Full Paper

Introduction

> *"To me, thermodynamics is a maze of vague quantities, symbols with superscripts, subscripts, bars, stars, circles, etc., getting changed along the way and a dubious method of beginning with one equation and taking enough partial differentials until you end up with something new and supposedly useful"* (student quote reported in Krishnan & Nalim, 2009)

The above quote summarises the frustrations of many thermodynamic students. As a fundamental component to an engineering education, thermodynamics is core to the mechanical and chemical engineering disciplines. The fundamental first and second laws of thermodynamics emerged in the 1850's. Since this time, students of thermodynamics have struggled with these core concepts and their correct application (Dukhan & Schumack, 2013, Meltzer, 2004, Prince, 2009, Loverude, 2002). Many studies continue to highlight the ongoing struggle of engineering students with these concepts (Dukhan & Schumack, 2013, Meltzer, 2004, Prince, 2009, 4, Kavanagh, 2009, Nasr & Thomas, 2004, Olakanmi & Doyoyo, 2014), despite over 150 years of instruction and knowledge building. The problem of continued poor student performance within thermodynamics is not limited to Australia, but is recognised as a worldwide issue (Dukhan & Schumack, 2013, Meltzer, 2004, Prince, 2009, Loverude, 2002, Kavanagh, 2009, Nasr & Thomas, 2004, Olakanmi & Doyoyo, 2014).

Recent evidence indicates that the traditional method of teaching instruction employed in engineering education may actually result in the decreased understanding of concepts (Strevelar, 2008, Prince, 2009). Coupled with student's inherent perceived difficulty of thermodynamics and understanding core concepts, it becomes apparent that a paradigm shift in thermodynamic instruction technique is required to improve student performance. A number of thermodynamic instructors have experimented with alternate pedagogical approaches to improve student understanding of core concepts and engagement with the subject matter (Dukhan & Schumack, 2013, Prince, 2009, Nasr & Thomas, 2004, Mulop, 2012, Olakanmi & Doyoyo, 2014).

This paper reports on a pilot study aimed at collecting data to support the hypothesis that the 'difficulty' of learning thermodynamics is associated with the pedagogical approach of tutorials rather than actual difficulty in subject content or deficiency in students.

Background

A review of the literature identifies two key challenges preventing students from achieving deep-holistic learning of thermodynamics: understanding core concepts (Dukhan & Schumack, 2013, Meltzer, 2004, Prince, 2009, 4-5, Olakanmi & Doyoyo, 2014) and their application (Dukhan & Schumack, 2013, Meltzer, 2004, Beall, 1994, Krishnan & Nalim, 2009). A large body of research confirms that students fail to properly understand the fundamental concepts and principles of thermodynamics, such as temperature (Meltzer, 2004, Prince, 2009, Loverude, 2002) heat (Dukhan & Schumack, 2013, Meltzer, 2004,

Prince, 2009), work (Dukhan & Schumack, 2013, Meltzer, 2004, Loverude, 2002), energy

(Dukhan & Schumack, 2013, Meltzer, 2004, Prince, 2009, Loverude, 2002) and the first (Dukhan & Schumack, 2013, Meltzer, 2004) and second (Prince, 2009) law. As a consequence, students are repeatedly reported as having difficulty recognising and assembling relevant concepts and principles required to solve thermodynamic problems (Dukhan & Schumack, 2013, Meltzer, 2004).

Fundamental to understanding the concepts of thermodynamics is a lecturer/tutor's ability to effectively break down commonly held student misconceptions, such as the difference between heat/temperature, rate/amount, and work/energy (Prince, 2009, Strevelar, 2008). Once these misconceptions have been recognised, the lecturer/tutor can guide student learning to the correct, scientific, meaning of these terms and how they relate to thermodynamics. This can often be a challenging task for both student and lecturer/tutor, as these terms are common in everyday language (Dukhan & Schumack, 2013, Meltzer, 2004) and often over-generalized in pre-university level education (eg $Q = mc\Delta T$) that reinforce misconceptions at university level (Meltzer, 2004). Only once fundamental concepts are completely understood can students apply these correctly to thermodynamic problems with confidence.

Prince et al (2009) piloted a study on inquiry-based activities to address common misconceptions in heat transfer and thermodynamics to a small cohort. Activities included a combination of experiments and simulations aimed at targeting and addressing commonly held misconceptions regarding rate of heat transfer and amount of energy transfer and, the impact that entropy has on real-world processes. Although noting several limitations in the study, (lack of a control group and small sample sizes for statistical relevance), the results show an immediate and long term (measured 10 weeks later) improvement in student understanding after the intervention when compared to student knowledge measured in the year when no intervention was utilised.

