Development and Implication of a Two-tier Thermodynamic Diagnostic Test to Survey Students' Understanding in Thermal Physics

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Abstract

This study aimed to develop, implement and evaluate a conceptual survey, the Thermodynamic Diagnostic Test (TDT), covering the three fundamental laws of thermodynamics. The test consisted of 15 two-tier multiple-choices questions, with a first tier of content-based questions and a second of reasoning-based questions. The development of TDT combined both qualitative and quantitative methods, investigating student reasoning, and their reasons were then used to develop the second tier questions. The 1st version of the test was administered to 48 students taking a fundamental physics course and their responses used to improve and develop the final version of the TDT, which was then administered to a further 46 students the next academic year. The student responses on the final version of TDT were analyzed in terms of their alternative concepts. Nine alternative concepts in three laws of thermodynamics were identified. There were three predominant alternative concepts regarding "heat and temperature", "increasing temperature causes increase in pressure" and "entropy always increases." Therefore, these results indicated that the two-tier multiple choice questions are effective in diagnosing alternative conceptions in thermodynamics.

Introduction

Over the past four decades, physics education research has investigated students' misconceptions in diverse topics, including thermal physics. Many studies in thermal physics have covered topics such as heat and temperature (Sözbilir, 2003), thermodynamics and heat transfer (Vigeant, Prince, & Nottis, 2009), heat transfer mechanisms and elementary kinetic theory (Pathare & Pradhan, 2010), thermodynamic processes and the implications (Georgiou, Sharma, O'Byrne, Sefton, & McInnes, 2009; Georgiou & Sharma, 2012), the first law of thermodynamics relating work to the adiabatic compression of an ideal gas (Loverude, Kautz, & Heron, 2002), entropy and the second law of thermodynamics (Christensen, Meltzer, & Ogilvie, 2009).

These studies employed various techniques to obtain information on student misconceptions including concept maps, open-ended questions, inquiry based activities, interviews and conceptual surveys. Recently, diagnostic multiple-choice questions have been used extensively because they are convenient and low cost to administer in a large class

(Chandrasegaran, Treagust, & Mocerino, 2007; Chu, Treagust, & Chandrasegaran, 2009; Tan & Treagust, 1999; Rollnick & Mahooana, 1999; Odom & Barrow, 1995). The multiple-choice conceptual test enables a large numbers of students to be sampled in a given amount of time as compared to time-consuming interviews. This type of test is also easy to administer, score, process and analyze results.

A few conceptual surveys had been developed and implemented in both Thailand and Australia. The first survey, called Wave Diagnostic Test (WDT) aimed to diagnose students' conceptions of basic mechanical wave. It consists of 22 multiple-choice questions categorized into four subtopics including propagation, superposition, reflection and standing wave (Tongchai, Sharma, Johnston, Arayathanitkul, & Soankwan, 2009). The second survey is Quantum Physics Conceptual Survey (QPCS), consisting of 25 multiple-choice questions separated into four subtopics—photoelectric effect, waves and particles, de Broglie wavelength, double slit interference and uncertainty principle. QPCS provided an instructor with a valuable resource for evaluating students 'understanding before and after instruction (Wuttiprom et al., 2009). The third survey is Thermodynamic Conceptual Survey (TCS), consisting of 35 multiple-choice questions (Wattanakasiwich, Taleab, Sharma, & Johnston, 2013). The first version of TCS

The TCS had been implemented both in Thailand and in Australia to evaluating thermodynamic understanding of college students before and after an instruction using traditional approach versus active-learning approach (Wattanakasiwich et al., 2013; Georgiou & Sharma, 2015).

However, general multiple-choice questions can have limitations in terms of providing in-depth information on students' reasoning which can help physics education researchers understand characteristics of student misconceptions. Therefore, there is an emerging trend in science education to develop two-tier multiple choice tests in order to obtain more information about students' understanding. The two-tier tests usually consist of a content tier and a reasoning tier which have been found to provide significantly better results in terms of student misconceptions as compared with traditional multiple-choice questions (Tan et al., 2002; Tüysüz, 2009). In wider physics education, many researchers have also tended to construct conceptual surveys using two-tier multiple-choice questions including a study of floating-sinking, buoyancy and pressure concepts (Şahin & Çepni, 2011), secondary students' understanding of wave (Caleon & Subramaniam, 2009), and student ideas of thermodynamics (Rollnick & Mahooana, 1999).

Treagust found that conceptual tests composed of two-tier multiple-choice questions had the potential to make a valuable contribution to researching students' conceptions because of two major benefits over typical multiple-choice questions (Treagust, 1995). Firstly, they allow for probing two aspects of the same phenomenon. Students are asked to predict an outcome of a certain situation in the first tier and to provide their reasoning in the second tier. Students' reasoning provides details of their alternative concepts. Secondly, they reduce measurement uncertainty from students' random guessing. While students have a 25% chance of guessing correctly in a question with four choices, in two-tier questions, students have to respond correctly on both tiers, so they have only a 6.25% chance of guessing correctly.

Two-tier multiple-choice questions were found to be a good instrument to diagnose predominant alternative conceptions (Treagust, 1995). During the past two decades many studies in science education have emphasized alternative concepts (AC) in physics (Driver, 1981; Gilbert & Watts, 1983; McDermott, 1984; Maurines, 1992).These alternative concepts have been defined as misunderstandings, misinterpretation of fact, misleading ideas (Barrass, 1984) and as private concepts and naïve theories (Mintzes, 1984). These studies have given strong confirmation of the importance of ideas in the understanding of important concepts in physics. A well-designed two-tier test was used to identify AC and allows the instructor to detect student physics understanding more easily than other methodologies such as concept maps or clinical interviews (Odom & Barrow, 1995).

There are few two-tier conceptual tests on topics in thermal physics, so in this study, we developed, implemented and evaluated a conceptual; survey covering the three fundamental laws of thermodynamics, called Thermodynamic Diagnostic Test (TDT). This test was modified from TCS2.1, a conceptual test consisting of 15 multiple-choice questions (Kamcharean & Wattanakasiwich, 2014).

