CHAPTER 7

Results and Discussion on Physics Education Research

This chapter presents results from conducting physics education research (PER), as the PER methodologies were described in the previous chapter. The PER methodologies included model analysis of the Thermodynamics Conceptual Survey (TCS), the developmental process of ILDs and Thermodynamic Diagnostic Test (TDT). In this chapter, results of PER are described and discussed.

7.1 Thermodynamics conceptual survey

In this part, student responses on the TCS were analyzed using the model analysis. The responses were from 73 students taking pre-test and post-test during a fundamental physics I course at Chiang Mai University, Thailand. This course consisted of three hour traditional lectures per week. The class homework was traditional textbook problems and assigned with weekly readings. Seven TCS questions [Question 9 - 15] were analyzed with the model analysis, as an example to demonstrate the model estimation algorithm. The item-based modeling scheme is shown in Table 7.1.

Table 7.1 Associations between the physical models and the choices of the seven TCS questions on the Thermodynamics conceptual survey

Questions	Model 1	Model 2	Model 3
9	c	a	b
10	a	c	b
11	c	a	b
12	c	a	b
13	a	b	c
14	a	b	c
15	b	a	c

Then students' responses were analyzed with the procedures as in Equations (1) – (7), and then the average model state regarding thermodynamic concepts was calculated. The results in terms of class density matrix and its eigenvalues and eigenvectors are shown in Table 7.2.

Table 7.2. Results of class model density matrices and class model states on the thermodynamics concept with data from Chiang Mai University students.

Results	Pre			Post		
Class Density matrix	$\begin{bmatrix} 0.27 & 0.15 & 0.23 \\ 0.15 & 0.13 & 0.13 \\ 0.23 & 0.13 & 0.20 \end{bmatrix}$			$\begin{bmatrix} 0.25 & 0.18 & 0.21 \\ 0.18 & 0.16 & 0.17 \\ 0.21 & 0.17 & 0.21 \end{bmatrix}$		
Eigenvalues	0.56	0.04	0.01	0.59	0.02	0.01
Eigenvectors	$\begin{bmatrix} 0.69 \\ 0.42 \\ 0.59 \end{bmatrix}$	$\begin{bmatrix} 0.33 \\ -0.91 \\ 0.26 \end{bmatrix}$	$\begin{bmatrix} 0.64 \\ 0.02 \\ -0.76 \end{bmatrix}$	$\begin{bmatrix} 0.64 \\ 0.50 \\ 0.58 \end{bmatrix}$	$\begin{bmatrix} 0.77 \\ -0.48 \\ -0.42 \end{bmatrix}$	$\begin{bmatrix} 0.07 \\ 0.72 \\ -0.69 \end{bmatrix}$

There were considered three models for analysis: (1) gas process model, (2) reducing the number of variables model, and (3) null models. The results are shown in Table 7.2. As there can see from this table, the eigenvalues for the class states corresponding to the null models are very small. This indicates that most students use either the correct model or the incorrect model and the model space defined from the qualitative research matches with this population. In addition, the primary class model states have eigenvalues around 0.6.Using the results in Table 7.2. The class model states on the thermodynamics concept are displayed on a model plot spanned by model 1 [correct model] and model 2 [incorrect model].

The class model states or eigenvectors with dominant eigenvalues can be represented as a class model point on the model plot with a coordinate (P_1, P_2). From Table 7.3, vertical and horizontal components for pre/post class model point are calculated

Table 7.3 Pre and post dominant eigenvalues, class model eigenvectors and vertical/horizontal components for the class model point

Results	Pre	Post
Eigenvalues	0.56	0.59
Eigenvectors	$\begin{bmatrix} 0.69 \\ 0.42 \\ 0.59 \end{bmatrix}$	$\begin{bmatrix} 0.64 \\ 0.50 \\ 0.58 \end{bmatrix}$
Model Point		
A vertical component	$P_1 = (0.56)^2(0.69)^2 = 0.15$	$P_1 = (0.59)^2(0.64)^2 = 0.14$
A horizontal component	$P_2 = (0.56)^2 (0.42)^2 = 0.05$	$P_2 = (0.59)^2 (0.50)^2 = 0.09$

The class model state for pre and post-test were plotted, as in Figure 7.1. These can be interpreted that before instruction most students used the incorrect model on all the questions related to reducing the number of variables in thermodynamics process. After instruction, the model state indicates that most students still used the incorrect model rather consistently.

