes
- No

Which subjects/topics would you like to see more of in the junior science curriculum?

Which subjects would you like to see less of in the junior science curriculum?

Question 5

Overall, how much in favour would you say you were with the new curriculum

- | | | | | | | |
|---------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|---------|
| | 1 | 2 | 3 | 4 | 5 | |
| Hate it | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | Love it |

Question 6

If you were involved in the consultation process for the national curricula, what would you describe at the largest change to junior and senior science?

Questions on Thermal Physics as an example

The next few questions isolate one part of the syllabus for questioning:

4.6.6 heat energy a) identify processes of heat transfer by conduction, convection and radiation.

Question 7

How much time would you usually allocate for the statement provided above from the stage 4/5 syllabus?

- One lesson (equivalent one hour)
- Two lessons
- Three lessons
- Four lessons
- Five or more lessons
- Other: _____

Question 8

Which 'unit' do you teach this statement in your schemes of work? For example, 'energy'

Question 9

Which demonstrations, investigations or practical experiments would you carry out for this statement of the syllabus?

Question 10

There are many concepts related to this topic that are not listed in the syllabus. Place a tick next to the ones you feel you have time to teach when teaching **4.6.6 heat energy**

- The scientific definition of temperature and the different temperature scales (Celsius, Fahrenheit and Kelvin)
- The scientific definition of heat as being energy in transit
- The difference between heat and temperature and the ambiguity of the language used in science for these terms
- Thermal Equilibrium (two bodies of different temperature exchanging energy until they are both at the same temperature)
- The particulate theory of matter
- The microscopic picture of conductivity
- That the hand is not a good thermometer (e.g., metals feeling cold compared to woods that are the same temperature)
- Specific heat capacity
- Internal energy
- Entropy
- Other (please state): _____

Question 11

How important do you think thermal physics is to the scientific literacy of a student leaving high school?

	1	2	3	4	5	
Not important	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Vital

Question 12

Which current social, scientific or political issues related to thermal physics do you discuss during the teaching of this statement of the syllabus?

Thank you!

Appendix B Interactive Exercises

Interactive Exercise 1

Instructor:		Name:	
Lecture:		SID:	

Answer the review question below and return at the end of the lecture. No marks are allocated for the content of your answer, only for attempting the question (attending the lecture). Make sure you spell your name correctly and provide correct SID.

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.

Heat transfer Cold transfer Temperature Heat Conductivity Insulation
--

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:

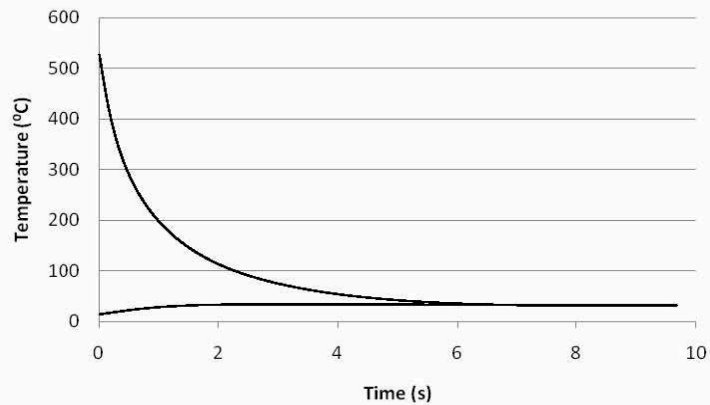
Interactive Exercise 2

Instructor:		Name:	
Lecture date:		SID:	

Answer the review question below and return at the end of the lecture. No marks are allocated for the content of your answer, only for attempting the question (attending the lecture). Make sure you spell your name correctly and/or provide correct SID.

A blacksmith who forges (heats and shapes) a metal horseshoe may cool it down by placing it in a bucket of cool water.

The graph below represents the temperature of the horseshoe and water over a period of 10s.



Label the curve representing the horseshoe and the curve representing the water. Explain why the curves are drawn in this way. (Assume none of the water evaporates)

What would happen to the temperature of the water in the same time period if there was a much smaller bucket of water (about one-eighth of the original volume)? Draw a curve that represents the temperature of the new volume of water on the same graph.

Interactive Exercise 3

Instructor:		Name:	
Lecture:		SID:	

Answer the review question below and return at the end of the lecture. No marks are allocated for the content of your answer, only for attempting the question (attending the lecture). Make sure you spell your name correctly and/or provide correct SID.

1. On a warm summer day a large cylinder of compressed gas (propane or butane) was used to supply several large gas burners at a cookout (the valve was open to release the gas). After a while, frost formed on the outside of the tank. In a few sentences, **explain at least one mechanism** associated with the frost formation.

Interactive Exercise 4

Instructor:		Name:	
Lecture:		SID:	

Answer the review question below and return at the end of the lecture. No marks are allocated for the content of your answer, only for attempting the question (attending the lecture). Make sure you spell your name correctly and/or provide correct SID.

Imagine a special air filter placed in the window of a house. This filter allows only air molecules moving faster than a certain speed to exit the house and allows only air molecules moving slower than that speed to enter the house from the outside. Explain why such an air filter would cool the house and why the second law of thermodynamics makes building such a filter an impossible task.

Rebecca's Problem

Heat is always transferred from the hot object (your hand) to the cold object (everything else). A colder sensation is registered when heat transfer is greatest from the hand/foot.



- Heat transfer occurs more effectively in the tiles and glass bottle, hence these objects register as 'feeling colder'
- Each pair of objects (tiles/carpet) (glass bottle/plastic bottle) are actually at the same temperature (Zero-th law)
- The hand is NOT a good thermometer because it does not come to thermal equilibrium with these objects.

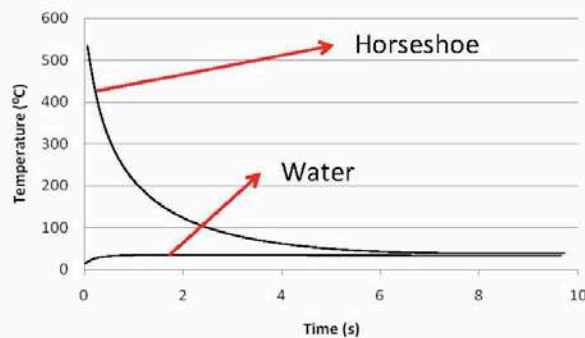
Contact Helen Georgiou;
georgiou@physics.usyd.edu.au

But I thought....

- **'Cold was transferred from the tiles/bottle to Rebecca's hand'** There is no such thing as cold transfer in terms of physical processes: energy is transferred in one 'direction', the sensation of cold or cold transfer is just a lack of heat or heat transfer
- **'The liquid inside the glass bottle was cold but not the bottle itself'** Both the bottle walls and the liquid must be at the same temperature because they have been in the fridge for a significantly long period of time
- **'Glass is an insulator and that's why it felt colder'** Actually, if glass was an insulator for the contents/cola it would also insulate against your hand's energy i.e., you would not lose heat from your hand and therefore wouldn't feel cold.
- **'Carpet stored the heat and kept warm'** No object can 'store' heat or be at a perpetually higher temperature unless they produce energy; Energy will always be transferred as heat when two objects of different temperatures are in contact

Contact Helen Georgiou;
georgiou@physics.usyd.edu.au

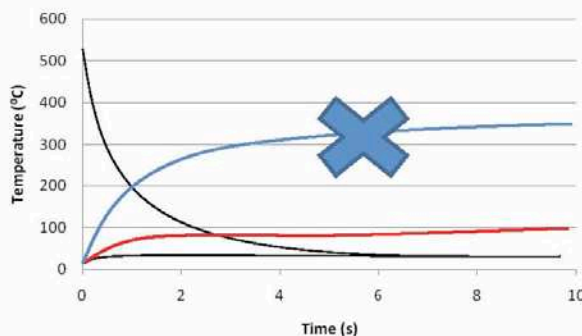
Blacksmith's problem



- Horseshoe curve: Starts at a higher temperature and decreases; large change in temperature at first; temperature change occurs in a small amount of time because water is a good conductor and allows greater heat transfer (same ΔT will take much longer for air, which is not a good conductor and therefore limits heat transfer)
- Water curve: Starts at a lower temperature and increases (slightly); Water has a high specific heat capacity so there is a small change in temperature (there is also more of it compared to the horseshoe) for the energy transferred from horseshoe.
- Both objects eventually reach thermal equilibrium, a temperature closer to the initial temperature of the water

Contact Helen Georgiou:
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Blacksmith's problem



Be careful:
Final temperature of water
cannot exceed 100°C

Water temperature (and therefore equilibrium temperature) will be higher. It is likely there will be some evaporation but the water temperature will not exceed 100°C

Sample curve is shown on the graph

TIPS: The question asked to **explain**; as discussed in lectures, this means using physical principles. You must discuss thermal principles covered in lectures, even if the answer appears to be 'commonsense'

Marks below 5 indicated errors, or insufficient use of physical principles to explain

Contact Helen Georgiou:
georgiou@physics.usyd.edu.au

Frosty cylinder problem

This was a complicated question with many parts....

Two clear mechanisms:

1. The gas in the cylinder does work as it expands. An expanding gas (lower pressure) results in heat transfer from surroundings (lower temperature).
2. Condensation is a change of phase from gas to liquid, which releases thermal energy. More energy is released as liquid freezes to solid. The cause of the release of thermal energy is the transfer driven from the surroundings (air) to the cylinder- and its contents. Moisture/water vapour in the air condenses and then freezes on the cylinder due to this heat transfer.



Why does the frost form only on the bottom of the cylinder?

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georgiou@physics.usyd.edu.au

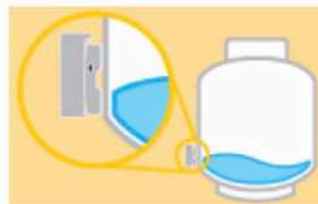
Frosty cylinder problem

The frost on the bottom indicates that the heat transfer is occurring largely in the **liquid** butane/propane section. Heat transfers from the liquid as it evaporates to replace the gas vapour that exists in the top of the cylinder. Liquids are generally better conductors than gases, accounting for the frost at the liquid level only.

This phenomenon is well known and temperature changes occur in cylinder walls when gas is released even if they aren't extreme enough to cause frost formation. The device on the left is used to measure the liquid level in cylinders by detecting small changes in temperature of the walls. Instructions include placing the device right at the bottom of the cylinder and out of direct sunlight.

The GasGenie solves one of the oldest problems of Barbecuing using gas: Running out of propane whilst cooking.

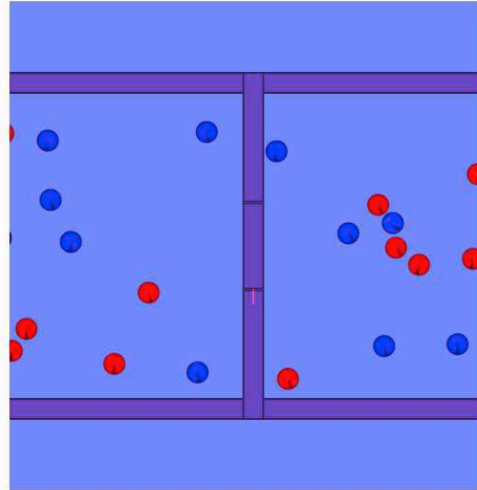
Buy the GasGenie for \$24.95



Impossible house filter

The filter cools the house by separating the higher speed and lower speed particles. More of the lower speed particles end up inside the house, meaning the temperature will be measured as lower there.

