Assessing the Conceptual Understanding about Heat and Thermodynamics at Undergraduate Level

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Abstract
In this study, a Thermodynamic Concept Test (TCT) was designed to assess student's conceptual understanding heat and thermodynamics at undergraduate level. The different statistical tests such as item difficulty index, item discrimination index, point biserial coefficient were used for assessing TCT. For each item of the test these indices were calculated. For the entire test, test reliability and Ferguson's delta was calculated. Analysis of data shows that the students have serious difficulties in understanding of heat and thermodynamics in particular and physics in general when taught through traditional teaching method.

Keywords: Physics education, Thermodynamics, heat engines, Ideal gas laws.

Introduction

Physics Education Researchers showed that acquiring a conceptual understanding of physics has proven to be one of the most difficult challenges faced by the students (McDermott, 2001; Engelhardt and Beichner, 2003). Heat and Thermodynamics are important topics studied in physics as they are applicable in many fields of science and technology. Physics Education Research has showed that students have difficulties in understanding the basic concept of heat and work, entropy, and thermodynamic processes. Students frequently failed to differentiate the concepts of heat, temperature, work and internal energy. Students have difficulties of understanding the role of entropy in the second law of thermodynamics (Yeo and Zandik, 2001; Meltzer, 2004). The researchers observed that students frequently confused concepts of heat, temperature, and internal energy. The results from investigations indicate that after instruction in introductory physics and chemistry, as well as in more advanced courses, many students cannot properly interpret the macroscopic variables such as pressure, temperature, and volume in an ideal gas (Loverude *et. al.*, 2002). The interactive tutorial lectures and tutorial, laboratory experiment, both separately and in combination, helped students improve their understanding of the macroscopic concepts of pressure and volume in a gas. The conceptual change oriented instruction appeared to be successful in changing students many misconceptions related to the fundamental ideas about heat and temperature (Kautz *et. al.*, 2005; Baser, 2006; Tanahoung *et. al.*, 2010). The students have difficulties in understanding of first law of thermodynamics and how to apply for problem solving. The students also have difficulties how to apply P-V diagram for problem solving. Researcher found that students have misinterpreted the understanding of ideal gas laws. The researcher found that instruction using tutorial is effective in improving students' performance (Barbera and Wieman, 2009; Christensen *et. al.*, 2009; Gönen and Kocakaya, 2010).

There are many research studies reported in western countries about students' difficulties in learning of heat and thermodynamics, but rarely research done in Indian Universities. It seems unclear that the western students' understanding and their difficulties in learning heat and thermodynamics are similar to or different from the Indian students'. The researcher suggested that traditional teaching method is not sufficient , and that most of the students were confused about thermodynamics concepts and students' did not have problem-solving abilities.

This study aimed to investigate Indian Undergraduate students' conceptions, alternative concepts dealing with heat and thermodynamics in the existing teaching and learning environment. The Heat and Thermodynamics course is taught in first year of undergraduate studies at Pune University.

Authors were interested in whether Pune university students who have studied Heat and Thermodynamics are able to apply the first law of thermodynamics to a simple physical phenomenon. Specifically, authors wanted to examine the extent to which students could (1) recognize the thermodynamic processes, (2) apply First law to predicting or explaining an observation, and (3) relate thermodynamic quantities to a change in the internal energy of the system (Kruatong *et.al.* 2006; Harrison *et. al.*, 1999; Kesidou and Duit, 1993).

Research Questions

To obtain data on various points of conceptual understanding in Thermodynamics, following research questions were set for the study.

(1) Student's ability to interpret verbal representations in thermodynamics.
(2) Student's ability to interpret equations in thermodynamics.
(3) Student's ability to interpret graphical representations.

Methodology

This research is a survey research based on students responses to multiple choice test on heat and thermodynamics. The study employed a combination of qualitative and quantitative items in the test which allowed a deeper understanding of the way students thought of scientific concepts and the reasons of holding conceptions in heat and thermodynamics.

The subjects of this study were first year undergraduate students (aged 17 to 19) from two different colleges affiliated to Pune University in the academic year 2011-12. The total number of students were selected from these colleges was 156.