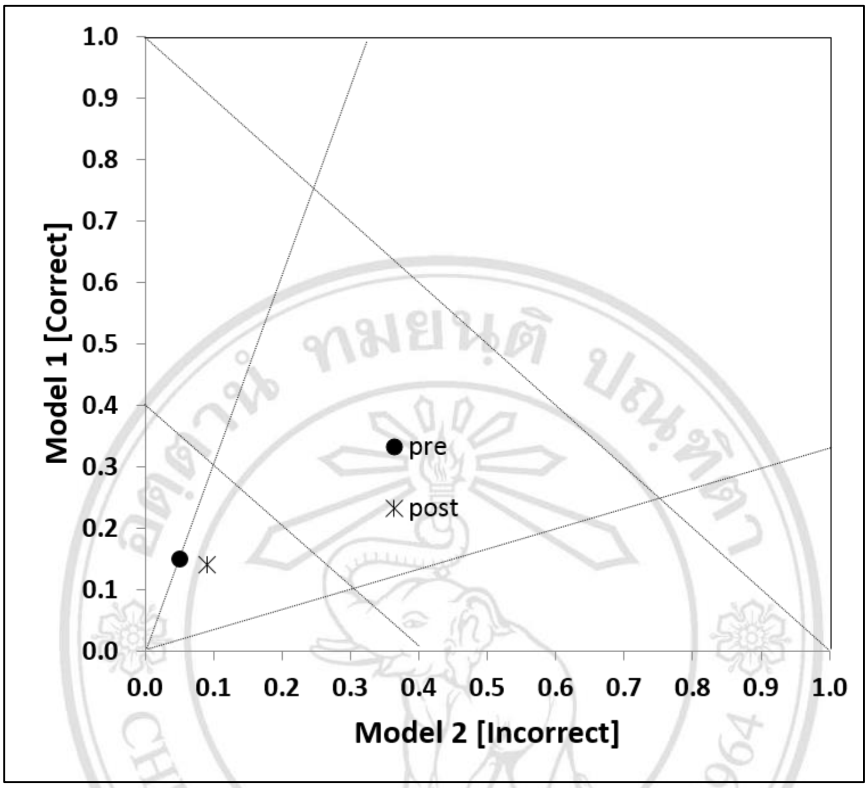

Figure 7.1 Model plot comparing between pre- and post-class model points

From the model plot in Figure 7.1, the post-class model point is located in the model 2 region. This indicates that most students in the class still had a misconception about thermodynamics. Due to the model analysis, the characteristics of this misconception are known, so an instructor can use this information to improve teaching of this class. A small shift of post-class model point towards the incorrect model indicated that an instruction did not improve overall class understanding in this topic.

7.2 Physics education results for Seebeck effect demonstration

In this section, results of using Seebeck effect demonstration are presented and discussed into two parts. First, students' written responses on the worksheet were analyzed and reported. Second, results of student satisfaction on learning with this demonstration were reports. The results were from the thermoelectric effect satisfaction questionnaire which was given to students after the instruction.

7.2.1 Student responses on Seebeck effect demonstration

Students' completed worksheets were analyzed in terms of 1) their prediction, discussion and 2) their synthesis.

1) Student prediction and discussion the result of demonstration 1 and 2
For the results of the prediction, students were used the thermal properties and electrical properties to explain their results. They gave their explanation as follow:

"The demonstration 1 used the same material, electrons and holes have the same mobility, so the potential difference is zero"

"The demonstration 2, for the difference material, there are different thermal conductivity, so they have the potential difference"

They were used the thermal properties and electrical properties of materials to predict the results. It seems that the most of students have the correct prediction on both demonstrations. Their predictions are shown in the Table 7.4.

Table 7.4 Statistics of student predictions on the demonstration 1 and 2

Demonstration	Prediction result on electric potential difference (ΔV) (*N=40*)		
	$\Delta V > 0$	$\Delta V = 0$	$\Delta V < 0$
1	29.2%	58.3%*	12.5%
2	70.8%*	12.5%	16.7%
			* correct prediction

2) Student synthesis for improving the experiment
In the worksheets, students were asked to provide alternative ways to improve results of the experiment. Their written explanations are as follow:

"To improve the results of experiment, the materials have to have high purity and have the same cross section area"

"The materials were doped to improve their thermal conductivity and electrical conductivity"

"The materials have low resistivity, the conductivity was high, and so the potential difference was high too"

"The high thermal conductivity materials were selected because they caused electron to have high kinetic energy, so the electric potential difference was high too."