Purpose of study

This study has two objectives, firstly, we developed a two-tier Thermodynamic Diagnostic Test or TDT based on a previous Thermodynamic Conceptual Survey (TCS) (Wattanakasiwich et al., 2013) and results from interviewing students. Secondly, we used the TDT to diagnose the first year students taking a fundamental physics course at Chiang Mai University (CMU) in 2012 and 2013.

Methodology

Development of the two-tier diagnostic test

The development of this test used both quantitative and qualitative methods. The TDT was constructed based on one tier of questions from TCS. The development consisted of two phases with eight steps, as shown in the figure 1.

Phase I

Both correct and incorrect student responses to the one-tier TCS were analyzed. Item numbers 1, 4, 7, 8, 9, 10, 32, 33 and 34 were then selected to be developed into two-tier questions. However, the TCS covered only the 0^{th} and the 1^{st} law of thermodynamics. For the 2^{nd} law, results from previous physics education research studies were analyzed and used to create two-tier questions (Christensen, Meltzer, & Ogilvie, 2009). Finally, the TDT consisted of 15 two-tier questions, aiming to detect predominant ACs for the three laws. These ACs indicated students' difficulties in learning thermodynamics. These ACs were classified into the zero, first and second law as indicated in Table 1.

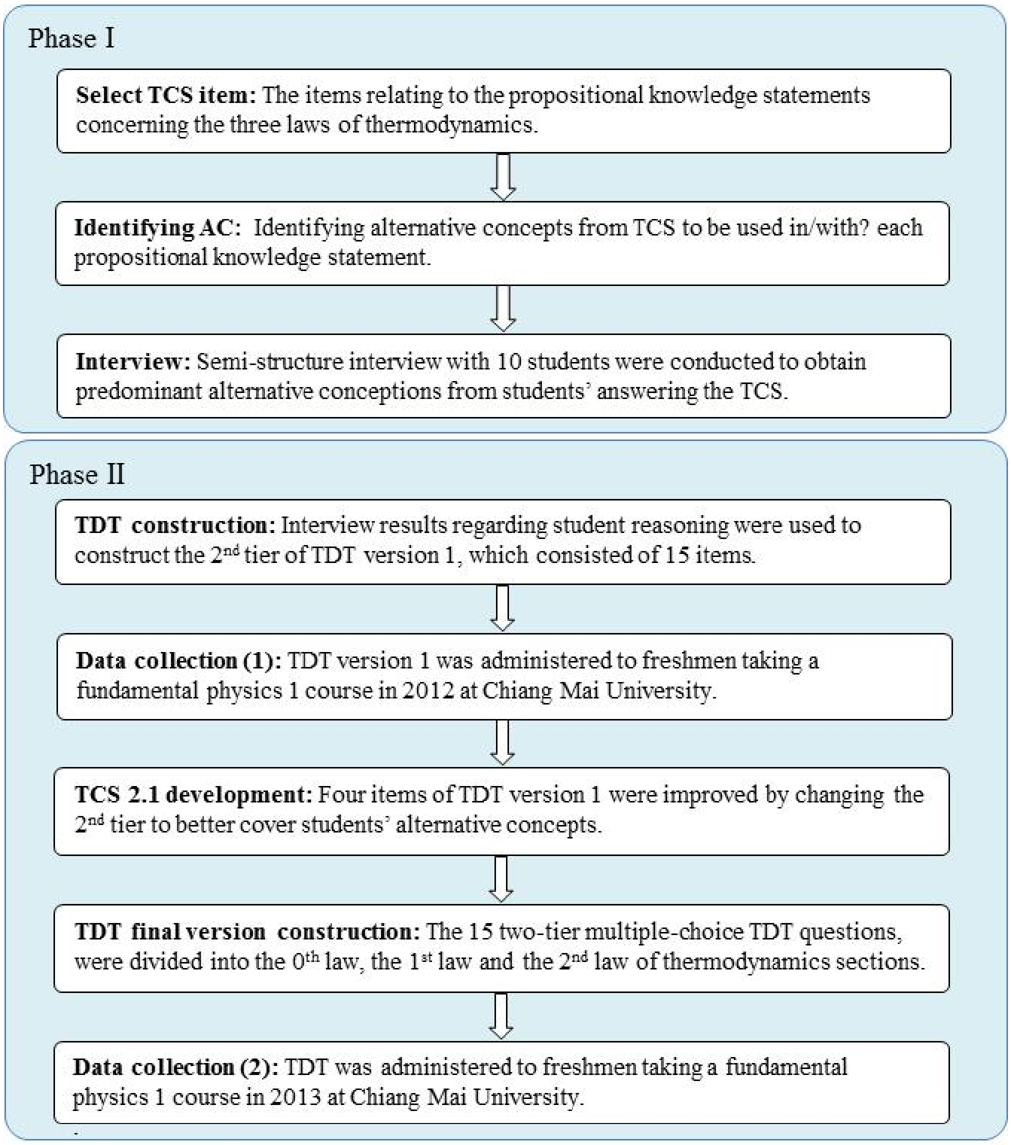


Figure 1. Diagram displaying steps in the TDT development process

Table 1: Significant Alternative Concepts covered in the TDT

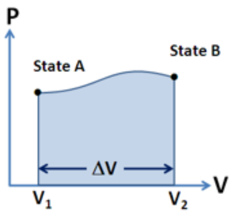
Areas of alternative concept (AC)	item
The zeroth law of thermodynamics	
AC1) Temperature is the amount of heat contained in a body (Kesidou & Duit, 1993).	2,4
AC2) If there is heat transfer into (out of) an object, then its temperature increase (decrease) (Bodner, 1991; Thomaz, Malaquias, Valente, & Antunes, 1995).	3
The first law of thermodynamics	
AC3) The work done depends only on the initial and final states of the system. Work is a state variable (Meltzer, 2004).	5