Nasr and Thomas (2004) performed a comparative study on student learning with a traditional based approached and a problem based learning (PBL) approach. They report that students who were involved with the PBL delivery rather than the traditional teacher- centred delivery performed better in their final assessment exam with PBL students performing better on the open ended 'work-out' problems with an average score of 87% compared to 63%.

Olakanmi and Doyoyo (2014) investigated the use of teacher intervention in the form of structured examples and prompted reflective questions to correct misconceptions held by final year mechanical engineering students associated with air-conditioning and heat transfer from finned walls. Results of their study are encouraging in that better student understanding of core concepts can be achieved with a more student-centred approach to learning.

Dukhan and Schumack (2013) provide a comprehensive review of efforts and techniques used for improving students learning. In particular, they focus on studies focused on thermodynamic learning based on real-life examples and experiments, inquiry-based learning, PBL and project-based learning and, the use of electronic media. The overarching theme reported by Dukhan and Schumack (2013) is that each of these pedagogies resulted in some level of better student engagement, self-efficacy, improved knowledge retention and a deeper conceptual understanding of thermodynamics.

Hall et al (2010) report that when approached with problem solving, students draw guidance from lecturers/tutors, peers, and technology, however, continue to rely heavily on tutors to demonstrate how to solve problems. These findings demonstrate the continued importance of tutor demonstration on students learning, together with varied but complementary pedagogies such as online, collaborative and problem based learning.

The subtext to the past research in different teaching approaches in thermodynamics is that students all learn differently. Most alternate pedagogies in thermodynamic instruction have focused on learning in the lecture environment, with no specific focus (or limited to a few topics and weeks of instruction) on the tutorial instruction style.

Tutorials in technically challenging engineering subjects, such as thermodynamics, continue to primarily follow a traditional tutor-centred format. This is true at least at the university where this study was conducted. The typical structure of a tutor-led traditional tutorial is a brief, didactic review, of the previous lecture topic where the tutor tells the student what they need to know, followed by tutor-led worked solutions, often with little to no student engagement. Students are typically passive throughout this process, focused only on copying the solutions and “getting the right formula” rather than focusing on understanding the concepts underpinning the solution process. These types of tutorial, although anecdotally appealing to students as they “get the worked solution”, require no significant student engagement. As such, traditional tutorials result, at best, in surface learning that is often manifested as the ability to recognise a pattern/process in the solving of a problem, which students then adopt without thought of the underlying conceptual aspects of the question at hand. These traditional tutor–led tutorials have a number of failings when it comes to student learning. Foremost, is the passive engagement of students through the use of pedagogical approaches that are not conducive to deep learning (Ramsden 2003) with students often disengaged from the learning process. Secondly, and equally importantly, this format of tutorial does not recognise or address different learning styles of students and/or cohorts. This is particularly important for cohorts with increasing diversity, which, is the norm in Australian engineering courses.

Adapting tutorials in technically challenging subjects, to the different learning styles of an increasingly diverse student cohort will ideally; engage more students, encourage active involvement in the learning process and, result in deep, life-long learning. Key to achieving this is understanding how a representative cohort of engineering students apply their learning in tutorials, and which activities result in greater student engagement levels and overall increased student learning.

Methodology and Data Collection

Two tutorial styles were trialled in this pilot study: Traditional (T) and Non-Traditional (NT). Traditional tutorials were typical of a tutor-led session, focusing on the tutor supplying worked examples to the assigned homework problems. This type of tutorial is characteristic of 2nd, 3rd and 4th year technical units in mechanical engineering where the trial was conducted. Non- traditional tutorials were designed to be student-led with the tutor acting more as a facilitator and a guide to student reasoning. In these tutorials, a series of activities were developed to

promote active student engagement, and encouraging discussion on the fundamental concepts including when and why we apply these to real-world thermodynamic problems. Student-led activities utilised in the NT tutorials included peer-to-peer instruction, inquiry based learning, group based problem solving, peer-led instruction and group discussion to name a few.

Four tutorial sessions, and three tutors were selected for this trial as summarised in Table 1. Each tutorial group had a three-week period of T and NT tutorials. Tutor A had two sessions (A1 and A2) that alternated between T and NT tutorial styles. This was purposefully done to remove tutor influence from the data analysis. Tutors B and C were recruited to increase the sample size of students participating in the study. Tutorials were timetabled for two hours to accommodate the format of the NT tutorial. Students were requested to stay in their timetabled tutorial, however, they were free to move to alternate tutorials.