The filter is impossible as it violates the second law of thermodynamics since at some point during this process heat transfer will occur from cold to hot (without work being done). i.e., the house will be cooler than outside and heat transfer will still occur from inside to outside- cold to hot.



Maxwell's Demon

The full explanation of this situation involves statistical physics but you can learn a little more through explanation of the thought experiment called 'Maxwell's Demon', which is similar to the house filter situation.

- Read the Wikipedia article:
http://en.wikipedia.org/wiki/Maxwell%27s_demon
- Watch a video:
<http://www.khanacademy.org/video/maxwell-s-demon?playlist=Chemistry>
- Play the game:
<http://www.flasharcade.com/sports-games/demon-game.html>

Appendix D Prediction and Results Sheets for ILDs

Name _____

Hand in this sheet

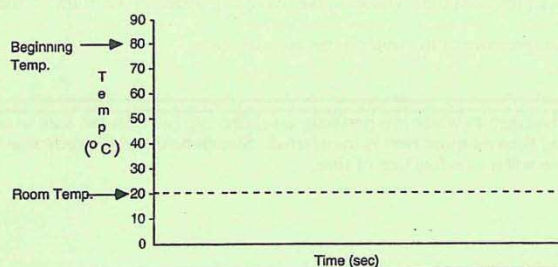
SID _____

INTERACTIVE LECTURE DEMONSTRATIONS PREDICTION SHEET—INTRODUCTION TO HEAT & TEMPERATURE

Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

Demonstration 1: A small piece of metal has been raised to a high temperature, around 80-90°C. Sketch below your prediction for the temperature-time graph for the piece of metal cooling in the room air. Be sure to carefully sketch the shape of the curve.

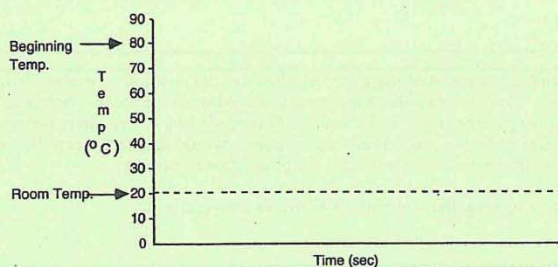
What do you think the final temperature of the metal will be? Zero degrees C? Room temperature? Something different?



Demonstration 2: Now the same piece of metal at a high temperature (around 80-90°C) is immersed in a cup filled with cool water (around 20°C). Sketch below your predictions for the temperature-time graphs of the piece of metal and the water in the cup. Be sure to carefully sketch the shapes of the curves.

What do you think the final temperature of the metal will be? (Zero degrees C? Midway between the initial temperatures of the water and the metal? Closer to the initial water temperature? Closer to the initial metal temperature? Other?)

What do you think the final temperature of the water in the cup will be?



Demonstration 3: Now a small film container filled with water at a high temperature (around 80-90°C) is immersed in a cup filled with room temperature water (around 20°C). Sketch below your predictions for the temperature-time graphs of the film container of hot water and the water in the cup. Be sure to carefully sketch the shapes of the curves.

Compare these temperatures to those in Demonstration 2.

What do you think the final temperature of the water in the film container will be? (Zero degrees C? Midway between the initial temperatures of the water in the film container and water in the cup? Closer to the initial film container water temperature? Closer to the initial cup water temperature? Other?)

What do you think the final temperature of the water in the cup will be?

Demonstration 4: Heat is transferred to water in a perfectly insulated cup (no heat can leak in or out) at a steady rate for 80 seconds, and then no more heat is transferred. Sketch below your prediction for the graph of the temperature of the water as a function of time.

Demonstration 5: A heat pulser can transfer a fixed amount of heat into water for each pulse. The temperature of a small amount of water increases by 8°C when 3 pulses are delivered. What is the temperature change when 6 pulses of heat are transferred to the water?

What happens when 3 pulses are transferred to twice as much water?

Does the same amount of heat always produce the same temperature change even in different amounts of water?

Demonstration 6: You saw that a hot piece of metal cooled down in the room in an earlier demonstration. Hot water would do the same. You also saw the temperature of cold water increase when heat was transferred to it. We want to keep some water at 80°C for 100 seconds in a room where the temperature is 20°C. If it took 12 heat pulses to do so, predict how many pulses would it take to keep the same water at 50°C for 100 seconds under the same circumstances. Explain your reasoning.

How many pulses would it take to keep the water at 20°C (room temperature)?

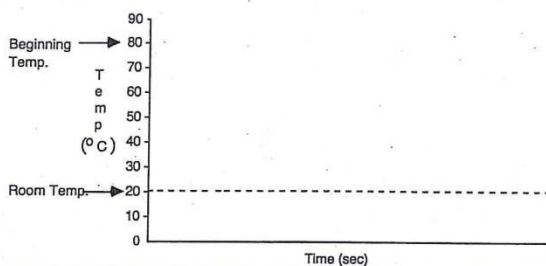
Keep this sheet

INTERACTIVE LECTURE DEMONSTRATIONS
RESULTS SHEET— INTRODUCTION TO HEAT & TEMPERATURE

You may write whatever you wish on this sheet and take it with you.

Demonstration 1: A small piece of metal has been raised to a high temperature, around 80-90°C. Sketch below your prediction for the temperature-time graph for the piece of metal cooling in the room air. Be sure to carefully sketch the shape of the curve.

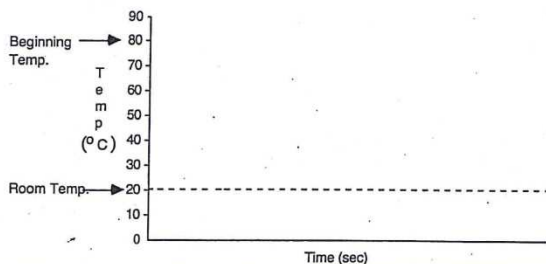
What do you think the final temperature of the metal will be? Zero degrees C? Room temperature? Something different?



Demonstration 2: Now the same piece of metal at a high temperature (around 80-90°C) is immersed in a cup filled with room temperature water (around 20°C). Sketch below your predictions for the temperature-time graphs of the piece of metal and the water in the cup. Be sure to carefully sketch the shapes of the curves.

What do you think the final temperature of the metal will be? (Zero degrees C? Midway between the initial temperatures of the water and the metal? Closer to the initial water temperature? Closer to the initial metal temperature? Other?)

What do you think the final temperature of the water in the cup will be?



Demonstration 3: Now a small film container filled with water at a high temperature (around 80-90°C) is immersed in a cup filled with room temperature water (around 20°C). Sketch below your predictions for the temperature-time graphs of the film container of hot water and the water in the cup. Be sure to carefully sketch the shapes of the curves.

Compare these temperatures to those in Demonstration 2.

What do you think the final temperature of the water in the film container will be? (Zero degrees C? Midway between the initial temperatures of the water in the film container and water in the cup? Closer to the initial film container water temperature? Closer to the initial cup water temperature? Other?)

What do you think the final temperature of the water in the cup will be?

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Demonstration 5: A heat pulser can transfer a fixed amount of heat into water for each pulse. The temperature of a small amount of water increases by 8°C when 3 pulses are delivered. What is the temperature change when 6 pulses of heat are transferred to the water?

What happens when 3 pulses are transferred to twice as much water?

Does the same amount of heat always produce the same temperature change even in different amounts of water?

Demonstration 6: You saw that a hot piece of metal cooled down in the room in an earlier demonstration. Hot water would do the same. You also saw the temperature of cold water increase when heat was transferred to it. We want to keep some water at 80°C for 100 seconds in a room where the temperature is 20°C. If it took 12 heat pulses to do so, predict how many pulses would it take to keep the same water at 50°C for 100 seconds under the same circumstances. Explain your reasoning.

How many pulses would it take to keep the water at 20°C (room temperature)?

Name _____

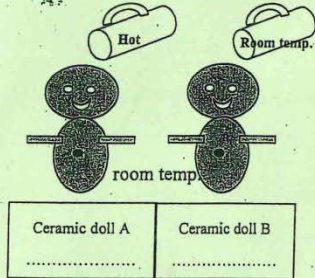
SID _____

Hand in this sheet

INTERACTIVE LECTURE DEMONSTRATION
PREDICTION SHEET—THERMAL PROCESSES 1

You may write whatever you wish on this sheet and take it with you.

Demonstration 1 Ceramic dolls¹ A and B contain room temperature water. When pouring hot water on ceramic doll A and room temperature water on ceramic doll B, which ceramic doll will have water shooting out from the hole in front? Please explain your reasoning.



Reasoning.....

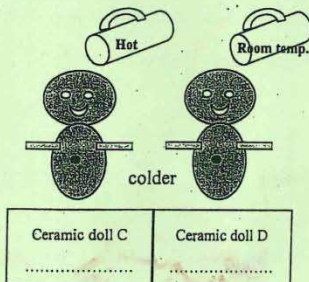
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Demonstration 2 Ceramic dolls C and D containing water were submerged in ice-cold water until they are at thermal equilibrium with the cold water. When pouring hot water on ceramic doll C and room temperature water on ceramic doll D, which ceramic doll will have water shooting out from the hole in front? Please explain your reasoning.



Reasoning.....

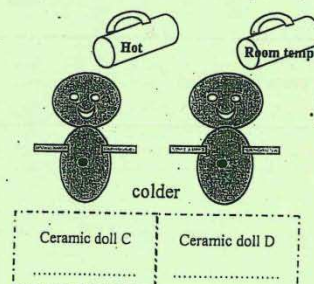
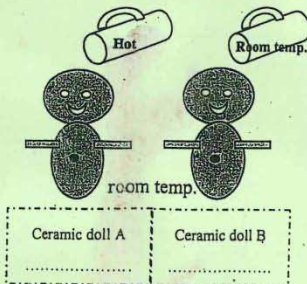
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2. Write down the results of the demonstrations for ceramic dolls A, B, C and D. Please explain your reasoning.



¹ The ceramic doll is called "Pee-pee boy," often found in a Chinese tea shop. It is an attention-grabber in showing when the water is hot enough for making tea.

Hand in this sheet

The ceramic doll contains mostly water but there is a small amount of air inside. Consider the air trapped inside the ceramic doll to be the system.

3. When the water is shooting out of the doll, is the work done by the system (ΔW) (positive, negative or zero)? Please explain your reasoning.

4. When the water is shooting out of the doll, is the heat transfer between the system and the environment (ΔQ) (positive, negative or zero)? Please explain your reasoning.

5. When the water is shooting out of the doll, is the change in internal energy of the system (ΔU) (positive, negative or zero)? Please explain your reasoning.

6. (a) Please write down the relationship between ΔW , ΔQ and ΔU for the system.

(b)

This process is called

Name _____

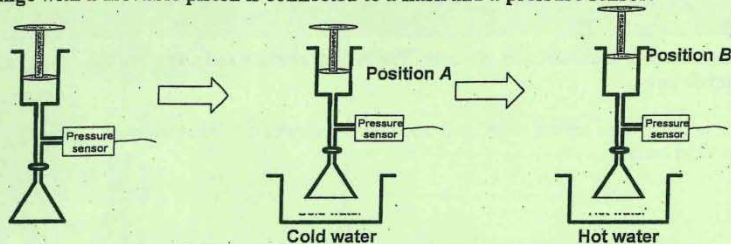
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SID _____

INTERACTIVE LECTURE DEMONSTRATION
PREDICTION SHEET—THERMAL PROCESSES 2

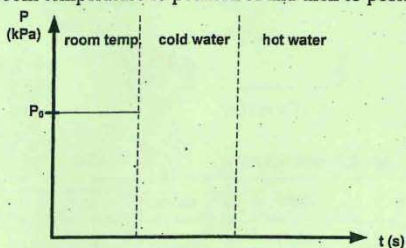
You may write whatever you wish on this sheet and take it with you.

