SURVEYING SYDNEY INTRODUCTORY PHYSICS STUDENTS' UNDERSTANDINGS OF HEAT AND TEMPERATURE

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Abstract
In 2006, a project was undertaken at the School of Physics, University of Sydney with the aim of measuring introductory students' conceptual understanding of heat and temperature. Students' conceptual understanding of heat and temperature has been measured using the Heat and Temperature Conceptual Evaluation survey (HTCE) developed by Thornton and Sokoloff (2001). A total of 175 students have been tested before and after standard first year university instruction giving pre and post data. The students were divided into an Advanced class and a Regular class. Both classes were taught by traditional teaching methods, but with different lecturers. There are some differences in the teaching, for example computer simulations were used in some classes. This study found that the average mark for pre and post test of the Advanced class is higher than the Regular class. The average pre test mark for all students is 61.02 percent, 77.76 percent for post test, and average normalized gain is 0.43 – a value comparable to instruction based on interactive engagement as defined by Hake (1998). In future, pre and post instruction comparisons for Thai and Australian students will be made and study guides/teaching methods developed for introductory physics classes.

Introduction
The objective of some physics education research is to study students' understandings or misconceptions in introductory physics using standardized tests. Examples of well known tests include the Force and Motion Conceptual Evaluation test (FMCE) (Thornton and Sokoloff 1998), the Electric Circuits Conceptual Evaluation test (ECCE) (Maloney et al., 2001), and the Heat and Temperature Conceptual Evaluation survey (HTCE) (Thornton and Sokoloff 2001). This study focuses on the HTCE survey.

Recent research has shown that students have difficulties understanding basic thermal physics. For example, Harrison, Grayson and Treagust (1999), Carlton (2000), and Yeo and Zadnik (2001) all found that students are unable to differentiate clearly between the concepts of heat and temperature. Researchers have subsequently tried to improve conceptual understandings of thermal physics by designing active teaching methods, such as *RealTime Physics* (Sokoloff 2004). Wittmann and Breen (2000) have shown that students learn more successfully in such classes than with traditional instruction.

The aim of the present project was to use a standard test to explore students' conceptions of thermal physics and compare pre and post test results for Advanced and Regular students.

Method
Study sample
In 2006, 175 students from the University of Sydney were surveyed using the Heat and Temperature Conceptual Evaluation survey. The students were from first year mainstream physics courses which are divided into an Advanced class (students who have done senior high school physics and are high achieving students) and a Regular class (students who have done well in senior high school physics). All classes were taught by traditional teaching methods, although there were some differences in the teaching techniques. For example, in-class computer simulations were used in some classes. In all classes the survey was administered *pre and post instruction*.

The conceptual test
The HTCE is a 28 item, multiple choice survey dealing with some basic concepts related to thermal physics. This survey takes about 40 minutes to complete. For this research, the questions of the HTCE survey are divided into eight "conceptions" (see table 1).

Table 1: Categories of conceptions

Conceptions	Question Numbers
1. Heat and temperature	1, 2, 3, 4
2. Rate of cooling	5, 6, 7
3. Calorimetery	8, 9
4. Rate of heat transfer	10, 11
5. Perception of hotness	12, 13, 14, 15
6. Specific heat capacity	16, 17, 18, 19
7. Change of Phase	20, 21, 22, 23, 25
8. Thermal conductivity	26, 27, 28

One item requires students to draw a graph (item 24) and has been removed from the analysis because it was difficult to mark objectively.

Calculating normalized gain

The average normalized gain <g> for a course is defined as the ratio of the actual average gain to the maximum possible average gain (Hake, 1998, 1999);

$$\text{the average normalized gain } \langle g\rangle = \frac{\%\text{posttest}-\%\text{pretest}}{100-\%\text{pretest}}.$$

The average normalized gain is divided into three levels that are high average normalized gain, (*High-g*, ($\langle g\rangle$)> 0.7), medium average normalized gain, (*Medium-g*, 0.7 > ($\langle g\rangle$) > 0.3) and low average normalized gain (*Low-g*, ($\langle g\rangle$) < 0.3) (Hake, 1999). Further Hake states that

> "Fourteen ''traditional'' (*T*) courses (*N* = 2084) which made little or no use of interactive-engagement (IE) methods achieved an average gain $\langle g\rangle_{T\text{-ave}} = 0.23 \pm 0.04$ (std dev). In sharp contrast, 48 courses (*N* = 4458) which made substantial use of IE methods achieved an average gain $\langle g\rangle_{\text{IE-ave}} = 0.48 \pm 0.14$ (std dev), almost two standard deviations of $\langle g\rangle_{\text{IE-ave}}$ above that of the traditional courses".