สังเคราะห์ที่ 1: ถ้านักศึกษาต้องปรับปรุงการทดลองนี้ให้ดีขึ้น นักศึกษาต้องเปลี่ยนวัสดุให้มีสมบัติเชิงความร้อนและสมบัติเชิงไฟฟ้าที่มีลักษณะเป็นเช่นไร?

1.) วัสดุที่ในการทดลองจะมีค่าสัมประสิทธิ์การนำความร้อนที่มาก เพื่อให้เกิดการนำไฟฟ้า

2.) วัสดุที่ต้องเป็น SuperConductor ตัวนำยิ่งยวด (R = 0) เพื่อไม่ให้เกิดค่าความต้านทานรบกวนระบบหรือเกิดให้น้อยที่สุด

3.) ควบคุมอุณหภูมิ ให้มีความแม่นยำ ไม่มีสิ่งแวดล้อมมารบกวนการทดลอง

Figure 7.2 An example of student written explanation to improve the demonstration results (in Thai)

In conclusion, most of the students had partially correct concepts of Seebeck effect. Most students only considered either thermal conductivity or the electrical conductivity.

7.2.2 Student's response on thermoelectric effect satisfaction questionnaire

After finished the ILD, students were asked to fill in the thermoelectric effect satisfaction questionnaire, which is a Likert-scale questionnaire. The full questionnaire can be found in an appendix T. Results of average students' satisfaction level on each statement in the questionnaire are shown in Table 7.5.

Table 7.5 Summary of student responses on the thermoelectric effect satisfaction questionnaire

No.	Details	Average	S.D.	Designation
1.	The difficult level of the thermoelectric effect ILDs is suitable.	4.27	0.67	Satisfied
2.	After this activity, the thermoelectric effect ILDs helps me understand the thermal properties and electrical properties.	4.31	0.79	Satisfied
3.	The question in the worksheet helps me understand the Seebeck effect phenomena.	4.00	0.75	Satisfied
4.	This activity makes me become enthusiastic and interested in physics and materials science.	4.31	0.74	Satisfied
5.	I can exchange an opinion with friends and learn to work as a group.	4.04	1.00	Satisfied
6.	Time spent in finishing the thermoelectric effect ILDs is suitable.	4.00	0.85	Satisfied
7.	Thermoelectric effect ILD is interesting and challenging.	4.27	0.72	Satisfied
8.	Thermoelectric effect ILD is related to the lecture.	4.42	0.64	Satisfied

Table 7.5 (continued)

No.	Details	Average	S.D.	Designation
9.	Thermoelectric effect ILD helps me understand and apply physics and materials concepts to explain the Seebeck effect phenomena.	4.23	0.71	Satisfied
10.	Overall, I satisfy with learning from this thermoelectric effect ILDs.	4.35	0.63	Satisfied
	Overall	4.22	0.75	Satisfied

From the results of the students' ratings (see, Table 7.5), it was found that the overall student satisfaction level was satisfied (Average = 4.22, S.D. = 0.75). This means that students were satisfied with the thermoelectric effect ILDs on the topic of Seebeck effect. The highest satisfaction level was 4.42 which was explained by the students as:

"The thermoelectric effect ILDs are correlated to the content from the lecture".

The lowest satisfaction level was 4.00, and the student wrote that

"The question in the worksheet, the thermoelectric effect ILDs helps me to understand the Seebeck effect phenomena and time spent in the thermoelectric effect ILDs is suitable".

There were no negative feedbacks from students. They were all satisfied with the thermoelectric effect ILDs, but a few students wrote that time was not enough to do this activity, as shown in Figure 7.3. That particular student also suggested that this activity may be used in an electrical properties course (210351). The student found the thermoelectric effect ILDs to be very interesting and should have more activity, especially in the topic of dielectric.

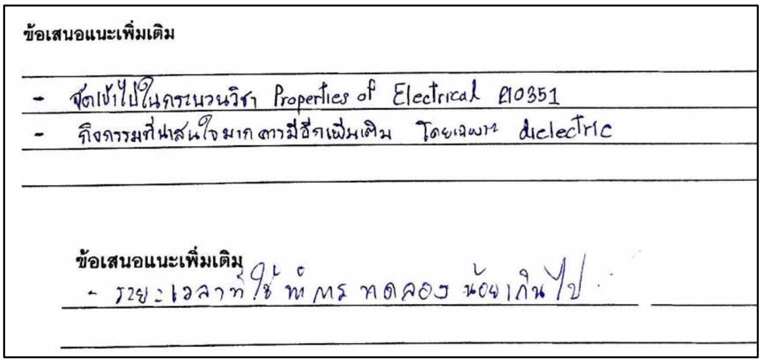

Figure 7.3 An example of student opinion on the thermoelectric effect ILD (in Thai)