A glass syringe with a movable piston is connected to a flask and a pressure sensor.

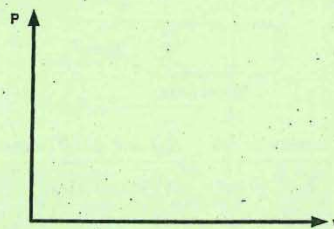


1. When submerging the flask in cold water, will the piston of the syringe move up or down?
2. When moving the flask from cold to hot water, will the piston move up or down?
3. Consider the air inside the flask and the syringe as a closed system.

(a) Please plot pressure versus time of the system as it goes from room temperature to position A and then to position B.



(b) Please plot pressure versus volume of the system while the piston is moving up.



4. Consider the piston going from position A (the initial state) to position B (the final state). What happens to ΔW , ΔQ and ΔU ? Please circle one choice for each quantity.

Work done by the system (ΔW)	positive	zero	negative
Heat transfer (ΔQ)	positive	zero	negative
Change in internal energy (ΔU)	positive	zero	negative

5. (a) Please write down the relationship between ΔW , ΔQ and ΔU for the system.

- (b)

This process is called

Name _____

Hand in this sheet

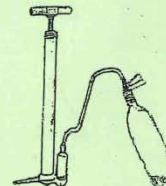
SID _____

INTERACTIVE LECTURE DEMONSTRATION
PREDICTION SHEET—THERMAL PROCESSES 3

You may write whatever you wish on this sheet and take it with you.

A pet bottle contains a small amount of water. The rubber stopper and a clip are used to connect the bottle with the bicycle pump.

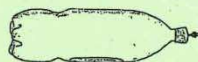
1. The pump is compressed several times until the stopper is blasted out. What will you observe inside the bottle?



2. When the pump is compressed several times but the rubber stopper is still intact, what happens to the air inside the bottle in terms of the state variables—volume, pressure and temperature? Please circle one choice for each state variable.

Volume	increases	the same	decreases
Pressure	increases	the same	decreases
Temperature	increases	the same	decreases

3. Consider the air inside the bottle as the system. The initial state is the state of air a few second before the rubber is blasted out. The final state is the state of air a few second after the rubber is blasted out, as shown in the below figure.



Initial state

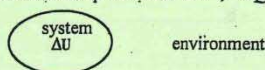


Final state

What happens to ΔW , ΔQ and ΔU ? Please circle one choice for each quantity.

Work done by the system (ΔW)	positive	zero	negative
Heat transfer (ΔQ)	positive	zero	negative
Change in internal energy (ΔU)	positive	zero	negative

4. (a) Please complete the diagram representing a relationship between ΔW , ΔQ and ΔU .



(b) Please write down the relationship between ΔW , ΔQ and ΔU for the system.

(c)

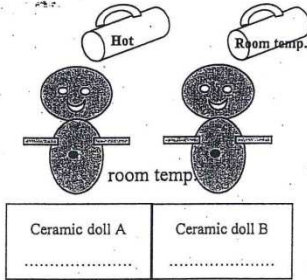
This process is called

Keep this sheet

INTERACTIVE LECTURE DEMONSTRATION
PREDICTION SHEET—THERMAL PROCESSES 1

You may write whatever you wish on this sheet and take it with you.

Demonstration 1 Ceramic dolls ¹A and B contain room temperature water. When pouring hot water on ceramic doll A and room temperature water on ceramic doll B, which ceramic doll will have water shooting out from the hole in front? Please explain your reasoning.



Reasoning.....

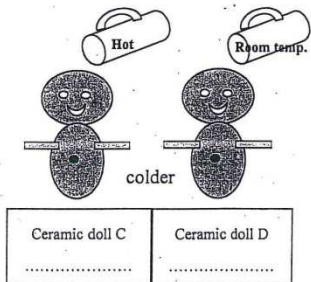
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Demonstration 2 Ceramic dolls C and D containing water were submerged in ice-cold water until they are at thermal equilibrium with the cold water. When pouring hot water on ceramic doll C and room temperature water on ceramic doll D, which ceramic doll will have water shooting out from the hole in front? Please explain your reasoning.



Reasoning.....

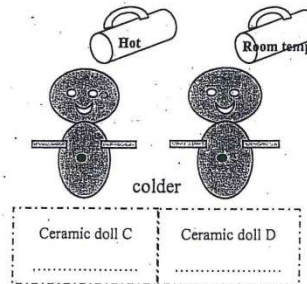
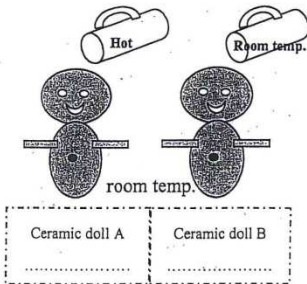
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2. Write down the results of the demonstrations for ceramic dolls A, B, C and D. Please explain your reasoning.



¹ The ceramic doll is called "Pee-pee boy," often found in a Chinese tea shop. It is an attention-grabber in showing when the water is hot enough for making tea.

Keep this sheet

The ceramic doll contains mostly water but there is a small amount of air inside. Consider the air trapped inside the ceramic doll to be the system.

3. When the water is shooting out of the doll, is the work done by the system (ΔW) (positive, negative or zero)? Please explain your reasoning.

4. When the water is shooting out of the doll, is the heat transfer between the system and the environment (ΔQ) (positive, negative or zero)? Please explain your reasoning.

5. When the water is shooting out of the doll, is the change in internal energy of the system (ΔU) (positive, negative or zero)? Please explain your reasoning.

6. (a) Please write down the relationship between ΔW , ΔQ and ΔU for the system.

(b)

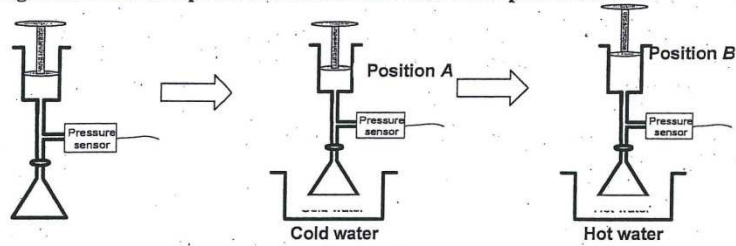
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INTERACTIVE LECTURE DEMONSTRATION
PREDICTION SHEET – THERMAL PROCESSES 2

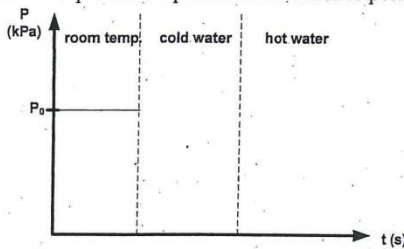
You may write whatever you wish on this sheet and take it with you.

A glass syringe with a movable piston is connected to a flask and a pressure sensor.



- When submerging the flask in cold water, will the piston of the syringe move up or down?
- When moving the flask from cold to hot water, will the piston move up or down?
- Consider the air inside the flask and the syringe as a closed system.

(a) Please plot pressure versus time of the system as it goes from room temperature to position A and then to position B.



(b) Please plot pressure versus volume of the system while the piston is moving up.



- Consider the piston going from position A (the initial state) to position B (the final state). What happens to ΔW , ΔQ and ΔU ? Please circle one choice for each quantity.

Work done by the system (ΔW)	positive	zero	negative
Heat transfer (ΔQ)	positive	zero	negative
Change in internal energy (ΔU)	positive	zero	negative

- (a) Please write down the relationship between ΔW , ΔQ and ΔU for the system.

- (b)

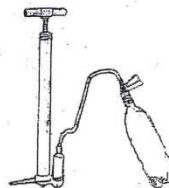
This process is called

Keep this sheet

INTERACTIVE LECTURE DEMONSTRATION
 PREDICTION SHEET – THERMAL PROCESSES 3
 You may write whatever you wish on this sheet and take it with you.

A pet bottle contains a small amount of water. The rubber stopper and a clip are used to connect the bottle with the bicycle pump.

1. The pump is compressed several times until the stopper is blasted out. What will you observe inside the bottle?



2. When the pump is compressed several times but the rubber stopper is still intact, what happens to the air inside the bottle in terms of the state variables—volume, pressure and temperature? Please circle one choice for each state variable.

Volume	increases	the same	decreases
Pressure	increases	the same	decreases
Temperature	increases	the same	decreases

3. Consider the air inside the bottle as the system. The initial state is the state of air a few second before the rubber is blasted out. The final state is the state of air a few second after the rubber is blasted out, as shown in the below figure.



Initial state



Final state

What happens to ΔW , ΔQ and ΔU ? Please circle one choice for each quantity.

Work done by the system (ΔW)	positive	zero	negative
Heat transfer (ΔQ)	positive	zero	negative
Change in internal energy (ΔU)	positive	zero	negative

4. (a) Please complete the diagram representing a relationship between ΔW , ΔQ and ΔU .



(b) Please write down the relationship between ΔW , ΔQ and ΔU for the system.

(c)

This process is called

SID _____

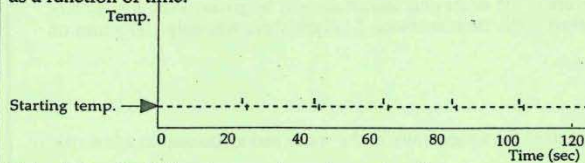
Name _____

Hand in this sheet

INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET— SPECIFIC HEAT

Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

Demonstration 1: 100 grams of water is initially at room temperature in a perfectly insulated cup (no heat can leak in or out). Heat energy is transferred to the water at a steady rate for 90 seconds, and then no more heat is transferred. Sketch below your prediction for the graph of the temperature of the water as a function of time.



Record Temperatures Below:

Starting Temperature: _____

Ending Temperature: _____

Change in Temperature: _____

Calculation 1: Using the actual starting and ending temperatures of the water, determine the amount of heat energy that was transferred to the water in this process. The specific heat of water is $4186 \text{ J/kg } ^\circ\text{C}$.

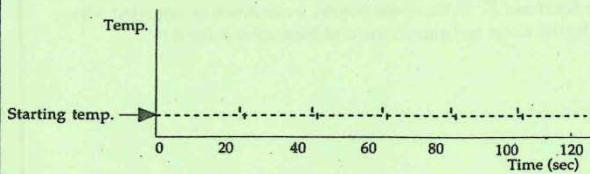
Heat Energy Transferred = $Q_1 =$ _____

Demonstration 2: 50 grams of aluminum is added to 100 grams of water. The aluminum and the water are both initially at room temperature in a perfectly insulated cup. Heat energy is transferred to the system at the same steady rate as in the previous demonstration for 90 seconds, and then no more heat energy is transferred.

Discussion Question:

Do you think that the final temperature of the water plus aluminum will be greater than, less than or equal to the final temperature reached in the previous demonstration?

Sketch below your prediction for the graph of the temperature of the water and aluminum as a function of time.



Record Temperatures Below:

Starting Temperature: _____

Ending Temperature: _____

Change in Temperature: _____

Calculation 2: Using the actual starting and ending temperatures of the system, determine the amount of heat that was transferred to the water and aluminum in this process. The specific heat of water is $4186 \text{ J/(kg } ^\circ\text{C)}$ and the specific heat of aluminum is $900 \text{ J/(kg } ^\circ\text{C)}$.