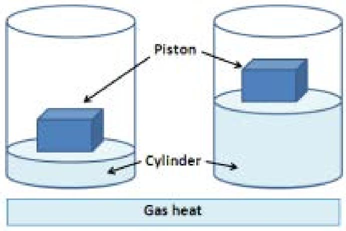
Areas of alternative concept (AC)	item
AC4) Temperature is an indicator for a change in internal energy (Kesidou & Duit, 1993).	6
AC5) Heat transfer is independent of process, depends only on the initial and final states (Meltzer, 2004).	7
AC6) Temperature increase caused the pressure to increase (Rozier & Viennot, 1991).	9
The second law of thermodynamics	
AC7) According to the second law the entropy of the system must increase (Thomas & Schwenz, 1998) for any spontaneous process (Granville, 1985).	11,14,15
AC8) An increase (decrease) in entropy means an increase (decrease) in temperature (Johnstone, Macdonald, & Webb, 1977).	11,12
AC9) In the real process, the entropy of the system plus that of the environment remains the same (Christensen, Meltzer, & Ogilvie, 2009).	13

Identifying propositional knowledge, which is composed of four parts, syntactic (learning equations, vocabulary etc.) semantic (linguistic sense, how to use the vocabulary etc.), schematic (structural awareness, similarities and differences between categories) and finally there is strategic knowledge (Odom & Barrow, 1995) is essential to developing an effective test. A course outline and objective for Fundamental Physics 1 course was used to generate propositional knowledge statements. These statements were then paired with corresponding items in the TDT. The 18 propositional knowledge statements required for TDT are shown in Table 2.

Table 2: Propositional knowledge statements and corresponding item number for TDT

Propositional knowledge statements	Item
(1) Heat transfer is normally from a higher to a lower temperature object.	1
(2) The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius.	1
(3)The amount of heat energy (Q) gained or lost by a substance is equal to the mass of the substance (m) multiplied by its specific heat capacity (c) multiplied by the change in temperature (final temperature - initial temperature: Δt) $Q = mc\Delta t$	1,2,3,4
(4) Water requires twice as much heat to cause the same temperature change in twice the mass of water.	1,2
(5) Specific heat is causing a change of state in the substance that absorbs it. The values for the specific heat of freezing is equal to the mass of the substance (m) multiplied by its latent heat of freezing (L) : $Q = mL$	3,4

Propositional knowledge statements	Item
(6) The work done by a gas at constant pressure is: $W = P\Delta V$ For non-constant pressure, the work can be visualized as the area under the pressure-volume curve which represents the process taking place. The more general expression for work done is: $W = \int_{V_1}^{V_2} PdV$  	5
(7) Internal Energy: U is energy stored in a system at the Molecular Level.	6
(8) The change in internal energy of a system is equal to the heat added to the system minus the work done by the system. $\Delta U = \Delta Q - \Delta W$ when ΔU = change in internal energy, ΔQ = heat added to the system and ΔW = work done by the system	6
(9) Heat Energy transfer across the system's boundaries cannot produce macroscopic-mechanical motion of the system's center-of-mass. Energy transfer at the molecular level	7
(10) Common types of heat transfer: Solids or Liquids $Q = mc\Delta t$, $Q = mL_f$, $Q = mL_V$ Gas- Constant Pressure Process $Q = mc_P\Delta t$ Gas - Constant Volume Process $Q = mc_V\Delta t$ $Q = PV \ln\frac{V_f}{V_i}$ Gas - Constant Temperature Process Gas - Adiabatic Process $Q = 0$	7
(11) When the gas temperature is increased by the heat addition while the gas is allowed to expand so that its pressure is kept constant, the gas volume will increase according to Charles' law.	8
(12) Isobaric is a process where the pressure of the system is kept constant $\Delta P = 0$.	9
(13) The first figure shows an example of an isobaric system, where a cylinder with a piston is being lifted by a quantity of gas as the gas gets hotter. The gas volume is changing, but the weighted piston keeps the pressure constant.	10

Propositional knowledge statements	Item
	
(14) The 2nd law of thermodynamics states that the total entropy of the universe will increase in any real process. The universe can be divided into two regions, a system and its surroundings.	11,12,13
(15) The entropy of the surroundings must increase as a consequence of the 2nd law.	11,12,13
(16) The total entropy either increasing or remaining the same.	14,15
(17) There is no constraint on the change in entropy of either the system or the environment, so the entropy of either one may be increase or decrease.	14,15
(18) The sum of two entropy changes must be positive.	14,15

To develop the second-tier questions, the researcher conducted semi-structured interviews with ten second-year physics students who had taken an advanced thermodynamics course. The interview questions were selected from TDT items to probe student reasoning. Student explanations in the interview were analyzed in terms of their reasons regarding the three laws of thermodynamics and these reasons were then developed into the reasoning tier of the test.

Phase II

TDT version 1 was administered to 48 first-year students taking the fundamental physics course at CMU in 2012. The student responses were used to improve the second reasoning tier, so the improved test was called TDT. This test was then administered as pre and post-test to 46 students taking fundamental physics I during the 2nd semester of 2013 and the summer of 2013. The students had 30 minutes to finish the test. They were informed that they would receive class credits for doing the test but in fact their test scores did not affect their course grades. After administering the test, five student responses were not analyzed because of incompleteness.

Treatment of data

In this study, both qualitative interview data and quantitative students' responses were analyzed. Interviews were transcribed and analyzed using content analysis. Students' reasoning and explanations during interviews were used as the main resource for developing distractors in the second tier. For qualitative analysis of students' responses on TDT, two scores were calculated per question and each item was only considered to be correctly answered if a student correctly responded to both parts of each item. This interpretation of test score that have been assigned a code number for each of the following are summarized in Table 3. (Kamcharean & Wattanakasiwich, 2014).

Table 3: The numbers from the code of the test results

		1st tier (Content)	
		2 = Correct	0 = Incorrect
2nd tier (Reasoning)	1 = Correct	3	1
	0 = Incorrect	2	0

The numbers obtained from the answers of the test represent to

3 = correct content tier and correct reason tier
2 = correct content tier but incorrect reason tier
1 = correct content tier but correct reason tier
0 = incorrect content tier and incorrect reason tier

The answer sheets of the students were analyzed. Following the procedure each item was considered to be correctly answered if students correctly responded to both parts of the item. In addition, the data collected from interview in the previous steps were used to modify the reasoning tier of the TDT version 1 and the feedback from TDT version 1 was used to develop the TDT.