7.3 Physics education results for thermodynamics of rubber band

These results are from administering the Thermodynamic Diagnostic Test (TDT) to the student participants in active-learning laboratory on thermodynamics of rubber band. Student responses on both pre and post-test were analyzed statically in terms of arithmetic means, standard deviations, median, mode, minimum, maximum, normalize gain <g>, and KR-20, as shown in Table 7.6. The data was collected in 2013 for a test that was administered to 7 third year students who enrolled in the advance physics laboratory 207314 at the Department of Physics and Materials Science, Faculty of Science Chiang Mai University. The post-test scores are higher.

Table 7.6 Test statistics for student's response on TDT

Parameter	Pre-test	Post-test
Number of cases	7	7
Number of items	15	15
Total score	15	15
Mean	6.43	10.29
Median	5.00	10
Mode	5.00	10
Minimum	3	7
Maximum	10	14
Standard deviation	2.57	2.36
KR-20	0.63	0.66

The average point of the post-test is higher than the pre-test by 3.86. The reliability of TDT was determined by Kuder-Richardson reliability (KR-20) as a pre-test and a post-test were close to 0.70 which was acceptable. The lowest normalized gain <g> was 0.33 , which was still considered to be medium toward high. The percentage of correct responses and normalized gains in all items are shown in Figure 7.4.

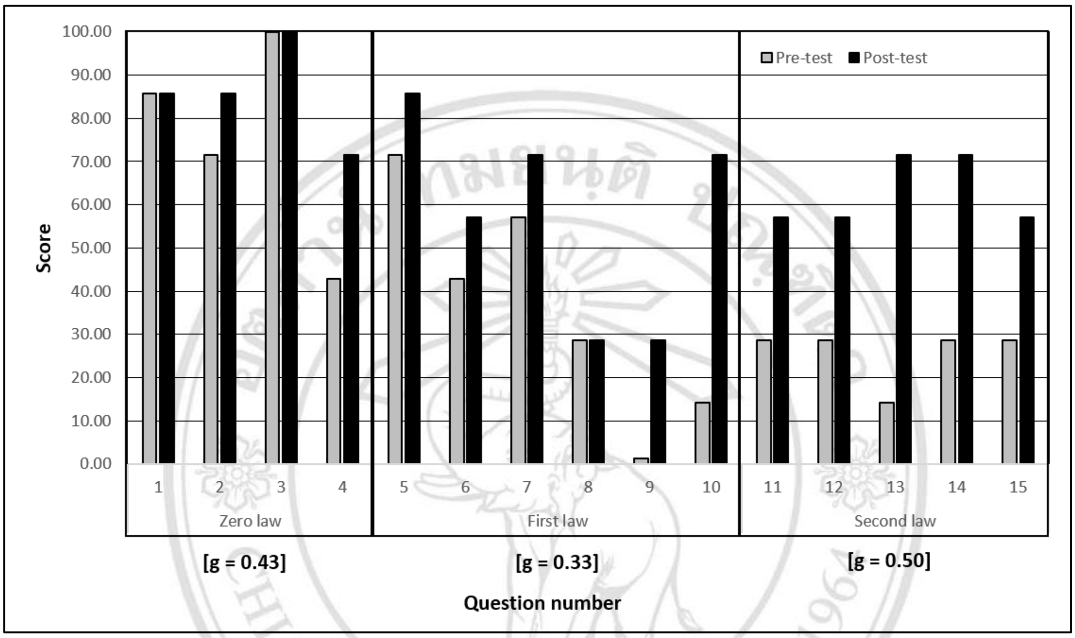

Figure 7.4 Proportion of correct responses in all question of pre and post-test for thermodynamics of rubber band.

The result from TDT showed that the post-test score was higher than pre-test results. The correct responses confirmed that this active-learning laboratory improved students' understanding in thermodynamics. Furthermore, these students were interested in this experiment because it helped them understand other thermodynamic system besides an ideal gas or Vander Waal gas.

7.4 Physics education results for fog in the bottle demonstration

PER results of this demonstration are presented and discussed into two parts. Student predictions were analyzed and discussed in section 7.4.1. Participated students were administered the Thermodynamic Diagnostic Test (TDT). The results were analyzed and discussed in section 7.4.2.