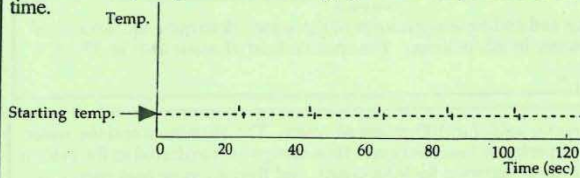
Heat Transferred = $Q_2 =$ _____

Demonstration 3: Now 50 grams of aluminum are used to *replace* 50 grams of water, so that we start with 50 grams of water and 50 grams of aluminum, both initially at room temperature in a perfectly insulated cup. Heat energy is transferred to the water and aluminum at the same steady rate as in the previous demonstrations for 90 seconds, and then no more heat energy is transferred. Again, the specific heat of water is $4186 \text{ J/(kg } ^\circ\text{C}^\circ)$ and the specific heat of aluminum is $900 \text{ J/(kg } ^\circ\text{C}^\circ)$.

Discussion Questions:

1. Do you think that the final temperature of the water plus aluminum will be greater than, less than or equal to the final temperature achieved in the Demonstration 2 (where there was 100 grams water with 50 grams aluminum)?
2. Do you think that the final temperature of the water plus aluminum will be greater than, less than or equal to the final temperature achieved in the Demonstration 1 (where there was only 100 grams of water)?

Sketch below your prediction for the graph of the temperature of the water and aluminum as a function of time.



Record Temperatures Below:

Starting Temperature: _____

Ending Temperature: _____

Change in Temperature: _____

Calculation 3: Now let's assume that the same amount of heat energy will be transferred to this system as was transferred in the previous two demonstrations. Since you probably found that these amounts were slightly different, first take the average of the two amounts of heat:

$$\text{Heat Transferred} = Q_3 = \frac{1}{2}(Q_1 + Q_2) =$$

Since this heat will be transferred to the water and the aluminum, we can write down an equation that will allow us to predict the theoretical change in temperature of our system. The amount of heat energy gained by each part of the system will be of the form $mc\Delta T$. In the space below, write down an equation which sets Q_3 equal to the heat energy gained by the water and aluminum, and then solve it for ΔT :

$$Q_3 =$$

$$\Rightarrow \Delta T =$$

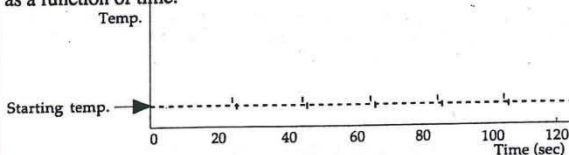
How does the theoretical numerical answer you just calculated compare with the actual change in temperature of the system? Can you think of a possible explanation for any discrepancy?

Keep this sheet

INTERACTIVE LECTURE DEMONSTRATIONS
RESULTS SHEET— SPECIFIC HEAT

You may write whatever you wish on this sheet and take it with you.

Demonstration 1: 100 grams of water is initially at room temperature in a perfectly insulated cup (no heat can leak in or out). Heat energy is transferred to the water at a steady rate for 90 seconds, and then no more heat is transferred. Sketch below your prediction for the graph of the temperature of the water as a function of time.



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Starting Temperature: _____

Ending Temperature: _____

Change in Temperature: _____

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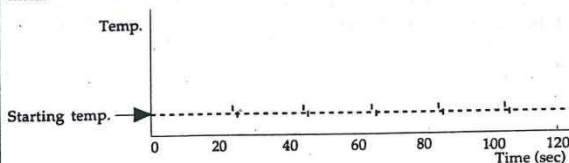
Heat Energy Transferred = $Q_1 =$ _____

Demonstration 2: 50 grams of aluminum is *added* to 100 grams of water. The aluminum and the water are both initially at room temperature in a perfectly insulated cup. Heat energy is transferred to the system at the same steady rate as in the previous demonstration for 90 seconds, and then no more heat energy is transferred.

Discussion Question:

Do you think that the final temperature of the water plus aluminum will be greater than, less than or equal to the final temperature reached in the previous demonstration?

Sketch below your prediction for the graph of the temperature of the water and aluminum as a function of time.



Record Temperatures Below:

Starting Temperature: _____

Ending Temperature: _____

Change in Temperature: _____

Calculation 2: Using the actual starting and ending temperatures of the system, determine the amount of heat that was transferred to the water and aluminum in this process. The specific heat of water is $4186 \text{ J/(kg } ^\circ\text{C)}$ and the specific heat of aluminum is $900 \text{ J/(kg } ^\circ\text{C)}$.

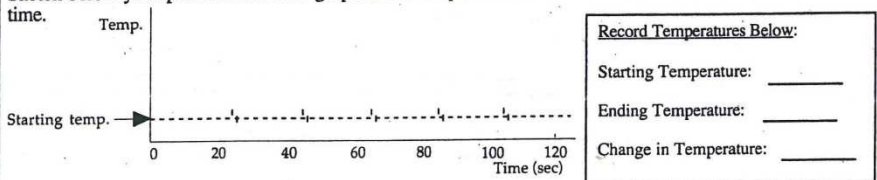
Heat Transferred = $Q_2 =$ _____

Demonstration 3: Now 50 grams of aluminum are used to *replace* 50 grams of water, so that we start with 50 grams of water and 50 grams of aluminum, both initially at room temperature in a perfectly insulated cup. Heat energy is transferred to the water and aluminum at the same steady rate as in the previous demonstrations for 90 seconds, and then no more heat energy is transferred. Again, the specific heat of water is $4186 \text{ J/(kg } ^\circ\text{C}^\circ)$ and the specific heat of aluminum is $900 \text{ J/(kg } ^\circ\text{C}^\circ)$.

Discussion Questions:

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2. Do you think that the final temperature of the water plus aluminum will be greater than, less than or equal to the final temperature achieved in the Demonstration 1 (where there was only 100 grams of water)?

Sketch below your prediction for the graph of the temperature of the water and aluminum as a function of time.



Calculation 3: Now let's assume that the same amount of heat energy will be transferred to this system as was transferred in the previous two demonstrations. Since you probably found that these amounts were slightly different, first take the average of the two amounts of heat:

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Since this heat will be transferred to the water and the aluminum, we can write down an equation that will allow us to predict the theoretical change in temperature of our system. The amount of heat energy gained by each part of the system will be of the form $mc\Delta T$. In the space below, write down an equation which sets Q_3 equal to the heat energy gained by the water and aluminum, and then solve it for ΔT :

$$Q_3 =$$

$$\Rightarrow \Delta T =$$

How does the theoretical numerical answer you just calculated compare with the actual change in temperature of the system? Can you think of a possible explanation for any discrepancy?

Name _____

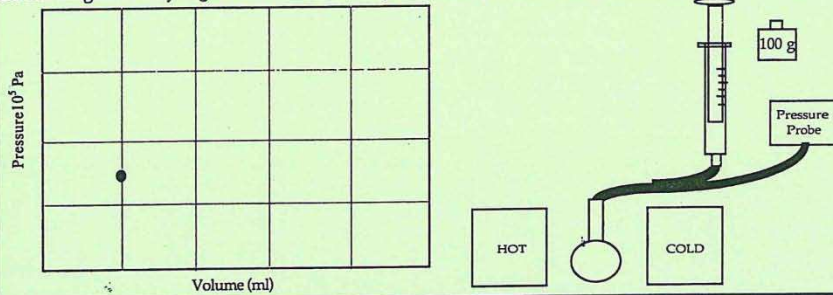
Hand in this sheet

SID _____

INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET— HEAT ENGINE

Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

A model of a heat engine consists of a cylinder (a glass syringe) connected by tubing to a pressure probe and a flask filled with air. The flask may be submerged into a HOT reservoir filled with hot water or a COLD reservoir filled with ice water. The job to be done by this engine is to lift a 100 gram mass a certain height. The pressure probe measures the pressure in the syringe and the volume of gas in the syringe can be measured using the markings on the syringe. The axes below may be used to plot a P-V diagram of the cycle of this engine.



Demonstration 1a: The cycle of the engine begins with the flask in the COLD reservoir, and the 100 gram mass off of the piston. This state is represented by the black dot on the axes above. Sketch on the axes the process that takes place when the mass is quickly put on top of the piston, with the flask left in the COLD reservoir. Describe in words what happens to the pressure and the volume of the air in the syringe.

Demonstration 1b: In the next process of the cycle, the flask is moved from the COLD reservoir to the HOT reservoir, with the mass left on top of the piston. Sketch this process on the axes. Describe in words what happens to the pressure and the volume of the air in the syringe.

Demonstration 1c: In the next process of the cycle, the mass is removed from the top of the piston, with the flask left in the HOT reservoir. Sketch this process on the axes. Describe in words what happens to the pressure and the volume of the air in the syringe.

Demonstration 1d: In the last process of the cycle, the flask is moved from the HOT reservoir back to the COLD reservoir with the mass removed from the top of the piston. Sketch this process on the axes. Describe in words what happens to the pressure and the volume of the air in the syringe.

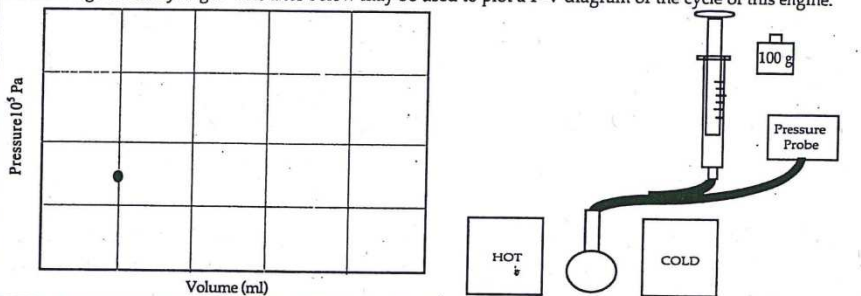
Demonstration 1e: How would you calculate the work done by the gas during this cycle? Show on your P-V diagram what represents the work done during the cycle.

Keep this sheet

INTERACTIVE LECTURE DEMONSTRATION
RESULTS SHEET—HEAT ENGINE

You may write whatever you wish on this sheet and take it with you.

A model of a heat engine consists of a cylinder (a glass syringe) connected by tubing to a pressure probe and a flask filled with air. The flask may be submerged into a HOT reservoir filled with hot water or a COLD reservoir filled with ice water. The job to be done by this engine is to lift a 100 gram mass a certain height. The pressure probe measures the pressure in the syringe and the volume of gas in the syringe can be measured using the markings on the syringe. The axes below may be used to plot a P-V diagram of the cycle of this engine.



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Demonstration 1b: In the next process of the cycle, the flask is moved from the COLD reservoir to the HOT reservoir, with the mass left on top of the piston. Sketch this process on the axes. Describe in words what happens to the pressure and the volume of the air in the syringe.

Demonstration 1c: In the next process of the cycle, the mass is removed from the top of the piston, with the flask left in the HOT reservoir. Sketch this process on the axes. Describe in words what happens to the pressure and the volume of the air in the syringe.

Demonstration 1d: In the last process of the cycle, the flask is moved from the HOT reservoir back to the COLD reservoir with the mass removed from the top of the piston. Sketch this process on the axes. Describe in words what happens to the pressure and the volume of the air in the syringe.

Demonstration 1e: How would you calculate the work done by the gas during this cycle? Show on your P-V diagram what represents the work done during the cycle.