Results and Data analysis

The data analysis was divided into three parts-overall analysis, test item analysis and analysis of student reasoning. Firstly, student test responses were analyzed in terms of descriptive statistics (as shown in Table 4) and test reliability (as shown in Table 5). Secondly, each item was analyzed and linked to alternative conceptions in thermodynamics, as shown in Table 6. Lastly follow-up interviews with seven students were conducted to deepen our understanding of student reasoning. These students were randomly selected and were asked to explain the reasoning they used to select their answers in the TDT. Each interview took about 20 minutes. The interview results provided more information to help us better understand student reasoning.

Descriptive Statistics

In this analysis, student responses to each item were considered to be correct only if both tiers were correct. In Table 4, all groups had higher scores on post-test compared with pre-test.

The reliability of TDT was determined using Kuder-Richardson reliability (*KR-20*), Cronbach's alpha (α), proportion of agreement (P_0), and Cohen's Kappa (κ_0). Table 5 displayed reliability of TDT compared with acceptable values.

Table 4: Descriptive statistics of student responses on TDT

Parameter	Statistic							
	2012		2013		2013-3rd		Overall group	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Number of cases	48	48	46	46	15	15	109	109
Number of items	15	15	15	15	15	15	15	15
Total score	15	15	15	15	15	15	15	15
Mean	7	9	6	9	6	7	6	8
Median	7	9	6	9	7	8	7	9
Mode	7	8	6	11	8	9	7	8
Minimum	1	5	4	4	3	5	1	4
Maximum	13	14	13	13	10	10	13	14
Standard deviation	2.19	1.98	2.00	2.26	2.37	1.46	2.12	2.07

Table 5: The reliability of TDT with a range of statistics *(N = 109)*

Reliability	statistics	Acceptable value	TCS2.2
Internal consistency	*KR-20*	*KR-20* $\geq$ 0.70	
	Pre-test		0.62
	Post-test		0.77
	Cronbach's alpha(α)	$0.70 \leq \alpha < 0.80$	
	Pre-test		0.68
	Post-test		0.92
Consistency of decision	Proportion of agreement (P_0)		0.53
	Cohen's Kappa (κ_0)	$0.41 \leq \kappa_0 < 0.60$	0.44

KR-20 for pre-test and post-test are in a moderate range compared with the acceptable value of *KR-20* $\geq$ 0.70 (Ding & Beichner, 2009). The reliability, in term of Cronbach's alpha (α), for the content tier was acceptable for criterion-referenced tests (Bland & Altman, 1997). The consistency of decision that can be calculated were Cohen's Kappa (κ_0) and proportional of agreement (P_0). The Cohen's Kappa (κ_0) was also with in an acceptable range (Landis & Koch, 1997). These results indicated that TDT has acceptable reliability or this test is reliable.

Item Analysis

The combination of content-tier and reasoning-tier on several items could be used to identify alternative conceptions or ACs, which were confirmed by previous physics education research, as shown in Table 1. As results, student responses related to these ACs deteriorated and the responses related to scientific concepts increased, as shown in Table 6.

Table 6. Significant Concepts of TDT *(N=109)*

Areas of concepts	Content (reason)	% TDT responses	
		Pre-test	Post-test
The zero law of thermodynamics			
AC1) Temperature as the amount of heat contained in a body (Kesidou & Duit, 1993).	Q2A(H) Q4B(G)	20.18 17.43	11.01 15.60
AC2) If there is heat transfer into (out of) an object, then its temperature increase (decrease) (Bodner, 1991; Thomaz et al., 1995).	Q3C(F)	9.17	7.34
The first law of thermodynamics			
AC3) The work done depends only on the initial and final states of the system. Work is a state variable (Meltzer, 2004).	Q5C(G)	25.69	2.75
AC4) Temperature as an indicator for a change in internal energy (Kesidou & Duit, 1993).	Q6A(H) Q6A(G)	12.84 9.17	10.09 2.75
AC5) Heat transfer is independent of process, depends only on the initial and final states (Meltzer, 2004).	Q7C(F)	16.51	4.59
AC6) Temperature increase caused the pressure to increase (Rozier & Viennot, 1991).	Q9A(G)	49.54	20.18
The second law of thermodynamics			
AC7) According to the second law the entropy of the system must increase (Thomas & Schwenz, 1998) for any spontaneous process (Granville, 1985).	Q11A(E) Q14A(E) Q15A(E)	28.44 51.38 38.53	36.70 58.72 26.61
AC8) An increase (decrease) in entropy means an increase (decrease) in temperature (Johnstone et al., 1977).	11A(H) Q12B(E)	12.84 12.84	6.42 11.93
AC9) In the real process, the entropy of the system plus that of the environment remains the same (Christensen et al., 2009).	Q13C(F)	33.03	45.87

Note: For content-reason Q1B (F), the question is Q1, content response is “B” and reasoning is “F”. %TDT refers to a percentage of the total sample who chose the content-reason combination.

Alternative concepts of the zeroth law

Concepts of temperature and heat transfer are essential to understanding the zeroth law. Items 1-4 in the TDT focused on this law and the percentage of correct student responses is shown in Figure 2. The number of correct responses was lowest for items 2 and 4 and this indicated that many students might have alternative concepts. From item analysis, AC1 and AC2 were identified.