Table 1: Tutors participating in study and scheduling of tutorial sessions

Tutor	Tutorial Time	Tutorial Style	
		Session 1 - 3	Session 4 - 6
A1	Friday, 1-3pm	T	NT
B	Friday, 3-5pm	NT	T
C	Friday, 1-3pm	T	NT
A2	Friday, 3-5pm	NT	T

Weekly feedback was solicited only after the NT tutorials and followed either a five-point (sessions 1-3, scale) or seven-point (sessions 4-6) Likert scale with three open ended questions focused on most liked / disliked activity and activities that facilitated their learning. Table 2 summarises the feedback collected during the trial. All tutorial sessions were asked to participate in a five-minute essay where they reflected on each tutorial style. Guiding questions on the five-minute survey focused on student preference in tutorial style, what facilitated their learning, and confidence in understanding the core concepts.

Table 2: Feedback collected from tutorial sessions.

Session / Feedback Type / Scale	Tutorial Session / Tutor			
	Friday,1-3pm		Friday,3-5pm	
	A1	B	C	A2
Session 1-3 / tutorial feedback / 5 point scale	?	?	?	?
Session 4-6 / tutorial feedback / 7 point scale	?	?	?	?
Five minute essay / tutorial feedback / NA	?	?	?	?

Semi-structured interviews were requested from the cohort of students who participated in the trial. The broad themes of tutor teaching characteristics and student ownership of learning were the focus of these interviews. To date, three students have volunteered to participate in these interviews, with further recruitment underway. Data analysis is still being performed on these interviews and results are not included in this paper.

Results and Discussion

Results from the NT tutorial sessions are given in Table 3. Results from the seven point Likert scale used in Sessions 4-6 were converted to a five-point scale for comparison with results from Sessions 1-3. Each scale asked the question how each activity facilitated their learning.

The pedagogical approach used for each activity in each session are indicated in the table and included: ownership of learning (O) (Chalmers & Partridge 2012), self-generated analogies (SGA) (Haglund & Jeppsson, 2012), inquiry based (IB) (Prince, 2009), Active learning (A) (Georgiou & Sharma 2015), peer-to-peer (P2P) (Brown, 2001) and Didactic (D) (Ramsden 2003). Mean and standard deviation (bracketed) for each activity in each tutorial session are shown. Results have been presented based on the tutor who took that particular session. Average class size for each tutor is also given below the tutor identifier with the standard deviation shown in brackets.

The cohort from Tutor B was the smallest with only two students attending B's tutorial in Session six. These results have been excluded from statistical analysis due to the small population size. Based on the number of feedback forms received after each NT session, fairly consistent numbers were observed in each tutorial over the pilot period.

Pedagogical Approach

Figure 1 shows the overall cohort average, and average for each tutor for how each pedagogical approach in the NT tutorials facilitated student learning. Error bars indicate the standard deviation. The cohort's response to the NT tutorials overall was that they considered the activities to have a neutral impact to their learning to agreeing that most activities were beneficial to their learning. The least liked activity was the self-generated analogy with an average response of µ3.1, σ1.2. This was a somewhat surprising result given previous literature indicating student's positive response and deep level of understanding when formulating self-generated analogies for difficult concepts (Haglund, J & Jeppsson, 2012).