Appendix E Ethics Approval



The University of Sydney

Human Research Ethics Committee

Web: <http://www.usyd.edu.au/ethics/human>

ABN 15 211 513 464

Gail Briody
Manager
Office of Ethics Administration

Marietta Coutinho
Deputy Manager
Human Research Ethics Administration

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Jane Foss Russell Building – G02
The University of Sydney
NSW 2006 AUSTRALIA

Ref: GB/PE

7 May 2009

Associate Professor Manjula Sharma
School of Physics – A28
The University of Sydney
Email: m.sharma@physics.usyd.edu.au

Dear Professor Sharma

Thank you for your letter dated 4 May 2009 addressing comments made to you by the Human Research Ethics Executive Committee. After considering the additional information, the Executive Committee at its meeting on **7 May 2009** approved your protocol entitled **"Investigating students interpretations of everyday thermal physics concepts"**.

Details of the approval are as follows:

Ref No.: 05-2009/11767
Approval Period: May 2009 – May 2010
Authorised Personnel: Associate Professor Manjula Sharma
Ms Helen Georgiou
Dr John O'Byrne

The HREC is a fully constituted Ethics Committee in accordance with the *National Statement on Ethical Conduct in Research Involving Humans-March 2007* under Section 5.1.29

The approval of this project is **conditional** upon your continuing compliance with the *National Statement on Ethical Conduct in Research Involving Humans*. We draw to your attention the requirement that a report on this research must be submitted every 12 months from the date of the approval or on completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of consent for the project to proceed.

Chief Investigator / Supervisor's responsibilities to ensure that:

2

- (1) All serious and unexpected adverse events should be reported to the HREC as soon as possible.
- (2) All unforeseen events that might affect continued ethical acceptability of the project should be reported to the HREC as soon as possible.
- (3) The HREC must be notified as soon as possible of any changes to the protocol. All changes must be approved by the HREC before continuation of the research project. These include:-
 - If any of the investigators change or leave the University.
 - Any changes to the Participant Information Statement and/or Consent Form.
- (4) All research participants are to be provided with a Participant Information Statement and Consent Form, unless otherwise agreed by the Committee. The Participant Information Statement and Consent Form are to be on University of Sydney letterhead and include the full title of the research project and telephone contacts for the researchers, unless otherwise agreed by the Committee and the following statement must appear on the bottom of the Participant Information Statement. *Any person with concerns or complaints about the conduct of a research study can contact the Manager, Ethics Administration, University of Sydney, on (02) 8627 8175 (Telephone); (02) 8627 8180 (Facsimile) or gbriody@usyd.edu.au (Email).*
- (5) Copies of all signed Consent Forms must be retained and made available to the HREC on request.
- (6) It is your responsibility to provide a copy of this letter to any internal/external granting agencies if requested.
- (7) The HREC approval is valid for four (4) years from the Approval Period stated in this letter. Investigators are requested to submit a progress report annually.
- (8) A report and a copy of any published material should be provided at the completion of the Project.

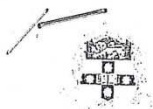
Yours sincerely



**Mrs. Gail Briody
Manager
Office of Ethics Administration**

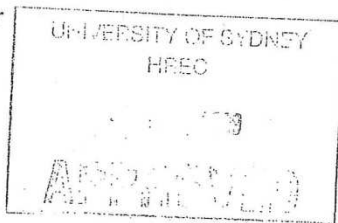
Copy: Ms Helen Georgiou georgiou@physics.usyd.edu.au

Encl. Approved Participant Information Statement
Approved Thermodynamic Pre-test 2009



ABN 15 211 513 464

Manjula Sharma
Associate Professor



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University of Sydney NSW 2006
AUSTRALIA
Telephone: +61 2 9351 2051
Facsimile: +61 2 9351 7726
Email: m.sharma@usyd.edu.au
Web: www.usyd.edu.au/

PARTICIPANT INFORMATION STATEMENT
Research Project

Title: Investigating students interpretations of everyday thermal physics concepts

(1) What is the study about?

This study is about determining the ways in which students explain everyday thermal physics phenomena and how these explanations compare with scientific understandings.

(2) Who is carrying out the study?

The study is being conducted by Ms Helen Georgiou and will form the basis for the degree of *BSc Honours in physics* at The University of Sydney under the supervision of Associate Professor Manjula Sharma and Dr John O'Byrne, both academics in the School of Physics.

(3) What does the study involve?

The study involves doing a pre-test on thermal physics and several lectures later doing a test question. After you have done these, the pre-test and test question will be placed on WebCT with their solutions. The tests do NOT contribute to your assessment in any way.

(4) How much time will the study take?

The pre-test will take 20 minutes and the test question 5 minutes during lectures.

PLEASE TURN OVER

(5) **Can I withdraw from the study?**

Being in this study is completely voluntary and you are not under any obligation to consent to complete the pre-test and test question. Submitting a completed test is an indication of your consent to participate in the study. You can choose to not submit your test. You can withdraw any time prior to submitting your completed test. Once you have submitted your test anonymously, your responses cannot be withdrawn. In all situations, there is no penalty and your relationship with the researchers, the School of Physics or the University of Sydney will not be affected in anyway.

(6) **Will anyone else know the results?**

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(7) **Will the study benefit me?**

Participating in this study will give you an opportunity to articulate your explanations of thermal physics and compare these with the scientifically correct ones. This process may help you learn thermal physics better. Also if you are interested in discussing the results of the study, you are invited to contact us, see details below.

(8) **Can I tell other people about the study?**

Yes, by all means. There is no reason to keep this study a secret.

(9) **What if I require further information?**

When you have read this information, Helen Georgiou will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Ms Helen Georgiou, 9351 2533, Honours student; Assoc/Prof Manjula Sharma, 9351 2051, Room 226E, Physics Building, m.sharma@physics.usyd.edu.au, Head of the SUPER group; or Dr John O'Byrne, 9351 3184, Chair of the Academic Programs Committee.

(10) **What if I have a complaint or concerns?**

Any person with concerns or complaints about the conduct of a research study can contact the Manager, Ethics Administration, University of Sydney on (02) 8627 8175 (Telephone); (02) 8627 8180 (Facsimile) or gbriody@usyd.edu.au (Email).

This information sheet is for you to keep



Address for correspondence:
 RESEARCH INTEGRITY
 LEVEL 6, JANE FOSS RUSSELL BUILDING - G02
 THE UNIVERSITY OF SYDNEY NSW 2006
 Email: ro.humanethics@sydney.edu.au
 Fax: +61 2 8627 8177

**HUMAN RESEARCH ETHICS COMMITTEE
 REQUEST FOR MODIFICATION**

APPROVED
 10/3/11
 ETHICS OFFICE
 18 JAN 2011
 DATE RECEIVED

1. **Principal Investigator:** Manjula Devi Sharma
Department: Physics
Address: Physics Building, University of Sydney
2. **Project Title:** Investigating student's interpretations of everyday thermal physics concepts
3. **HREC Approval No.:** 11767
4. **Names of Students/Co-Investigators:** Helen Georgiou and Pornrat Wattanakasiwich
5. **Project Description:**
 Please provide a one-paragraph lay summary of your original project

The original project was about determining the ways in which students explain everyday thermal physics phenomena and how these explanations compare with scientific understandings.

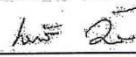
6. **Any previously approved minor amendments?** Yes No
 If YES, please briefly outline

An amendment was made in October '10 to alter the survey and administer to a larger sample that consisted of different cultures and ages.

7. **Nature of and reasons for amendment(s)**
 Please provide details of the changes you propose to make to the project and explain why they are necessary. Please justify any increase in sample size.

A new stage of the project has now been reached. Some comparisons will be made between different lecturing styles in thermal physics using a program called 'Interactive Lecture Demonstrations'. The Interactive Lecture Demonstrations is current practice in mechanics and is to be extended to thermal physics. To compare different lecture styles, a pre and post test will be administered. The changes made to the original survey are:
 - multiple choice questions to limit time taken to complete the survey,
 - more questions to address a larger range of thermal physics topics.
 The survey will be administered to physics students at the University of Sydney, as per the original survey.
 A new co-investigator is also added, Dr Pornrat Wattanakasiwich.

8. **Adding New Staff Member / Student / Research Assistant** Yes No
 If YES, provide the following (If more than one, please copy this page)

Name	Pornrat Wattanakasiwich
Title: (e.g: Mr, Ms, Dr, Associate Professor)	Dr
Faculty/Department/School/Centre/Institution	School of Physics
Address	226e Physics Building School of Physics No A28, Sydney University NSW 2006
Telephone Number	+61469092417
Facsimile Number	+61293517726
Email Address	pwattanakasiwich@gmail.com
Position (ie lecturer, PhD student)	Endeavour Research Fellow
Qualifications (if PhD indicate field of study)	PhD (Physics Education)
Role in the project	Researcher
Has the new staff member received a copy of the approved application?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
Signature of new staff member	 Signature Dr. Pornrat Wattanakasiwich Print Name _____ Date: <u> 1 </u> / <u> 3 </u> / <u> 2011 </u>

9. Removing Staff Member / Student / Research Assistant Yes No
 If YES, provide the following (if more than one, please copy this page)

Name	
Faculty/Department/School/Centre/Institution	
Position (ie lecturer, PhD student)	
Role in the project	
Date of Departure	_____ / _____ / _____

10. Possible inconveniences or risks to subjects: Yes No
 If Yes, please outline any inconvenience or possible risks that the changes you propose may create for participants (eg changes to confidentiality provisions, physical or psychological risks, increased time commitments etc).

11. **Actions to be taken by researchers to reduce risks:** Yes No
If Yes, please provide details of any additional actions and / or support that you will need to provide to participants as a result of the proposed changes.

12. **Expected date of implementation of amendments to research:**

Date: May 2011

13. **Time Extension:** Yes No
If Yes, state new finishing date

Date: May 2012

14. **Whether funding arrangements for the research been affected by the changes** Yes No

15. **Implications for compliance with legislative requirements:** Yes No
Please check current legislation and related requirements, if appropriate – including, for example Privacy Act 1998 (please refer to Guidelines under Section 95 of the Privacy Act produced by the NHMRC) and Children and Young Persons Act 1989.

16. **Attach copies of amended surveys, questionnaires or interview questions** Yes No

17. **Attach copies of the amended advertisement, participant information statement and consent form.** Yes No
Participants need to be advised of changes to procedures, time commitments, etc. You will need to update the participant information statement to reflect the changes.

18. Details of other permission or approvals required as a result of your proposed changes


19. Other Amendments

If you require an additional title to be added to the HREC Database (Grant for application)

Title:

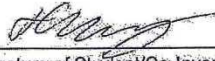
Granting Body:

20. Declaration of Researchers



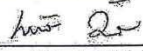
Signature of Chief Investigator:

Date: 1st March 2011



Signature of Student/Co-Investigators:

Date: 1/3/2011



Signature of Student/Co-Investigators:


Date: 1/3/2011

Signature of Student/Co-Investigators:

Date:

Signature of Student/Co-Investigators:

Date:



Signature of Head of Faculty/Department/School:

Date: 07/03/11

NOTE

- All Modification Requests require the signature of Head of Faculty/Department/School except where the request is ONLY to add/remove a researcher/s.
- The Modification Request will not be processed without the signature of Head of Faculty/Department/School.