We compare the findings in our study with this assessment of the nature of instruction. When comparing conceptions, we use the gain in the percentage of students who have understood the concept;

$$\Delta = (\%\text{ of students correct on Posttest}) - (\%\text{ of students correct on Pretest}).$$

Result and Discussion

Advanced class

Figure 1 shows the percentage of Advanced students answering each question correctly for pre and post test. Only students who completed the survey both times are included (total number, N=89). Table 2 shows the percentage of students who had all the questions for a conception correct for the pre test and for the post test.

It can be seen that Advanced students provide mostly correct answers for both the pre and post tests for most questions. The improvement from pre and post test is moderate. The average pre test score is 68.96 percent and the average post test score is 83.69 percent. The average normalized gain is 0.47 that is a Medium normalized gain level. It will be noticed from figure 1 and table 2 that questions 20 to 22 (change of phase) were done poorly in the pre test, but showed a marked improvement post instruction. It is interesting that on questions relating to rate of cooling (question 5 to 7) the gain was slightly negative. This is not controversial since that topic was not in the first year syllabus.

Figure 1. Comparison of percentage of Advanced students answering each question correctly on the pre and post tests

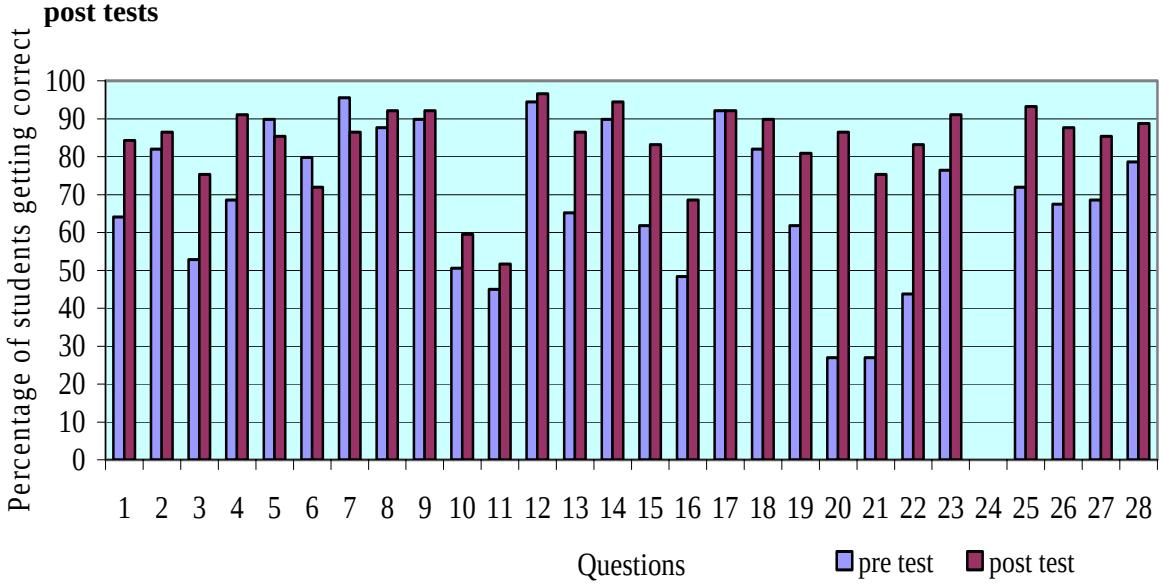


Table 2. Percentage of students answering each conception correctly on the pre and post tests. Gain on each conception for Regular and Advanced classes are given by Δ