7.4.1 Student's written responses on worksheets

Students' completed worksheets were analyzed in terms of 1) their prediction, discussion and 2) their synthesis. Students were asked to make their predictions and provide their reasoning before observing as shown in the Table 7.7.

Table 7.7 Student predictions and reasoning on fog in the bottle ILD (*correct answers).

State of variable changing	Student predictions		
	Increase	Decrease	Remain the same
Volume	35%*	12%	53%
Pressure	100%	0%*	0%
Temperature	59%	6%*	35%
Thermodynamics process	Student predictions		
Adiabatic process	41%*		
Isochoric process	35%		
Isobaric process	12%		
Isothermal process	12%		

For the volume changing, students provided incorrect answers and reasoning. Most students stated their reasons that volume depends on the volume of the container. They were confused about volume and quantity of the gas in the bottle, for example:

"Volume of gas inside the bottle remain the same because of the volume of bottle does not change."

"When the electric air pump was operated, the pressure of gas in the bottle increase, the volume decrease by the relation $P\alpha\frac{1}{V}$."

For the pressure changing, all of students provided incorrect answers because they were confused between the initial and final states of gas. They do not consider the result after the stopper was suddenly released, for example:

“The pressure increasing caused the stopper to expose.”

For the temperature changing, most of students provided incorrect answers because they were considered temperature depends on pressure. They thought about temperature relate pressure by the relation $P\alpha T$, for example:

“The gas particles were closed up and collide with each other frequently, then the internal energy of gas increase, so the temperature of gas increase too.”

For type of thermodynamics process, most students made correct predictions but provided incorrect reasoning. Most reasoning of students indicated that they were considered the state variables with ignored the others variable, for example:

“The volume of gas remained the same, so the process is called isochoric process.”

“The temperature of gas does not change, so the process called isothermal process.”

During the demonstration, they were observed the state of variable that displays on the screen. They were collected data and calculated the number of mole, the work done by the gas; the final state of variables, the results of experiment was shown in the Table 7.8.

Table 7.8 The students' results on fog in the bottle ILD.

Variable of state	Initial state	Final state	Changing
Pressure (kPa)	305.76	90.15	Decrease
Volume (cm^3)	1,250.00	2,987.50	Increase
Temperature (K)	301.65	299.75	Decrease
parameters of irreversible adiabatic process			
Number of mole: n	0.15		
Work: Δw (J)	-94.35		
Vapor pressure: P_V (bar)	0.041		
Irreversible adiabatic process			
P_f (kPa)	V_f (cm^3)	T_f (K)	Work w_{Ir} (J)
90.15	2,987.50	299.75	-156.64
Isobaric reversible process			
P_f (kPa)	V_f (cm^3)	T_f (K)	Work w_{re} (J)
90.15	2989.69	212.72	-281.70
Isochoric reversible process			
P_f (kPa)	V_f (cm^3)	T_f (K)	Work w_{re} (J)
90.29	2,987.50	212.88	-281.17

7.4.2 Student responses on TDT

After the students finished the ILDs, they administered on TDT. Student responses on both pre and post-test were analyzed statically in terms of arithmetic means, standard deviations, median, mode, minimum, maximum, and KR-20, as shown in Table 7.9. The data was collected in 2012 for a test that was administered to 17 first year students who enrolled in the fundamental physics 207198 at the Department of Physics and Materials Science, Faculty of Science Chiang Mai University. The post-test scores are higher.

Table 7.9 Test statistics for student's response on TDT

Parameter	Pre-test	Post-test
Number of cases	17	17
Number of items	15	15
Total score	15	15
Mean	3.67	5.33
Median	3.00	5.00
Mode	3.00	6.00
Minimum	2	3
Maximum	7	8
Standard deviation	1.41	1.41
KR-20	0.67	0.79

The average point of the post-test is higher than the pre-test by about 1.66. The reliability of TDT was determined by Kuder-Richardson reliability (KR-20) as a pre-test and a post-test were close to 0.70 which was acceptable. The percentages of correct responses in all items are shown in Figure 7.5. The correct response on items 8-15 are low because TDT is a two-tier multiple-choice test, and most students did not get both content and reasoning tier correctly.