Appendix F Internal Report on Student Evaluation Development

Lecture Observation: Inter-coder Reliability

Introduction:

Increasing interactivity in the large lecture theatre is cited in the physics education research literature as the most cost and time effective way to improve learning outcomes and motivation of first year physics students. Most studies focus on the learning environment and what the lecturer is doing (Bonwell & Eison, 1991; Hake, 1998; Meltzer & Manivannan, 2002; Sokoloff & Thornton, 1997). It is much less common to observe what the students are doing during this instruction (Lin, Liu, & Chu, 2011; Shieh, Chang, & Tang, 2010) though, arguably, it is just as important. If the Active Learning methods are being delivered but we cannot describe the student's engagement with them, our results will be much less illuminating. Therefore, before our own attempt at introducing Active Learning methods into the first year thermal physics lecture module, a method of observing lectures was developed. The purpose of the observation was to determine the level of engagement, not through the actions of the lecturer and the environment but rather *by its effect on the students*. Therefore, the method we ultimately developed involved recording the actions of a select group of students during the course of the lecture and throughout the course of different lecture activities thereby describing their engagement.

Method:

The method was established in two sessions prior to the beginning of the thermal physics module. The stream was chosen on the basis of availability and permission from lecturer. Details of the class are provided below:

Lecture stream	Stream 1 (Iver's thermal lecture stream)
Lectures	Last two lectures of mechanics stream
Topics	Rotational motion
Lecturer	Mike Wheatland
Student numbers	About 75 students

Table 1. Demographics of observed lecture

The first observation included establishing a method. The agreed method after careful discussion, reference to the literature and the limitations imposed by ethics and resources was to select a group of students and note their behaviour in given time periods. Ten students were selected on the basis of visibility. The two observers sat in the back row of the lecture. The lecture room has 150pax(?) capacity in three sections. The middle section is the largest. The observers sat at the back of the left wing, as you look towards the front of the lecture room.

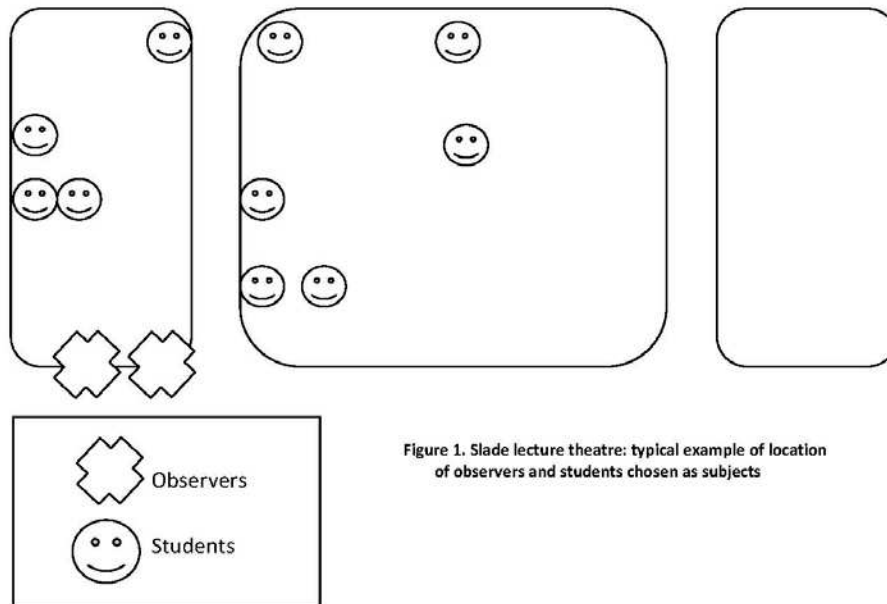


Figure 1. Slide lecture theatre: typical example of location of observers and students chosen as subjects

At first, the actions of the students were described, one student at a time. This led to an identification of small number of actions, thus leading to the table below. Students were given unique numbers to ensure the right action was agreed upon for the right student.

Time period	Activity	Student Observation				Other
		Paying attention	Not paying attention	Writing	Other	

Figure 2. Table used for student observation. Final table was amended slightly.

The table was used in this final form in the second lecture. The two observers agreed on eleven students to observe and observations agreed with a reliability of more than 99%.

Results:

Table 2. Results as recorded by two observers. Observers are distinguished by bold type and normal types

Time period	What was happening in the lecture	Student Observation	
		Paying attention	Not paying attention Writing Other
1- first minute of lecture	Introduction. Remind students what they covered last week and introduce today's content	4,5,6,7,8,11	1(organising), 2 (typing), 3,9,10 (all talking)
		4 (listening), 5, 6, 7, 8, 11	1, 2, 3, 9, 10
2- @ 7 minutes	Demonstration of gyroscope (demo 2 of 3)	1,2,3,4,5,6,7,8,9	10 (on phone),11 (sleeping)
		1, 2, 3 (all looking), 4, 5, 6, 7, 8, 9,	10, 11
3- @20min	Explaining gyroscope-summary	1,2,4,3,5,7,8,11	6,9 (phone) ,10 (watching 9)
		1 (listening), 5, 2 (looking), 6 (writing), 3 (writing), 7, 4 (writing?), 8, 11	9 (iphone), 10 writing)
4- @30min	Student questioning: 1 on 1	1 (asking Q), 3	2 (talking), 4,5,6,7,8,9,10,11
		1 (asking question), 3	2 (talking to F), 3(talking), 4 (spaced out), 5, 6, 7, 8 (talking and iphone), 9, 10, 11

Table 3. Summary of results

Time (min)	Activity	Number of students paying attention	Number of students NOT paying attention
1	Introduction	6	5
7	Demonstration	9	2
20	Summary of material	8	3
30	Student asking question	2	9

Discussion/general comments:***Some points on the table above:***

- The text in table 2 is as was written on the blank template by each of the observers
- The second time period in table 2 was taken slightly earlier on the discretion of the observers to take advantage of the variety of lecture activities (the demonstration)
- The lecture finished early
- The observations were made at exactly the same time by indicating a finger for the number of the student or whispering the number

General comments about the lecture

- Students were mostly quiet during the lecture.
- Very few had laptops (around 3-4 students each lecture)
- Very few were writing at any given time
- Not all students had lecture notes printed for the lecture
- Some had other work they were looking at throughout the lecture

Conclusions:

The developed method along with general observations about the lecture is an effective way in garnering the level of engagement of students throughout the lecture. For the second lecture during the observation trial (table 3), our observations indicate that the students took a while to settle down and pay attention at the very beginning of the lecture, paid most attention during the demonstration and mid-lecture summary and paid least attention during the last few minutes of the lecture when the lecturer was engaged in a line of questioning with one of the students we had chosen for the observation.

References

- Bonwell, C. C., & Eison, J. A. (1991). active learning: creating excitement in the classroom. In E. digest (Ed.), Washington DC: George Washington University.
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74. doi: 10.1119/1.18809
- Lin, Y. C., Liu, T. C., & Chu, C. C. (2011). Implementing clickers to assist learning in science lectures: The Clicker-Assisted Conceptual Change model. *Australasian Journal of Educational Technology*, 27(6), 979-996.
- Meltzer, D. E., & Manivannan, K. (2002). Transforming the lecture-hall environment: The fully interactive physics lecture. [Article]. *American Journal of Physics*, 70(6), 639-654. doi: 10.1119/1.1463739
- Shieh, R. S., Chang, W. J., & Tang, J. (2010). The Impact of Implementing Technology-Enabled Active Learning (TEAL) in University Physics in Taiwan. *Asia-Pacific Education Researcher*, 19(3), 401-415.
- Sokoloff, D. R., & Thornton, R. K. (1997). Using interactive lecture demonstrations to create an active learning environment. In E. F. R. J. S. Redish (Ed.), *Changing Role of Physics Departments in Modern Universities - Proceedings of International Conference on Undergraduate Physics Education, Pts 1 and 2* (pp. 1061-1074).

Appendix G Student Engagement Template (LASE)

Date/time:	Number of students:
Stream/Lecturer:	Lecture No.

Time period	Activity	Student Observation			
		Paying attention	Not paying attention	Writing	Other

Appendix H Alternative ILD Sheet (LASE)

Lecture ID: (state clearly which lecture observation this addition belongs too)				
ILD no. or description:				
	Paying attention	Not paying attention	Writing	Other
Introduction to ILD				
	Writing prediction	Not writing prediction	Other	
Prediction: Alone				
	Discussing with peer	Not discussing with peer	Other	
Prediction: in groups				
	Paying attention	Not paying attention	Writing	Other
Explanation and noting results				

Appendix I ILD Specific Student Evaluation

Regular Physics Survey	
Here are 18 statements which may or may not describe your experiences with this course. Please rate each statement by circling a number between 1 and 5 where the numbers mean the following:	
1 ⇨ Strongly disagree 2 ⇨ Disagree 3 ⇨ Neutral 4 ⇨ Agree 5 ⇨ Strongly agree	

Part 1: Learning experiences during the interactive lecture demonstrations (ILDS).						
1	I was engaged and stimulated to learn better.	1	2	3	4	5
2	I had opportunities to discuss with my peers.	1	2	3	4	5
3	I had opportunities to discuss my opinion with the instructor.	1	2	3	4	5
4	I had opportunities to perform scientific reasoning.	1	2	3	4	5
Part 2: Overall quality of the interactive demonstrations and worksheets.						
5	Interactive demonstrations are interesting and challenging for learning.	1	2	3	4	5
6	Questions in the interactive worksheets are clear and well put.	1	2	3	4	5
7	Questions in the interactive worksheets help me think and understand the materials.	1	2	3	4	5
8	Results of interactive lecture demonstrations are easy to see.	1	2	3	4	5
9	The interactive demonstrations are suitable and related to the lectures.	1	2	3	4	5
Part 3: Connection between lecture materials and ILDs						
10	ILD Heat & Temperature: helps me understand heat transfer and thermal equilibrium better.	1	2	3	4	5
11	ILD Specific heat capacity: helps me understand specific heat capacity (c) better.	1	2	3	4	5
12	ILD Pee-pee boy: helps me understand the first law of thermodynamics.	1	2	3	4	5
13	ILD Movable syringe: helps me understand the isobaric process.	1	2	3	4	5
14	ILD Fog in the bottle: helps me understand the adiabatic process.	1	2	3	4	5
15	ILD Heat engine: helps me understand the heat engine.	1	2	3	4	5
16	ILDs help me understand the lectures better.	1	2	3	4	5
17	Making predictions before hand help me realize my misconceptions about thermodynamics.	1	2	3	4	5
18	The conclusions after each ILD made me understand the concepts involved.	1	2	3	4	5

Please write down your opinion to each question and provide a brief reason. The questions are about the interactive lecture demonstrations (ILD) that you did in class.

- ILD 1: Heat and temperature
- ILD 2: Specific heat capacity
- ILD 3: Thermal processes 1 (pee-pee boy)
- ILD 4: Thermal processes 2 (movable syringe)
- ILD 5: Thermal processes 3 (fog in a bottle)
- ILD 6: Heat engine

19. Most favorite ILD is

Reason:

20. Least favorite ILD is

Reason:

21. ILD that you understand the most is

Reason:

22. ILD that you understand the least is

Reason:

23. Please write down any comments that we can use to improve this class.

Thank you for your feedback. This information will help the way we teach this class.