Conceptions	Advanced class			Regular class		
	% of students correct on Pre test	*% of students correct on Post test*	Δ	*% of students correct on Pre test*	*% of students correct on Post test*	Δ
1. Heat and temperature	48.84	68.60	19.77	25.58	54.65	29.07
2. Rate of cooling	73.26	58.14	-15.12	43.02	46.51	3.49
3. Calorimetery	84.88	89.53	4.65	56.98	65.12	8.14
4. Rate of heat transfer	36.05	44.19	8.14	12.79	32.56	19.77
5. Perception of hotness	53.49	79.07	25.58	38.37	70.93	32.56
6. Specific heat capacity	29.07	58.14	29.07	5.81	37.21	31.40
7. Change of Phase	13.95	56.98	43.02	3.49	23.26	19.77
8. Thermal conductivity	63.95	84.88	20.93	38.37	59.30	20.93

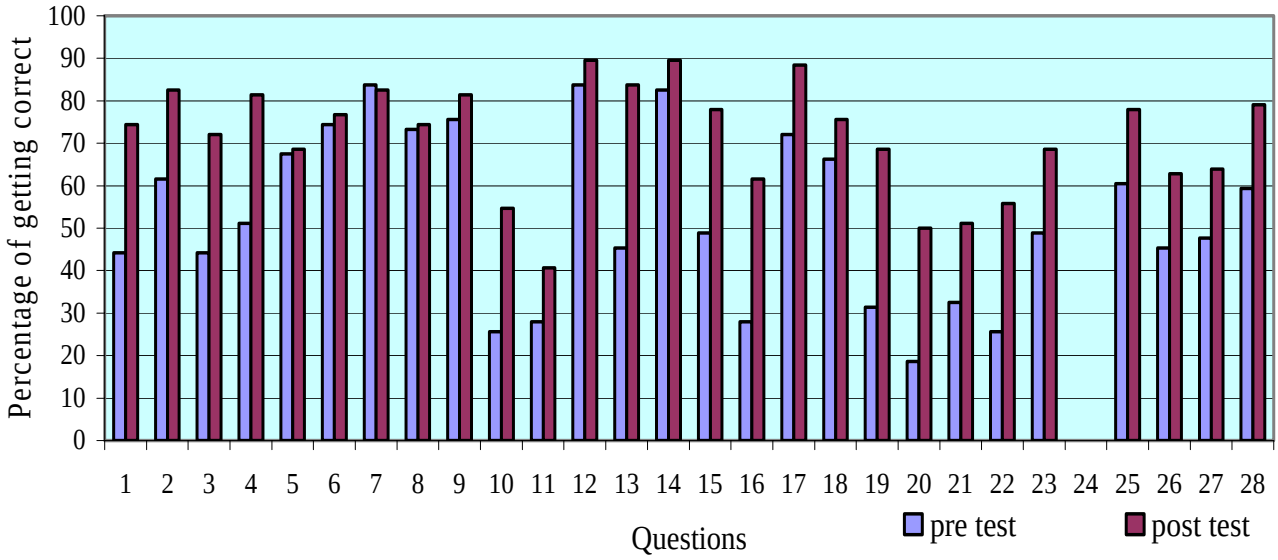
Regular class

Figure 2 shows the percentage of Regular students answering each question correctly for pre and post test. Only students who completed the survey both times are included (total number, N=86). Table 2 shows the percentage of students who had all the questions for a conception correct for the pre test and for the post test.

It can be seen that the Regular class provide fewer correct answers overall. The average pre test score is 52.80 percent and the average post test score is 71.62 percent. The average normalized gain is 0.40 that is a Medium normalized gain level. It is interesting to note that the negative gain on questions 3 to 5 is not present.

It is clear by inspection that the overall shape of the Regular and Advanced distributions are very similar. So the same misconceptions are evident in both classes. Further exploration of these misconceptions need to utilize works done by Chi, Slotta and de Leeuw (1994), and Duit and Treagust (1998).

Figure 2. Comparison of percentage of all Regular students answering each question correctly on the pre and post tests



Conclusion

This study indicates that, although Advanced students answer these questions better that the Regular students, they both have difficulty with the same conceptions. These are the most important: change of phase and rate of heat transfer. The clear message is that we should reconsider how these topics are taught. In particular, as university physics teachers, we expect that students should arrive with a complete understanding of change of phase. That expectation is not borne out by the data.

By far the most interesting aspect of our work is the finding that the average normalized gains are in the medium average normalized gain range implying that the instruction is "interactive engagement".

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