For data collection, a Thermodynamic Concept Test (TCT), which is composed of 24 items of multiple choices, was administered to subjects. The items in the TCT were selected from 35 items following advice of five senior teachers teaching heat and thermodynamics at undergraduate level on the basis of level of difficulty and the indexes of defined differences. The topics covered in the TCT are laws of thermodynamics, concept of heat, equation of state, isothermal, adiabatic, isochoric processes and heat engines. Test items are mostly qualitative questions with a few quantitative questions, which require only simple calculations. All test items are intended to assess students' understanding of basic concepts in heat and thermodynamic courses. The test was validated from ten senior most teachers who are teaching heat and thermodynamics.

Statistical Evaluation of TCT

Item analysis is a process, which examines student responses to individual test items in order to assess the quality of those items and of the test as a whole. Five different statistical tests were used for assessing the data from the sample. The item difficulty index, item discrimination index, and item point biserial coefficient were focused on individual test items. For entire test, test reliability and Ferguson's delta were calculated (Ding et. al., 2006; Day and Boun, 2011).

(a) Item difficulty index

For items with one correct alternative worth a single point, the item difficulty is simply the proportion of the students who answer a test item correctly. The item difficulty index (*P)* is a measure of the difficulty of a single test question and it is calculated by the formula

$$P = \frac{N_1}{N}$$

Where N_1 is number of correct responses on the item and N is the total number of students who attempted the item. The formula of average item difficulty index is

$$\overline{P} = \frac{1}{K}\sum_{i=1}^{K} P_i$$

Where K is the number of items.

The possible range of item difficulty index (*P)* is [0, 1]. The item difficulty indices of TCT are shown in Figure 1. The average item difficulty index is found to be 0.402 which is greater than 0.3.

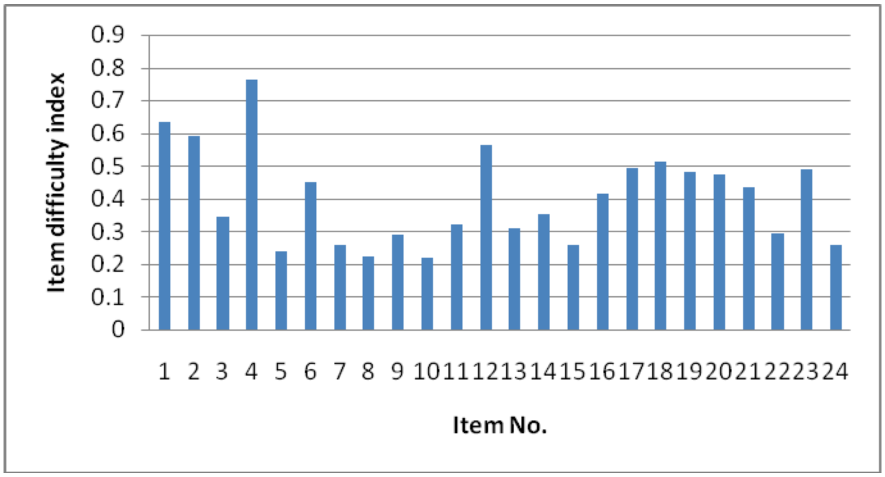

Figure 1. TCT item difficulty indices for each question, based on a sample of 156 students.

(b) Item discrimination index

Item discrimination refers to the ability of an item to differentiate among students on the basis of how well they know the material being tested. The item discrimination index (*D)* is a measure of the discriminatory power of each item in a test. In order to calculate the item discrimination index *D*, the subject were divided into two different groups of equal size, a high group (*H*) and a low group (*L*), based on whether an individual total score is higher or lower than the median total score of the entire sample and it is calculated by the formula

$$D = \frac{N_H - N_L}{N/2}$$

Where N_H is number of students in high group who responded the item correctly and N_L the number of students in low group who responded the item correctly out of N students who attempted the item. The average item discrimination index is calculated by