Appendix J Interview Questions 2011/2012

Interview questions (2011)

<p>Information: Student number Sex degree consent high school physics/ other high school science</p>	
<p>Physics: (refer to answer for high school physics) Opinions of University physics Compared to other subjects Which parts most relevant/interesting and why? Which parts least relevant or interesting and why? Choose one other subject you study here. How is physics the same/different, how is it better/worse What will/won't affect continuing physics at university</p>	
<p>Thermal Physics: Did you study Thermal physics last semester (refer to stream)</p>	
<p>Yes: How did you like/dislike thermal physics compared to other subjects, where did it fit in etc.</p>	<p>No: What is thermal physics?</p>
<p>Equations: Dependant on whether studied physics or not</p>	
<p>Yes: Ideal gas equation: $PV = nRT$ Kinetic theory, specific heat</p>	<p>No: Similar equations such as coefficient of friction, newtons second law, law of electrostatic attraction and constants.</p>
<p>Thermal Physics Demo: Eski question Idea of insulators/conductors Idea of heat amounts of heat</p>	

Interview questions (2012)

Pre-Interview

Tick column to indicate the following have been stated before interview begins.

Statement	Check
State interviewer name and number and nature of people in room	
State time and place	
Ask for permission from interviewee to use transcripts in research	
Ask for permission to compare transcripts with material handed in to lecturer (ILD sheets, IE sheets, TCS, Final exam)	

Demographics

Student number, Sex, degree, high school physics, Semester 1 physics course, Plans for next year

Section 1: Thermal physics concept

Last semester you completed the thermal physics module. Can you select one concept or 'thing' you learnt (something you were surprised at or didn't know before) and explain it to me?

Can you explain how you came to 'know' this concept? Further questions: When was it first introduced? When did you feel you really 'understood it'? Was it a 'light bulb' moment or was it more gradual?

Section 2: Thermal physics pedagogy

Last semester you experienced many different types of intentional instruction; ways in which the physics department and staff tried to help you understand physics. Can you select one or more methods of learning (as broad as 'labs' or as specific as 'demonstrations') and explain why or how you think it helped you understand physics. Further questions: During this activity, what were you doing (taking notes or listening)? What aspects of this activity were important for you?

ILD and IE specific questions: what did you like/dislike about them. Further comments encouraged.

Appendix K Thermal Concepts Survey



The University of Sydney

Contact:
Helen Georgiou
Telephone: 02 9351 8716
Email: georgiou@physics.usyd.edu.au
Or
Ass. Prof Manjula Sharma
sharma@physics.usyd.edu.au

Thermodynamics Survey 2012

Instructions:

- These questions should take about 15-20 minutes to complete.
- There are 16 questions in total. Please answer the questions on the very back page
- Read the questions carefully and answer by circling the correct multiple choice option
- There are no mark allocations for the questions.


Participation in this project by completing this test is completely voluntary.

Name:	SID:	(circle)
		M F

Thank you!

1. Cup A contains 100 grams of water at 0°C but cup B contains 200 grams of water at 50°C . The contents of the two cups are mixed together in an insulated container (no heat transfer occurs). When it reaches thermal equilibrium, what is the final temperature of the water in the container?
 - a. Between 0°C and 25°C
 - b. 25°C
 - c. Between 25°C and 50°C
 - d. 50°C
 - e. Higher than 50°C

2. Jim believes he must use boiling water to make a cup of tea. He tells his friends that, "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes." Which statement do you strongly agree with?
 - a. Joys says, "Yes it does, because the water boils below 100°C because the pressure decreases."
 - b. Tay says, "Jim is incorrect because 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°C ."
 - d. Mai says, "I agree with Jim. The water never gets to its boiling point."

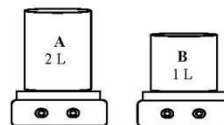
3. Cup A contains 100 grams of water and cup B contains twice as much water. The water in both cups was initially at room temperature. Then the water in cup A was heated to 75°C and the water in cup B was heated to 50°C . When the water in both cups cooled down to room temperature, which cup had more heat transferred from it?
 

- a. Cup A had more heat transferred out.
 - b. Cup B had more heat transferred out.
 - c. Both cups had the same amount of heat transferred.
 - d. Not enough information is given to determine the answer.
4. If 100 grams of ice at 0°C and 100 grams of water at 0°C are put into a freezer, which has a temperature below 0°C . After waiting until their temperature equals to the freezer temperature, which one will eventually lose the greatest amount of heat?
 - a. The 100 grams of ice.
 - b. The 100 grams of water.
 - c. They both lose the same amount of heat because their initial temperatures are the same.
 - d. There is no answer because ice does not contain any heat.
 - e. There is no answer because you cannot get water at a temperature of 0°C .

5. Jan announces that she does not like sitting on the metal chairs in the room because “when touching it, they are colder than the plastic ones.” Which statement do you strongly agree with?
- Jim agrees and says, “The metal chairs feel colder because metal is naturally colder than plastic.”
 - Kip says, “The metal chairs are not colder because they are at the same temperature.”
 - Lou says, “The metal chairs are not colder, the metal ones just feel colder because they are heavier.”
 - Mai says, “The metal chairs are colder because metal absorbs the heat from body faster.”

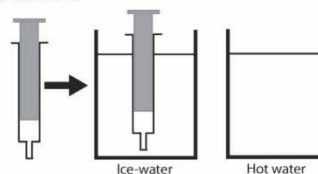
6. Kim picks up two rulers, a metal one and a wooden one. He announces that the metal one feels colder than the wooden one. What is your preferred explanation for this situation to Kim?
- Metal conducts heat faster than wood.
 - Wood is naturally a warmer substance than metal.
 - Metals are better heat radiators than wood.
 - Cold flows more readily from a metal.

7. Cup A contains 2 liters of water and cup B contains 1 liter of water. The water in both cups was initially at room temperature. Then both cups are placed on a hot plate and heated until the water in the cup is boiling (100°C). Which statement is correct?



- Water in both cups has the same heat transfer.
- Water in cup A has more heat transfer.
- Water in cup B has more heat transfer.

Please use the following information to answer questions 8-10.

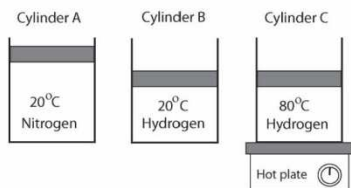


A syringe that contains an ideal gas and has a frictionless piston of mass M is moved from a beaker of cold water to a beaker of hot water. Answer the following questions and consider that the syringe reaches thermal equilibrium with hot water.

- How does the gas temperature change?
 - Increase
 - Decrease
 - No change
- How does the gas pressure change?
 - Increase
 - Decrease
 - No change
- How does the gas volume change?
 - Increase
 - Decrease
 - No change

Please use the following information to answer questions 11-12.

Three identical cylinders are filled with unknown quantities of ideal gases. The cylinders are closed with identical frictionless pistons of mass M . Cylinder A and B are in thermal equilibrium with the room at 20°C , and cylinder C is kept at a temperature of 80°C . The piston of each cylinder is in mechanical equilibrium with the environment.



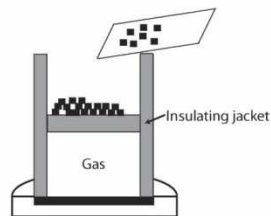
11. How does the pressure of nitrogen gas in cylinder A compare with the pressure of hydrogen gas in cylinder B?
 - a. Greater
 - b. Less than
 - c. Same

12. How does the pressure of hydrogen gas in cylinder B compare with the pressure of hydrogen gas in cylinder C?
 - a. Greater
 - b. Less than
 - c. Same

Please use the following information to answer questions 13-15.

An ideal gas is contained in a cylinder with a tightly-fitting piston so that no gas escapes. Several small masses are on the piston. (Neglect friction between the piston and the cylinder walls.) The cylinder is

placed in an insulating jacket. A large number of masses are quickly added to the piston.



13. How does the temperature of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged

14. How does the pressure of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged

15. How does the volume of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged

Please use the following information to answer question 16

A cylindrical pump contains one mole of an ideal gas. The piston fits tightly so that no gas escapes, and friction is negligible between the piston and the cylinder walls. The piston is quickly pressed inward so the volume of gas reduces instantly.



16. How does the temperature of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged



The University of Sydney

Contact:
Helen Georgiou
Telephone: 02 9351 8716
Email: georgiou@physics.usyd.edu.au
Or
Ass. Prof Manjula Sharma
sharma@physics.usyd.edu.au

Thermodynamics Survey 2012

Instructions:

- These questions should take about 40-50 minutes to complete.
- There are 35 questions in total. Please answer the questions on the very back page
- Read the questions carefully and answer by circling the correct multiple choice option
- There are no mark allocations for the questions, only for completing the survey.

Name:	SID:	(circle)
		M F

Thank you!

1. Cup A contains 100 grams of water at 0°C but cup B contains 200 grams of water at 50°C . The contents of the two cups are mixed together in an insulated container (no heat transfer occurs). When it reaches thermal equilibrium, what is the final temperature of the water in the container?
 - a. Between 0°C and 25°C
 - b. 25°C
 - c. Between 25°C and 50°C
 - d. 50°C
 - e. Higher than 50°C

2. Jim believes he must use boiling water to make a cup of tea. He tells his friends that, "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes." Which statement do you strongly agree with?
 - a. Joys says, "Yes it does, because the water boils below 100°C because the pressure decreases."
 - b. Tay says, "Jim is incorrect because 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°C ."
 - d. Mai says, "I agree with Jim. The water never gets to its boiling point."

3. Cup A contains 100 grams of water and cup B contains twice as much water. The water in both cups was initially at room temperature. Then the water in cup A was heated to 75°C and the water in cup B was heated to 50°C . When the water in both cups cooled down to room temperature, which cup had more heat transferred from it?



- a. Cup A had more heat transferred out.
 - b. Cup B had more heat transferred out.
 - c. Both cups had the same amount of heat transferred.
 - d. Not enough information is given to determine the answer.
4. If 100 grams of ice at 0°C and 100 grams of water at 0°C are put into a freezer, which has a temperature below 0°C . After waiting until their temperature equals to the freezer temperature, which one will eventually lose the greatest amount of heat?
 - a. The 100 grams of ice.
 - b. The 100 grams of water.
 - c. They both lose the same amount of heat because their initial temperatures are the same.
 - d. There is no answer because ice does not contain any heat.
 - e. There is no answer because you cannot get water at a temperature of 0°C .

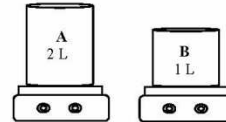
5. Jan announces that she does not like sitting on the metal chairs in the room because “when touching it, they are colder than the plastic ones.” Which statement do you strongly agree with?

- a. Jim agrees and says, “The metal chairs feel colder because metal is naturally colder than plastic.”
- b. Kip says, “The metal chairs are not colder because they are at the same temperature.”
- c. Lou says, “The metal chairs are not colder, the metal ones just feel colder because they are heavier.”
- d. Mai says, “The metal chairs are colder because metal absorbs the heat from body faster.”

6. Kim picks up two rulers, a metal one and a wooden one. He announces that the metal one feels colder than the wooden one. What is your preferred explanation for this situation to Kim?

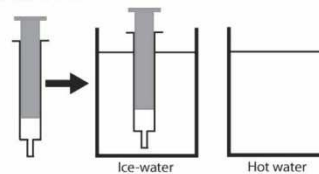
- a. Metal conducts heat faster than wood.
- b. Wood is naturally a warmer substance than metal.
- c. Metals are better heat radiators than wood.
- d. Cold flows more readily from a metal.

7. Cup A contains 2 liters of water and cup B contains 1 liter of water. The water in both cups was initially at room temperature. Then both cups are placed on a hot plate and heated until the water in the cup is boiling (100°C). Which statement is correct?



- a. Water in both cups has the same heat transfer.
- b. Water in cup A has more heat transfer.
- c. Water in cup B has more heat transfer.