Table 3: Feedback Survey Results

Tutorial Activity	Tutor			
	A1 **20 (3.2)**	**B** **4 (1.6)**	**C** **15 (3.4)**	**A2** **10 (2.4)**
Session 1				
Clearest / Muddiest Point (O)	-	-	2.6 (1.09)	3.1 (1.10)
Self-Generated Analogies (SGA)	-	-	2.7 (1.18)	3.4 (1.28)
In Class Experiment (IB)	-	-	3.9 (1.08)	4.4 (0.63)
Group Problem Solving (A, P2P)	-	-	3.6 (1.20)	3.9 (0.92)
Peer Led Problem Solving (P2P)	-	-	3.1 (1.21)	3.7 (1.20)
Session 2				
Lecture Review (D, A)	-	-	3.8 (0.93)	4.4 (0.73)
Concept Questions (A, P2P)	-	-	3.1 (1.20)	4.2 (0.83)
Individual Problem Solving (A)	-	-	2.8 (1.17)	3.8 (1.09)
Peer Marking & Feedback (P2P)	-	-	3.0 (1.03)	3.0 (1.50)
Worked Tutor Examples (D, A)	-	-	2.6 (1.22)	4.3 (0.71)
In Class Experiment (IB)	-	-	3.0 (1.13)	4.3 (0.71)
Group Discussion (O, A)	-	-	3.1 (1.15)	4.5 (0.53)
Session 3				
Lecture Review (D, A)	-	-	3.7 (1.11)	4.6 (0.53)
Concept Questions (A, P2P)	-	-	3.6 (1.01)	3.6 (1.33)
Worked Tutor Examples (D, A)	-	-	3.7 (1.16)	4.2 (0.67)
In Class Experiment (IB)	-	-	4.1 (1.08)	4.1 (0.93)
Group Discussion (O, A)	-	-	4.4 (0.65)	3.5 (1.31)
Group Discussion (O, A)	-	-	4.1 (1.00)	3.9 (1.25)
Session 4				
Clearest / Muddiest Point (O)	3.4 (0.94)	3.2 (1.92)	-	-
Peer led explanation (P2P)	3.6 (1.08)	3.4 (0.77)	-	-
Concept Questions (A, P2P)	4.2 (0.54)	3.7 (0.94)	-	-
Worked Tutor Examples (D, A)	4.5 (0.53)	3.7 (1.15)	-	-
Group Problem Solving (A, P2P)	3.4 (1.15)	2.3 (1.15)	-	-
Peer Led Problem Solving (P2P)	3.6 (1.14)	3.4 (0.77)	-	-
Session 5				
Concept Questions (A, P2P)	4.1 (0.78)	4.2 (0.27)	-	-
Worked Tutor Examples (D, A)	4.4 (0.67)	4.2 (0.27)	-	-
Student Marking (A, O)	3.8 (1.00)	3.5 (0.87)	-	-
Worked Tutor Solutions with Student Input (A, O)	4.1 (0.73)	4.3 (0.42)	-	-
Student Marking (A, O)	3.8 (1.00)	3.3 (1.01)	-	-
Session 6				
Concept Questions (A, P2P)	4.2 (0.49)	4.3 (0.00)	-	-
Worked Tutor Examples (D, A)	4.5 (0.50)	4.7 (0.47)	-	-
Individual / Small Group Problem Solving (A, P2P)	3.9 (0.77)	3.7 (0.94)	-	-
Tutor Supported Student Led Problem Solving (A, O)	4.3 (0.68)	5.0 (0.00)	-	-

5-point scale: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, (5) strongly agree

7-point scale: (1) strongly disagree, (2) somewhat disagree, (3) disagree, (4) neutral, (5) agree, (6) somewhat agree, (7) strongly agree

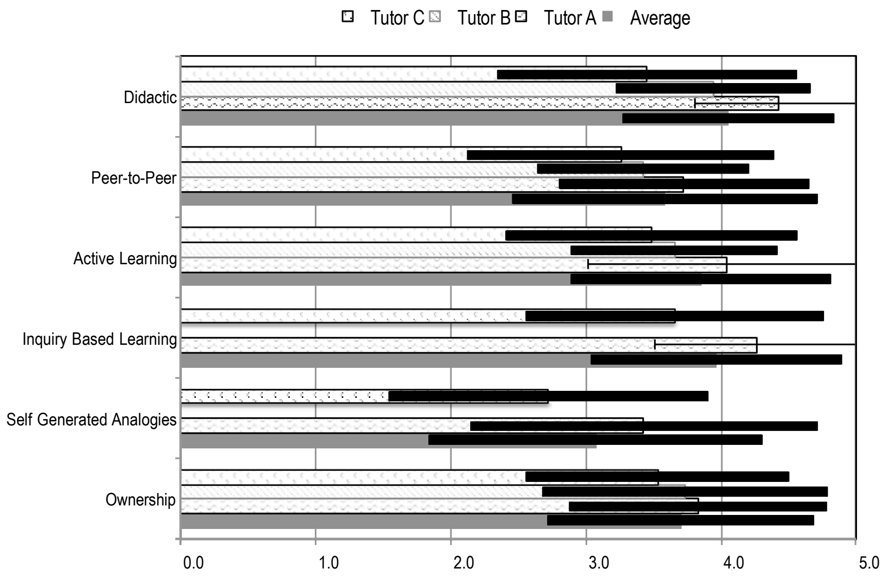

Figure 1: Average student response for activities trialled in NT tutorials for whole pilot cohort and for each tutor.