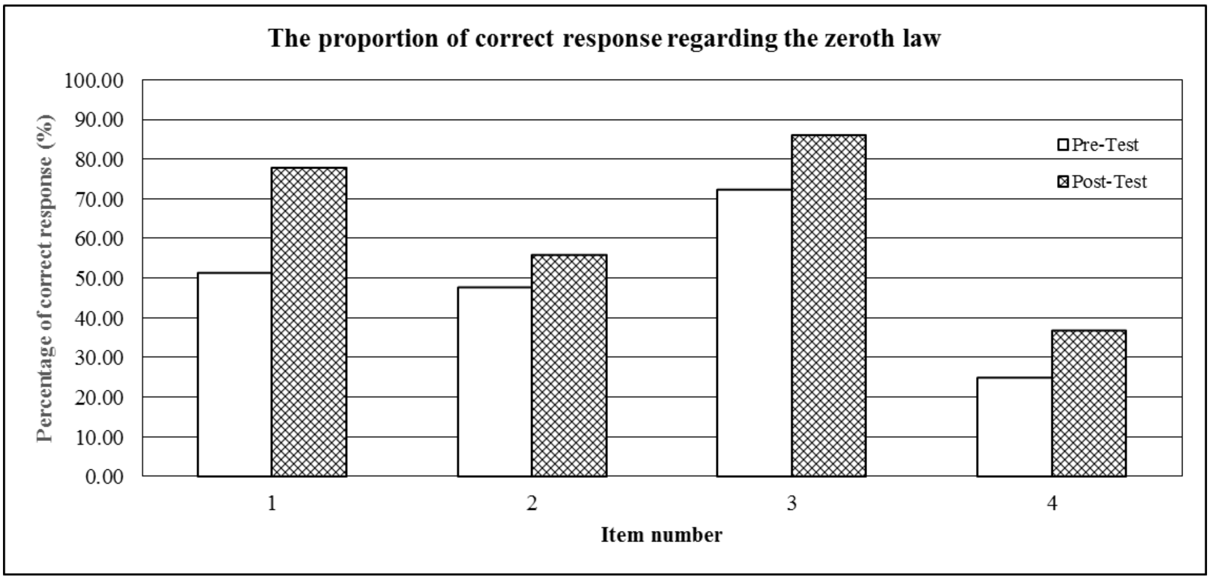


Figure 2. The proportion of correct responses regarding the zeroth law

AC1: Temperature as the amount of heat contained in a body

Previous studies suggest that this AC was rooted in students' views about extensive and intensive properties (Kesidou & Duit, 1993) and their views that heat and temperature are the same (Brook, Briggs, Bell, & Driver, 1984).They then use temperature as an indicator for the amount of heat transfer, or they think that if two bodies are at the same temperature or have the same changes in temperature then they have the same energy or heat. Here are examples of students' reasoning during the follow-up interview. (The notation "S01" refers to student #01, used for students in the interview sample)

"[S01]: If the initial temperature of objects is equal and they are the same type of object or substance, water in this case, then the heat transfer is equal"

"[S04]: The heat transfer does not depend on the mass of the object. Heat transfer is the same if they are the same type of substance, such as water."

Both S01 and S04 disregarded the amount of water. S01only used the initial and final temperature as their reasoning to answer the amount of heat transfer. S04 reduced the complexity of this situation by ignoring water mass. This is a good example of student common reasoning in dealing with a complexity of multi-variable problems, called "functional reduction" (Rozier & Viennot, 1991). When faced with a multi-variable problem, people commonly reduce the complexity by either ignoring some variables or combining variables into a single-variable relationship.

In this case, S04 ignored mass and only considered the type of substance as affecting the heat transfer. This functional reduction reasoning was also found again in students' reasons for answering item 4. They completely ignored surface areas and only considered difference in temperature when considering their answer. These students chose AC1 as their answers to item 2, for example:

“[S02]: Because the first metal block (one block at 200ºC) has a higher temperature than the second block (two blocks at 100ºC), it can melt more ice.”

AC1 was found to be significant and rooted in an inability to differentiate between extensive properties (heat transfer) and intensive properties (temperature). This might also a result from root memorization of the equation $Q = mc\Delta t$ without understanding its condition.

AC2: Heat transfer into an object causes a raise in its temperature

AC2 is similar to AC1 in terms of heat and temperature having a cause-effect relationship. Students with this AC used only temperature to think about the amount of heat transfer into or out of the object. In item 3, students answered that when put into a freezer, both water and ice at 0ºC lost the same amount of heat because both of them have the same initial temperature. The alternative concept was so predominant that they did not consider the phase change. However, this is a minor alternative concept because only a few students exhibited this AC2 (7.3% in post-test and 9.2% in pre-test). All students in the interview answered and reasoned correctly.

Alternative concepts of the first law

The concepts of work, heat transfer and change of internal energy are important to understanding and applying the first law. Items 5-10 in the TDT tested students’ understanding of these concepts and their application to thermal processes. Student correct responses were quite low on the pre-test, as shown in Figure 3. When performing item analysis, four alternative concepts were found.

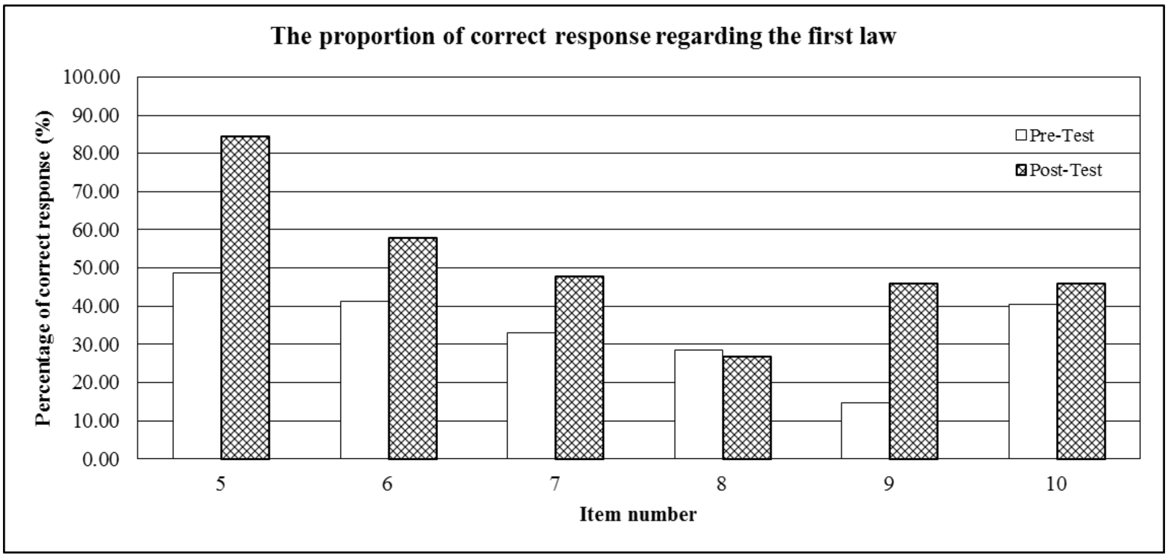


Figure 3. The proportion of correct responses regarding the first law

AC3: The work done depends only on the initial and final states of the system.