$$\overline{D} = \frac{1}{K}\sum_{i=1}^{k} D_i$$

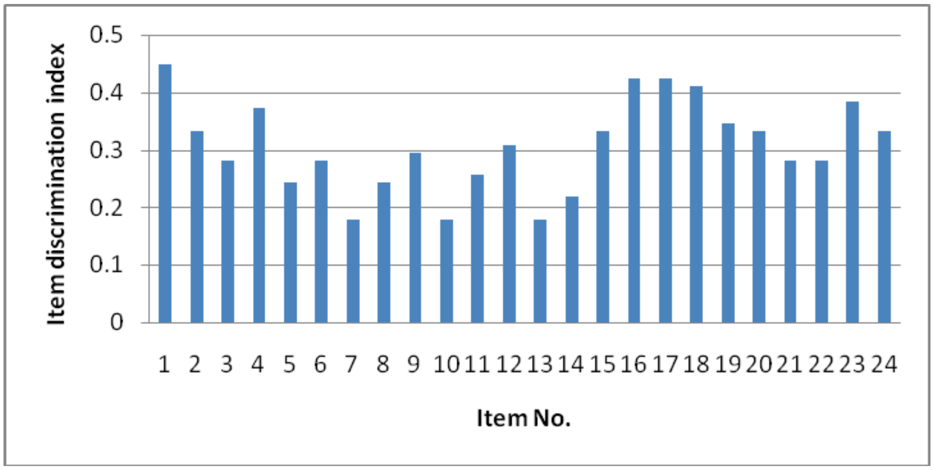

Figure 2. TCT item discrimination indices for each question, based on a sample of 156 students.

The possible range of item discrimination index (D*)* is [-1, 1]. The average item discrimination index of TCT is found to be 0.31.

(c) **Point biserial coefficient**

A point-biserial coefficient is a special type of correlation coefficient that relates observed item responses to a total test score. The point biserial coefficient for an item is calculated by the formula

$$r_{pbs} = \frac{\overline{X_1} - \overline{X}}{\sigma_x}\sqrt{\frac{P}{1-P}}$$

Where

$\overline{X_1}$ = The average total score for those students who correctly answer this item,

$\overline{X}$ = The average total score for a whole sample,

σ_x = The standard deviation of the total score for the whole sample,

and P = the difficulty index for the item.

The average point biserial coefficient ($\bar{r}_{pbs}$) of all items (K) in a test is

$$\bar{r}_{pbs} = \frac{1}{K}\sum_{i=1}^{K}\left(r_{pbs}\right)_i$$

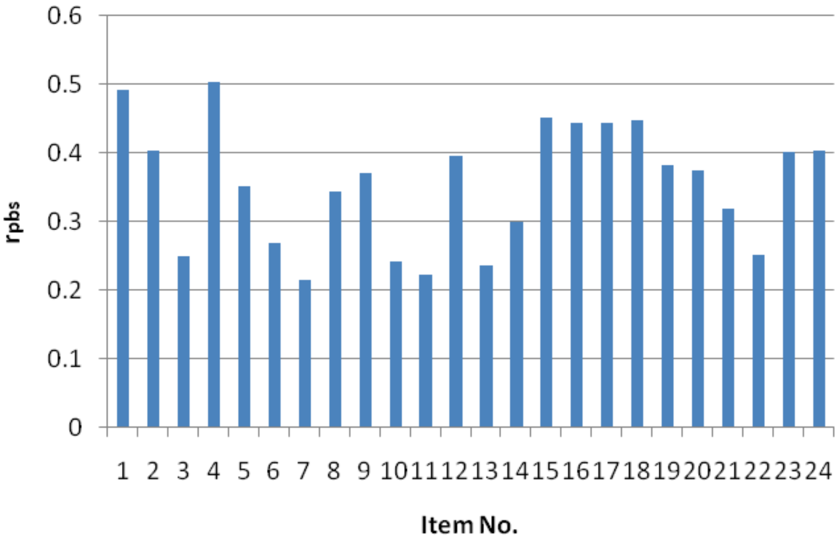

Figure 3. TCT item biserial coefficient for each question, based on a sample of 156 students.

The possible range of point biserial coefficient is [-1, 1]. The average point biserial coefficient is found to be 0.35.

(d) Kuder-Richardson reliability index

The Kuder-Richardson reliability index approximates inter-item consistency. A high value indicates a strong relationship between items and a lower value a weaker relationship. The Kuder-Richardson (KR-21) formula is given as

$$r = \frac{K}{K-1}\left(1 - \frac{\sum P(1-P)}{\sigma_x^{\ 2}}\right)$$

Reliability coefficients are related to the level of discrimination of the test items and to the number of test questions. The possible range of reliability index values is [0, 1]. The reliability index is higher than 0.8, it is reliable for individual measurement. Under most circumstances in physics education, evaluation instruments are designed to be used to measure a large group of students, so if a certain physics test has a reliability index greater than 0.7, one can safely claim it is a reliable test The reliability index for TCT test is to be 0.702, indicates that the TCT is satisfactorily reliable.