It is important to note, however, SGA was only trailed once, in one session. The most favoured activity, and the most surprising result, was the level of agreement (µ4.1, σ0.8) that the 'didactic' activities facilitated their learning given the literature. Caution is warranted when formulating conclusions on this result for a number of reasons. Firstly, the didactic activities were always coupled with others (often active learning) as indicated in Table 3, which is likely skewing the result. Secondly, most didactic actives involved a lecture review or tutor worked examples, both of which are highly tutor dependent. For example, Tutor A's teaching style is inherently student-led and encourages students to think, reason and discuss questions. Thus, the tutor's personal teaching philosophy is likely also skewing the results for the didactic activities. The second most favoured activity (µ4.0, σ0.9) was the inquiry based learning activities, which was expected given literature of the effectiveness of this pedagogy. These activities involved a simple in class experiment, using everyday items (e.g. hair dryers) that demonstrated fundamental concepts in thermodynamics, with students often citing these experiments as the most enjoyable and beneficial activity in the open comment section of the feedback form. Results for the active learning (µ3.9, σ1.0) and ownership of learning (µ3.7, σ1.0) were high with students agreeing that these were beneficial to their learning. Such results were expected given the literature on these pedagogical approaches to enhanced student learning. Overall, the students within this pilot study indicated a high level of agreement that student-centred activities that encouraged them to actively take ownership of their learning facilitated their overall learning in thermodynamics.

Tutor Influence

Tutor selection has an important influence in how students respond to activities and how they perceive these activities in facilitating their overall learning. This is clearly observed in Figure

1. For example, as a cohort, the average rating for the didactic activities was µ4.1, σ0.8. This result varies somewhat significantly, however, when student responses from each tutor are considered individually. Student-led learning is core to the teaching philosophy of tutor A. Thus, although the activities were characterised in part as didactic, the style delivered was a mix of tutor instruction with significant components of leading and open-ended questions that the students themselves had to answer. Overall, tutor A's two cohorts rated each

activity the highset of all students participating in the pilot study, with results consistently higher than the average. With the exception of the self-generated analogy activity in Tutor C's cohort, all students responded that the activities facilitated their learning to a degree. In activities that were less tutor focused, such as peer-to-peer learning and ownership of learning, the difference in students response in how this facilitates their learning is less. It is imperative to note that no tutors were formally trained in running student-led NT tutorials, relying only on the experience of the selected tutors, and this undoubtedly has an influence on the results. Results from each tutors cohort indicated two key results. Firstly, it is imperative to student engagement with activities that tutors are selected carefully. Secondly, selected tutors would benefit from targeted training on how to facilitate student-led NT tutorials, which are not commonly employed in technical units beyond first year at university where the study was performed.

Traditional versus Non---Traditional

Preliminary analysis from the five-minute essays highlights several key criteria for a successful NT tutorial as viewed by the student. Firstly, having the right tutor with a passion and extensive subject matter knowledge with the ability to find relevant everyday examples is imperative to the success of NT tutorials. Secondly, students themselves are also responsible for the success of the NT tutorials. Self-identified student responsibilities included; coming to class prepared, being up to date in lectures, attempting to solve problems individually rather than wait for the tutor's solutions and, coming prepared to "think".

Students preference for T versus NT tutorial style appears to be highly dependent on the tutor, which reflects the tutor differences reported in Figure 1. Tutor C's cohort had a strong preference for traditional tutorials. Tutor A's cohort had a mixed response, but overall were positive and receptive to the NT tutorial. Although students recognised that the NT tutorials helped them gain a better understanding of thermodynamic concepts and experience in solving problems on their own, there remained a preference that the T style was "best" as they got the "worked solutions". As one student said "for understanding concepts, the 'collaborative' (NT) style worked better, but for being able to pass exams (our end goal) the traditional style tutes are superior".

Conclusions and Future Work

Overall, students agreed that the activities and structure of the non-traditional, student-led tutorial style facilitated their learning, with several students reporting a greater confidence in understanding the core concepts of thermodynamics. Many students appreciated the time focused on them solving the problems, however, as the selected questions were individualistic with clear 'correct' answers, many questioned the purpose of solving these in groups. For future studies, more realistic, open-ended problems, requiring group discussion and thinking, with tailored IBL in-class experiments are recommended, as these activities engaged students more in both thermodynamic application and wider discussion. Despite the overall favourable response to the NT tutorial, students remain 'formula' and 'process' driven in the application of thermodynamic problems, with many students stating a preference for traditional tutorials because they "get the worked solution". A key theme emerging from this pilot study is that for NT tutorials to be most effective requires selecting appropriate tutors as well as communicating what is expected of the student in these sessions. Further, several students (a minority) expressed disagreement that any activity beyond a tutor worked solution helped their learning. This finding, together with the above, provides qualitative evidence that the student cohort learns in different ways, and for best student learning universities should consider tutorial streams running different styles that students can select based on their learning needs.

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