Students with AC3 thought that work is a state variable. This AC was found from previous studies (Meltzer, 2004; Loverude et al., 2002; Wattanakasiwich et al., 2013). This concept was rooted from a concept of work done by a conservative force in mechanics. Students then stated that work is independent of path taken like a conservative force. If the final and initial states of each process are identical, then work done in each process is equal (Loverude et al., 2002). Many students also supported their answers by considering related pressure to the work done by system. An example of student reasoning from the interview is as follows:

"[S02]: Work does not depend on path because of this equation, $W = P\Delta V$, so in both processes the same work is done"

Student S02 thought that work is a state variable because of the equation, $W = P\Delta V$. She thought that the value of pressure and volume could be determined from the initial point and the final point in the P-V diagram. However, this AC significantly decreased after Physics instruction.

AC4: Temperature as an indicator for a change in internal energy

Many students used the value of final temperature to consider a change in internal energy. Although internal energy depends on the temperature of a system, the change of internal energy is a state variable. Therefore, one can only use the initial and final temperature to consider the change of energy within a closed system. Students with this AC considered temperature as process dependent. Therefore, they used a path on the PV diagram to determine the change in temperature, so they answered that the change in internal energy of process 1 was higher than process 2 because the overall change of temperature of process 1 is higher than process 2, as this student explained here:

"[S03]: Process 1 has a higher change in internal energy because it has a higher temperature than process 2 [Pointing to the PV diagram]."

AC5: Heat transfer is independent of process, depends only on the initial and final states

Students with AC5 thought that heat transfer is a state variable. This AC might be rooted in AC1 view of temperature as the amount of heat contained in a body. Many students with this AC then answered that the heat transfer into process 1 is equal to process 2 because of the initial point and the final point of the identical.

"[S04]: Heat transfer for both processes is equal because heat transfer does not depend on path and both processes have the same initial and final point. The changes in temperatures are the same, so the heat transfer is the same."

Student S04 used only the change in temperature to consider the heat transfer. This seems to reflect the influence of AC1 on this AC5. However after instruction, most students developed the correct concept that heat transfer is dependent on process and not a state variable.

AC6: Temperature increase caused the pressure to increase

This is a major alternative concept in thermodynamics and was found in many previous studies (Kautz et al., 2005a; Rozier & Viennot, 1991; Jaisen & Oberem, 2002; Madden, Jones, & Rahm, 2011; Wattanakasiwich et al., 2013). When asked to compare the pressure of the gas inside a glass syringe with a frictionless piston when moving the syringe from cold water to hot water, most students gave the common incorrect answers that the final pressure would be greater than the initial pressure, as in previous studies (Kautz et al., 2005a; Rozier & Viennot, 1991). They provided the reason that pressure is directly proportional to temperature. This is an example of student reasoning during the interview.

"[S01]: From the equation, $PV = nRT$, pressure is directly proportional to temperature. So when temperature increases, pressure will increase as well."

This is another case of "functional reduction" reasoning. When students had to use the ideal gas law to make a prediction, which is a multiple-variables situation, they only considered the gas temperature as a variable and ignored other parameters (Rozier & Viennot, 1991). This AC is quite hard to change, as about 20% of students still held this view after instruction.

Alternative concepts of the second law

The concepts of a change in entropy and its relationship to heat transfer and temperature are central to understanding and applying the second law. Items 11-15 in the TDT tested students' understanding of these concepts and their correct responses were lowest, as shown in Figure 4. When performing item analysis, three alternative concepts were found.

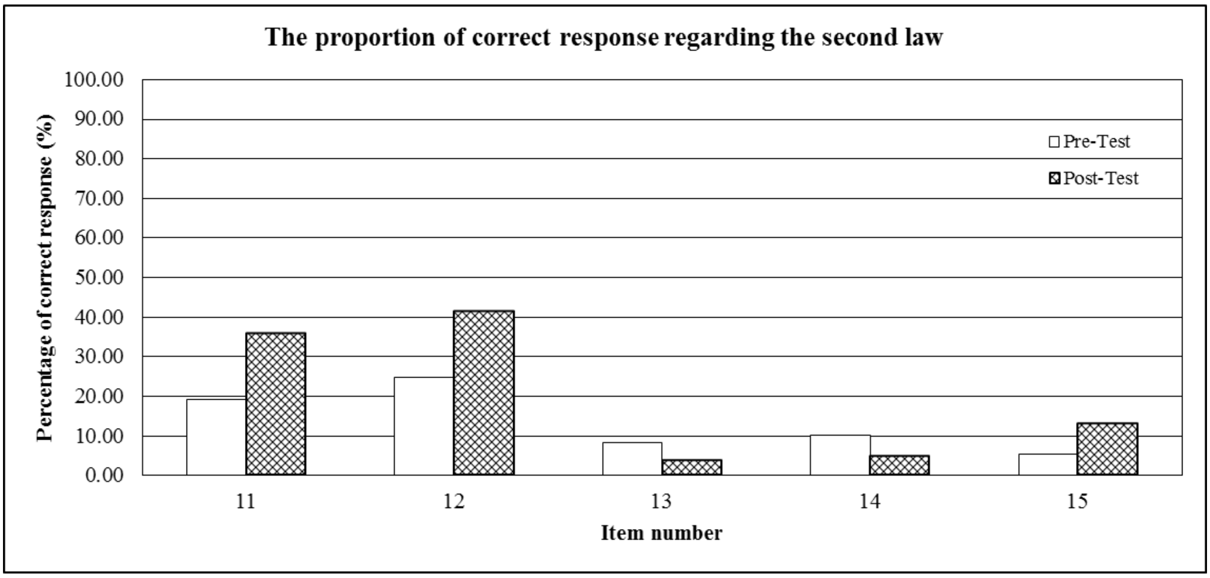


Figure 4. The proportion of correct responses regarding the second law

AC7: According to the second law the entropy of the system must increase

Students always think that the entropy of a system must increase without considering the processes in that system. This AC was highlighted out from student interview responses to item 11, 14 and 15, for example.