(e) Ferguson's delta

Discriminatory power can be measured by Ferguson's delta. The Ferguson's delta is calculated by the formula

$$\delta = \frac{N^2 - \sum f_i^{\ 2}}{N^2 - N^2/(K+1)}$$

where N is the number of students in a sample, K is the number of test items, and fi is the frequency (number of occurrence) of cases at each score.

The possible range of Ferguson's delta values is [0, 1]. If a test has Ferguson's delta greater than 0.9, the test is considered to offer good discrimination. Ferguson's delta for TCT test is 0.93, which is greater than 0.9.

Table 1. Summary of statistical results of TCT

Test statistics	Possible values	Desired values	Value for TCT
Item difficulty index (P)	[0,1]	> 0.3	Avg. 0.402
Item discrimination index (D)	[-1,1]	> 0.3	Avg. 0.31
Point biserial coefficient (r_{pbs})	[-1,1]	> 0.2	Avg. 0.35
KR-21 test reliability (r)	[0,1]	> 0.7 or > 0.8	0.702
Fergusson's delta (δ)	[0,1]	> 0.90	0.93

Discussion

Using TCT we have identified a number of specific difficulties students have with the understanding of heat, temperature, work and internal energy concepts and applications of the first and second laws of thermodynamics to simple physical processes (Barbera and Wieman, 2009**).**

Students' responses showed that only 14 % students were able to apply the ideal gas law in an adiabatic expansion. Many students seemed to confuse quantities associated with thermodynamics processes. They are confused about heat transfer and work with those associated with states, temperature and internal energy. About 52% students responded that the internal energy changes in an isothermal process (Meltzer, 2004). Students' responses showed that many of them did not treat the first law of thermodynamics as a cause–effect relationship in which work can bring about a change in the internal energy of a physical system (Loverude, Kautz and Heron, 2002). Although some students considered heat transfer as a process that can produce a change in internal energy, many others treated heat is the same as that of an internal energy. About 38% students believe that the heat supplied in isothermal process is used to change internal energy and work done against 28% who answered it correctly. The student believe that no work is done in an isothermal process because the temperature does not change, no heat is transferred, and if no heat is transferred, then no work is done (Meltzer,2004)

To probe student understanding of the path dependence of work, we designed several problems in which two different paths between an initial state and a final state are shown on a PV diagram. Only 30% students responded correctly. The students' responses indicated that many of them believed that work done by a system during a thermodynamic process either is, or behaves as, a state function. About 52% of the students responded incorrectly to the question based on work done in different three isothermal processes at different temperatures drawn on the same PV diagram. About 42% students believe that there is change in internal energy in both isothermal and adiabatic processes. It is observed that students have difficulty to understand that the process represented by a higher path on the P-V diagram generates more work since the area under the curve is greater. Thus the students have difficulties in applying the definition of work to an ideal gas undergoing a specific process. The failure of students to analyze the problems in terms of work is interdependent on misapplication of ideal gas concepts. Students' responses on problems in TCT corroborated the finding that a majority of the students were unable apply the first law of thermodynamics effectively in problem solving. Discussion with the students found that the difficulties in understanding of first law of thermodynamics are due to misinterpretation of the ideal gas laws (Loverude *et. al.*, 2001; Christensen *et. al.*, 2009).

Conclusions

The aim of this study was to examine students' conceptions in heat and thermodynamics. We have designed a Thermodynamic Concept Test (TCT) to assess student's conceptual understanding heat and thermodynamics at undergraduate level. The average item difficulty index, average item discrimination index and average item point biserial coefficient was calculated which was shown in Table 1 for item analysis. These results indicate that Thermodynamic Concept Test (TCT) is sufficiently reliable item wise. The test reliability and Ferguson's delta was calculated which is shown in table 1 for entire test. These results indicate that Thermodynamic Concept Test (TCT) is sufficiently reliable as whole test. The results of the test are indicative of a lack of conceptual mastery amongst undergraduate students of basic and familiar thermodynamic concepts, particularly the concept of first law of thermodynamics. It is necessary to use interactive teaching methods for proper understanding of these concepts (Coca, 2012). Computer simulations, animations and demonstrations may be useful in these respects. Physics educators should use these tools for interactive learning.

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