Please use the following information to answer questions 8-10.

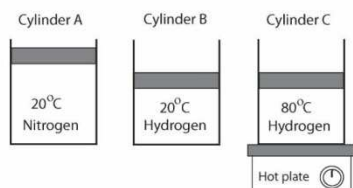


A syringe that contains an ideal gas and has a frictionless piston of mass M is moved from a beaker of cold water to a beaker of hot water. Answer the following questions and consider that the syringe reaches thermal equilibrium with hot water.

- 8. How does the gas temperature change?
 - a. Increase
 - b. Decrease
 - c. No change
- 9. How does the gas pressure change?
 - a. Increase
 - b. Decrease
 - c. No change
- 10. How does the gas volume change?
 - a. Increase
 - b. Decrease
 - c. No change

Please use the following information to answer questions 11-12.

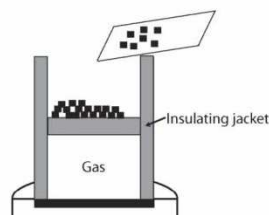
Three identical cylinders are filled with unknown quantities of ideal gases. The cylinders are closed with identical frictionless pistons of mass M . Cylinder A and B are in thermal equilibrium with the room at 20°C , and cylinder C is kept at a temperature of 80°C . The piston of each cylinder is in mechanical equilibrium with the environment.



11. How does the pressure of nitrogen gas in cylinder A compare with the pressure of hydrogen gas in cylinder B?
 - a. Greater
 - b. Less than
 - c. Same
12. How does the pressure of hydrogen gas in cylinder B compare with the pressure of hydrogen gas in cylinder C?
 - a. Greater
 - b. Less than
 - c. Same

Please use the following information to answer questions 13-15.

An ideal gas is contained in a cylinder with a tightly-fitting piston so that no gas escapes. Several small masses are on the piston. (Neglect friction between the piston and the cylinder walls.) The cylinder is placed in an insulating jacket. A large number of masses are quickly added to the piston.



13. How does the temperature of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged
14. How does the pressure of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged
15. How does the volume of the gas change?
 - a. Increase
 - b. Decrease
 - c. Remains unchanged

Please use the following information to answer question 16

A cylindrical pump contains one mole of an ideal gas. The piston fits tightly so that no gas escapes, and friction is negligible between the piston and the cylinder walls. The piston is quickly pressed inward so the volume of gas reduces instantly.



16. How does the temperature of the gas change?

- a. Increase
- b. Decrease
- c. Remains unchanged

17. How does the total work done by the system (gas) change?

- a. Increase
- b. Decrease
- c. Remains unchanged

18. How does the heat transferred into the system (gas) change?

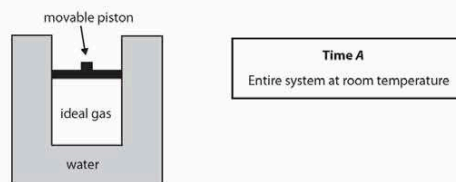
- a. Increase
- b. Decrease
- c. Remains unchanged

19. How does the internal energy of the gas change?

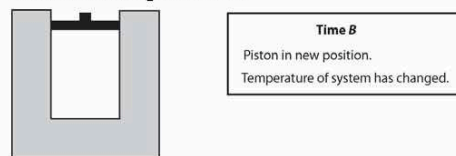
- a. Increase
- b. Decrease
- c. Remains unchanged

Please use the following information to answer questions 20-25.

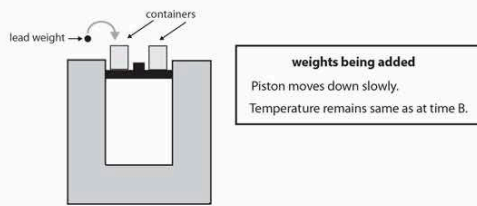
A fixed quantity of ideal gas is contained within a metal cylinder that is sealed with a movable, frictionless, insulating piston. (The piston can move up or down without the slightest resistance from friction, but no gas can enter or leave the cylinder. The piston is heavy, but there can be no heat transfer to or from the piston itself.) The cylinder is surrounded by a large container of water with high walls as shown.



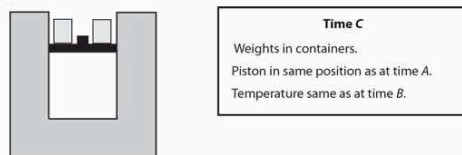
Step 1. Start of Process # 1: The water container is gradually heated, and the piston very slowly moves upward. At time *B* the heating of the water stops, and the piston stops moving when it is in the position shown in the diagram below:



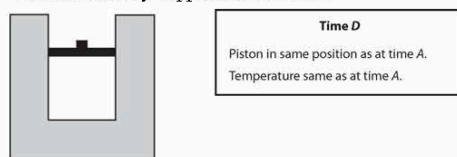
Step 2. Now, empty containers are placed on top of the piston as shown. Small lead weights are gradually placed in the containers, one by one, and the piston is observed to move down slowly. While this happens, the temperature of the water is nearly unchanged, and the gas temperature remains practically constant. (That is, it remains at the temperature it reached at time *B*, after the water had been heated up.)



Step 3. At time *C* we stop adding lead weights to the container and the piston stops moving. (The weights that were added until now are still in the containers.) The piston is now found to be at exactly the same position it was at time *A*.



Step 4. Now, the piston is locked into place so it cannot move; the weights are removed from the piston. The system is left to sit in the room for many hours, and eventually the entire system cools back down to the same room temperature it had at time *A*. When this finally happens, it is time *D*.



Step 5. Now let us begin Process # 2. The piston is unlocked so it is again free to move. We start from the same initial situation as shown at time *A* and *D* (i.e., same temperature and position of the piston). Just as before, the water is heated and we watch as the piston rises. However, this time, heat transfers to the water for a longer period of time. As a result, the piston ends up higher than it was at time *B* in Process # 1. The piston then continues from step 2 to step 4 and the final state when the weights are removed occurs at time *E*.

20. During the process that occurs from time *A* to time *B*, which following statement about work is true?

- Positive work is done on gas by the environment.
- Positive work is done by the gas on the environment.
- No net work is done on or by the gas.

21. During the process that occurs from time *A* to time *B*, the gas absorbs x Joules of energy from the water. What happens to the total kinetic energy of all of the gas molecules?

- Increases by more than x Joules.
- Increases by x Joules.
- Increases, but less than x Joules.
- Remains unchanged.
- Decreases by less than x Joules.
- Decreases by x Joules.
- Decreases by more x Joules.

22. During the process that occurs from time *B* to time *C*, what happens to the total kinetic energy of all gas molecules?

- Increase
- Decrease
- Remain unchanged

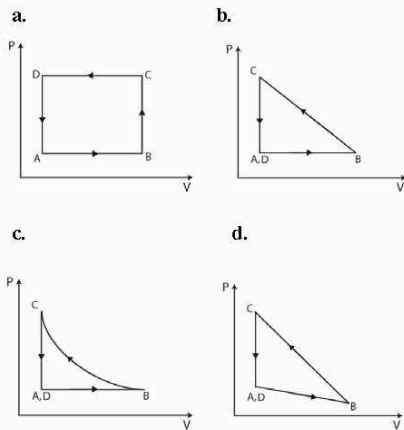
23. During the process that occurs from time *B* to time *C*, is there any net heat transferred between the gas and the water?

- There is the net heat transferred from gas to water.
- There is the net heat transferred from water to gas.
- There is no heat transferred.

24. During the process that occurs from time C to time D , y Joules of heat transfer occurs from the gas to the water. What happens to the total kinetic energy of all of the gas molecules?

- Increases by more than y Joules.
- Increases by y Joules.
- Increases, but by less than y Joules.
- Remains unchanged.
- Decreases by less than y Joules.
- Decreases by y Joules.
- Decreases by more than y Joules.

25. Which P-V diagram best describes the process that occurs from time A to time D ?



For questions 26-28, please consider the process that occurs from time A to time D , and then to time E .

26. What is the net work done by the gas on the environment during that process?

- Equal to zero.
- Less than zero.
- Greater than zero.

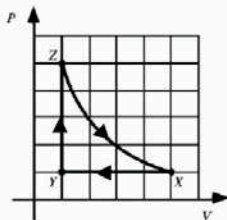
27. What is the heat transfer from water to gas during the process?

- Equal to zero.
- Less than zero.
- Greater than zero.

28. Consider the total kinetic energy of all the gas molecules at time A , D , and E ; call those KE_A , KE_D , and KE_E . Rank these in order of magnitude of total kinetic energy of the gas molecules at these times.

- $KE_A > KE_D > KE_E$
- $KE_A < KE_D < KE_E$
- $KE_A = KE_D = KE_E$
- $KE_A = KE_D < KE_E$

Please use the following information to answer questions 29-31.



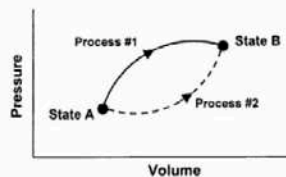
A student performs an experiment with an ideal gas that is contained in a cylinder with a piston. The P-V diagram below shows the values of pressure and volume of the gas throughout the

experiment, starting at point X , continuing to points Y and Z , and returning to point X . Process $Z \rightarrow X$ is isothermal.

29. What is the total work done by the gas in the entire cycle ($X \rightarrow Y \rightarrow Z \rightarrow X$)?
 - a. Positive
 - b. Negative
 - c. Zero
30. What is the total heat transfer for the entire cycle ($X \rightarrow Y \rightarrow Z \rightarrow X$)?
 - a. Positive
 - b. Negative
 - c. Zero
31. What is the change of internal energy of the gas in the entire cycle ($X \rightarrow Y \rightarrow Z \rightarrow X$)?
 - a. Positive
 - b. Negative
 - c. Zero

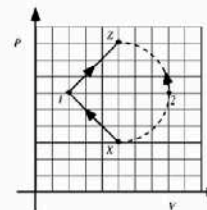
Please use the following information to answer questions 32-34.

This P-V diagram represents a system consisting of a fixed amount of ideal gas that can undergo two different processes in going from state A to state B through Process #1 and Process #2.



32. Work done by the system in Process # 1 is _____ than Process # 2.
 - a. greater than
 - b. less than
 - c. equal to
33. The change in internal energy of all molecules in the system for Process #1 is _____ than Process # 2.
 - a. greater than
 - b. less than
 - c. equal to
34. Heat transferred into the system in Process # 1 is _____ than Process # 2.
 - a. greater than
 - b. less than
 - c. equal to

35. A student performs an experiment with an ideal gas that is confined to a cylinder with a piston. The P-V diagram below shows the values of pressure and volume of the



gas throughout the experiment, starting at point X and ending at point Z . Compare the absolute value of the work done during process $X \rightarrow 2 \rightarrow Z$ (a dash line) and process $X \rightarrow I \rightarrow Z$ (a bold line). Which statement is correct?

- a. $X \rightarrow 2 \rightarrow Z$ is greater than $X \rightarrow I \rightarrow Z$.
- b. $X \rightarrow 2 \rightarrow Z$ is less than $X \rightarrow I \rightarrow Z$.
- c. $X \rightarrow 2 \rightarrow Z$ is equal to $X \rightarrow I \rightarrow Z$.

Supplementary Materials

The materials in this section are not publically available. They contain material that is either subject to copyright legislation, sensitive or is excessively lengthy. Materials may be granted by request from georgiou@physics.usyd.edu.au or The School of Physics, The University of Sydney, NSW, 2006. Ph: 9351 3037