"[S05]: (Entropy) increases because a change in entropy must always increase."

Christensen (2009) found that most students held alternative concepts that the entropy of any system must increase. From our results, we found that many students thought that the entropy must increase because they related that to an increase in temperature. They confused the entropy of the system with the total entropy, or the entropy of the system plus surroundings.

Many students also used this AC7 to answer item 14 and 15. When asked about an isolated system, students with this AC7 answered that the system entropy has to increase and the total entropy has to be zero. These are examples of student reasoning.

"[S02]: Total entropy has to be zero because the system is isolated."

"[S03]: The entropy of the system has to always increase."

Many students also used this AC to answer about the entropy of an isolated system undergoing an irreversible process.

AC8: An increase (decrease) in entropy means an increase (decrease) in temperature

This AC was a result of students relating temperature to the change in entropy. Students with this AC answered both item 11 and 12 with the same reasoning that the entropy of the system and surroundings depends on its temperature. In item 11, students were asked to predict the entropy of a system undergoing a spontaneous process. Many students answered that the entropy of the system increases because of the increase in temperature, for example:

"[S01]: Entropy of system increases because temperature tends to increase during the process."

The same students with this AC also answered item 12 with the same reasoning, so the percentage of student responses in Table 5 for Q11A(H) and Q12B(E) are the same. These students also answered that the entropy of the surrounding decreases because temperature decreases, as this student explained:

"[S04]: Entropy of surrounding decreases because its temperature decreases."

It is unclear why students used temperature to think about entropy (Johnstone et al. 1977). They perhaps used AC1 to relate temperature to heat transfer and then to the change in entropy. On the other hand, they perhaps though that when the temperature of the system increases, the kinetic energy or the internal energy increases, so the molecules in the system could move more freely, which indicates an increase in disorder of the system which most students think of as increase in entropy.

AC9: The entropy of the system plus that of the environment remains the same in the real process

This is an alternative concept which more students held after instruction. Students with this AC answered that the total entropy remains the same in a real process. They provided reasoning that the total entropy of a real process has to be zero. The results from the interview did not reveal further details about their thinking. Therefore, this has to be studied further because it seems that students might have constructed this alternative concept from unclear explanation in the physics class.

Conclusions and Discussion

In this study, we successfully developed the Thermodynamic Conceptual Test or TDT, which is a two-tier multiple-choice test with 15 questions. Test reliability was established using multiple methods. The TDT was then implemented to diagnose alternative concepts of the first year students taking a fundamental physics course at Chiang Mai University in 2012 and 2013. Follow-up interviews with seven students were conducted to provide more details about the alternative concepts.

Nine alternative concepts were identified from students' responses to the second-tier of the test. The predominant alternative concepts are AC1 (Temperature is the amount of heat contained in a body), AC6 (Temperature increase causes the pressure to increase), AC7

(According to the second law the entropy of the system must increase) and AC9 (In the real process, the entropy of the system plus that of the environment remains the same).

To help students become more aware of AC1, physics instructors should emphasize the concepts of extensive quantities (heat transfer) and intensive quantities (temperature). Also, our results support the observation that students seem to use functional-reduction reasoning when encountering multi-variable situations, in this case the specific heat equation and the ideal gas law AC1 and AC6. The instruction regarding these two equations has to be carefully planned to make students aware of their functional-reduction reasoning.

In conclusion, the TDT provides physics instructors with a valuable resource for evaluating student understandings both at the beginning of a thermodynamic course and at the end, and the questions in the test can be used to generate in-class discussion on teaching and learning thermodynamics.

Recommendations for further research

Two-tier multiple choice questions were not only used to determine the level of the students' conception but also the main causes on students' thinking. With the two-tier test, students become more aware of their own knowledge can also be determined. Moreover, two-tiered multiple choice questions can also built relationships between the cause and the result of the knowledge. Similarly, two-tiered multiple choice questions for the different units could also be prepared and applied for determining students' conceptual structure in different concepts.

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Appendix: Thermodynamic Diagnostic Test (TDT)

Directions: For each question, please indicate your answer by circling a choice.

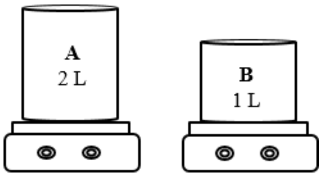
1. Cup A contains 100 grams of water at 0°C but cup B contains 200 grams of water at 50°C. The contents of the two cups are mixed together in an insulated container (no heat transfer occurs). When it reaches thermal equilibrium, what is the final temperature of the water in the container?

A) Between 0°C and 25°C
B) 25°C
C) Between 25°C and 50°C
D) 50°C

Please indicate your reasoning:

E) From calculation $Q_{lost}=Q_{gain}$
F) From finding an average of temperature
G) Water at temperature 50 ^{O}Chas more volume
H) Water at temperature 0 ^{O}Chas less volume

2. 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
D) No heat transfer between cup A and cup B

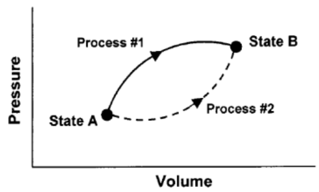
Please indicate your reasoning:

E) From equation $Q = mc\Delta t$, we find that cup A has more heat transfer than cup B
F) Cup A has more mass than cup B
G) Cup A has a bigger volume than cup B
H) Cup A and cup B contain the same substance, water

3. 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 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
D) There is no answer
Please indicate your reasoning:
E) Water must change to ice before it changes temperature
F) Both of them (water and ice) have the same initial temperature (0^{O}C)
G) Ice does not contain any heat
H) Water cannot reach 0^{O}C

4. You want to melt ice at 0^{O}C using hot blocks of metal as an energy source. One option is to use one metal block at a temperature of 200^{O}C and a second option is to use two metal blocks each at a temperature of 100^{O}C. All the metal blocks are made from the same material and have the same weight and surface area. Which option will melt more ice?
A) Both 100^{O}C blocks
B) The 200^{O}C block
C) Both options
D) Not enough information
Please indicate your reasoning:
E) Two blocks have twice as much surface area as 1 block so the energy transfer rate will be higher when more blocks are used
F) Energy transferred is proportional to block mass and the change in block temperature during the process
G) The higher temperature block will melt the ice faster because the larger temperature difference will increase the rate of energy transfer
H) The temperature of the hotter block will decrease faster as energy is transferred to the ice

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.



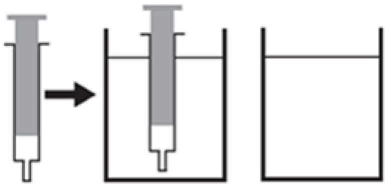
5. Work done by the system in Process # 1 is ________ than Process # 2.
A) greater than
B) less than
C) equal to
D) None of the above
Please indicate your reasoning:

E) Work can be calculated from the area under the P-V curve
F) Work does not depend on the path between the initial and final state
G) Considering the state functions between the initial and final point, if the initial and final points of two processes are the same then the work done has to be the same.
H) More pressure is used in one process

6. 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
D) None of the above
Please indicate your reasoning:
E) The initial and final point of the two paths are identical
F) The internal energy depends on temperature only
G) The temperature of process #1 is greater than process # 2
H) Because $U = \frac{3}{2}nRT$

7. Heat transferred into the system in Process # 1 is ________ than Process # 2.
A) greater than
B) less than
C) equal to
D) None of the above
Please indicate your reasoning:
E) $\Delta Q = \Delta U + \Delta W$ when $\Delta U = 0$ (from equation 6), so $\Delta Q = \Delta W$
F) The initial and final points of the two pathsare identical
G) Heat transfer does not depend on pressure or volume
H) Pressure is increasing

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 the hot water.



8. How does the gas temperature change?
A) Increase
B) Decrease
C) No change
D) Not enough information
Please indicate your reasoning:
E) Energy is exchanged to reach the equilibrium
F) The heat is transferred from the cylinder to the gas
G) The heat is transferred from the gas to the cylinder
H) At thermal equilibrium, temperature does not change

9. How does the gas pressure change?
   A) Increase
   B) Decrease
   C) No change
   D) Not enough information

Please indicate your reasoning:
   E) Temperature does not affect the pressure
   F) According to the equation $T_2 / T_1 = \left[P_2 / P_1 \right]^{\frac{(\gamma-1)}{\gamma}}$
   G) Pressure is directly proportional to temperature
   H) Heat makes volume increase but pressure is stable

10. How does the gas volume change?
   A) Increase
   B) Decrease
   C) No change
   D) Not enough information

Please indicate your reasoning:
   E) Heat causes the gas to expand
   F) According to the equation $\left[P_2 / P_1 \right]^{\frac{(\gamma-1)}{\gamma}} = \left[V_1 / \mathrm{V}_2 \right]^{\frac{(\gamma-1)}{\gamma}}$
   G)Temperature causes the gas to expand
   H) Pressure causes the gas to expand

For each of the following questions, consider a system undergoing a naturally occurring (spontaneous) process. The system can exchange energy with its surroundings

11. During this process, does the entropy of the system (S_{system}) increase, decrease, remain the same or this is not determinable with the given information
   A) Increase
   B) Decrease
   C) Remain the same
   D) Not determinable from the given information

Please indicate your reasoning:
   E) System can exchange energy with its surroundings
   F) No information is provided about the entropy change of the surroundings
   G) No information is provided of energy transfer between system and surroundings increasing or decreasing
   H) Temperature is increasing

12. During this process, does the entropy of the surroundings ($S_{surrounding}$) increase, decrease, remain the same or this is not determinable with the given information
   A) Increase
   B) Decrease
   C) No change
   D) Not determinable from the given information

Please indicate your reasoning:
   E) Temperature is decreasing
   F) No information is provided of energy transfer between system and surroundings increasing or decreasing

G) There is heat transfer to the surroundings
H) The entropy of the surrounding may increase or decrease

13. During this process, does the entropy of the system plus the entropy of the surroundings ($S_{system}+S_{surrounding}$) increase, decrease, remain the same or this is not determinable with the given information
A) Increase
B) Decrease
C) No change
D) Not determinable from the given information
Please indicate your reasoning:
E) The entropy of the surrounding may increase or decrease
F) The sum of entropy must be zero
G) According to the law of conservation of energy
H) It is in thermal equilibrium

14. A subsystem A is in thermal contact with its surroundings B, which together comprises an isolated system. Consider the following situation:
I. Entropy of system increases by 5J/K; entropy of the surroundings decreases by 5 J/K.
II. Entropy of system increases by 5J/K; entropy of the surroundings t decreases by 3 J/K.
III. Entropy of system increases by 3J/K; entropy of the surroundings decreases by 5 J/K.
IV. Entropy of system decreases by 3J/K; entropy of the surroundings increases by 5 J/K.
Which of the above four situations can actually occur in the real world?
A) I only
B) II only
C) III only
D) II and IV only
Please indicate your reasoning:
E) The sum of entropy must be zero
F) The sum of entropy is more than 2J/K
G) The sum of entropy is less than 2J/K
H) The entropy of system is higher than the entropy of the surroundings

15.A subsystem A is in thermal contact with its surroundings B and they together comprise an isolated system that is undergoing an irreversible process. Consider the following situation:
I. Entropy of system increases by 5J/K; entropy of the surroundings decreases by 5 J/K.
II. Entropy of system increases by 5J/K; entropy of the surroundings decreases by 3 J/K.
III. Entropy of system increases by 3J/K; entropy of the surroundings decreases by 5 J/K.
IV. Entropy of system decreases by 3J/K; entropy of the surroundings increases by 5 J/K.
Which of the above four situations can actually occur?
A) I only
B) II only
C) III only
D) II and IV only
Please indicate your reasoning:
E) The sum of entropy must be zero
F) The sum of entropy is more than 2J/K
G) The sum of entropy is less than 2J/K

H) The entropy of system is higher than the entropy of the surroundings