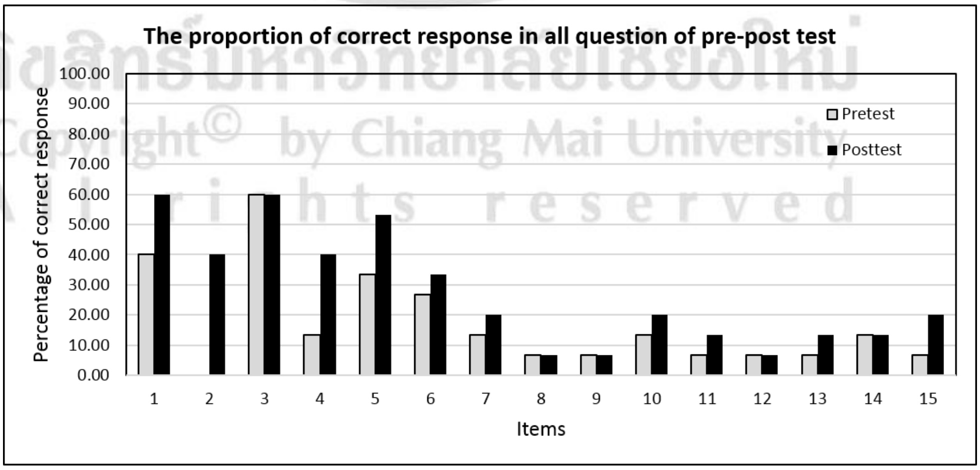

Figure 7.5 The proportion of correct response in all question of pre-post test for fog in the bottle demonstration.

7.5 Physics education results for pee-pee boys demonstration

The results are presented and discussed in two parts. Student predictions were analyzed and were discussed in section 7.5.1. Student opinions on using the pee-pee boys as one of the ILDs presented is compared with other ILDs in section 7.5.2.

7.5.1 Student predictions

Students' completed worksheets were analyzed in terms of 1) their prediction, discussion and 2) their synthesis. Demonstration 1 and Demonstration 2 were described as follows:

Demonstration 1 Ceramic dolls A and B contain room temperature water. When pouring hot water on ceramic doll A and room temperature water on ceramic doll B.

Demonstration 2 Ceramic dolls C and D containing water were submerged in ice-cold water until they were are at thermal equilibrium with the cold water. When pouring hot water on ceramic doll C and room temperature water on ceramic doll D.

Table 7.10 Student predictions and reasoning on Demonstration 1 and 2. (*correct answers)

Reasoning	Student predictions			
	Demonstration 1		Demonstration 2	
	Only A*	Both A and B	Only C	Both C and D*
Correct explanation	30%	0%	15%	3%
Incorrect explanations				
pressure depends on temperature	26%	0%	4%	26%
large temperature differences	29%	0%	2%	13%
Other reasoning	15%	0%	23%	14%

For both demonstrations, most students made correct predictions but provided incorrect reasoning. Most reasoning of students indicated that pressure depends on temperature, for example:

"Temperature of the air inside the doll increases. This increases the pressure of the air, ejecting water."

"When hot water is poured over it, the air heats up increasing air pressure in the doll, forcing the water out of the doll."

Student making their predictions based on this type of reasoning clearly relating pressure with temperature has been documented in previous literatures [99, 104]. When using this reasoning, students often visualize the system consisting of gas molecules. When the system is heated up, gas molecules move faster and hit a container wall more often, so gas pressure increases [104] and they strongly relate pressure with temperature so that they forget to consider a change in gas volume [99]. The instructor aware of this mental image that most students have with pressure and temperature is advised to point out to students that there are actually three variables in these demonstrations-temperature, volume and pressure. Also the system pressure is considered to be constant because the hole in front makes the system pressure at equilibrium with the atmospheric pressure.

Another reasoning categorized as "large temperature differences" was considered to be unclear because students did not provide enough wording to justify their reasoning. Most students provided reasoning in terms of large temperature difference causing water to shoot out. It might be that they based their predictions on volume expansion but they did not explain it well by writing. However, there cannot categorize this reasoning as correct because many students who answered "the large temperature difference between dolls and environment," also answered incorrectly that only doll C had water shooting out. This indicate that they might have some misunderstanding that only a really large temperature difference will make the water come out. However in case of doll D, the temperature difference is about 20ºC and the water is still shooting out slightly.

Table 7.11 Student responses to questions 3-5 in terms of work, heat transfer and change in internal energy. (*correct answers).

Reasoning	Answers			
	Positive*	Negative	No answer	Zero
Work done by the system (W)				
correct or partially correct explanation	55%			
incorrect explanation Increasing pressure pushes the water out	1%	5%		1%
Other reasoning	12%			
No explanation			26%	
Heat transfer (Q)				
correct or partially correct explanation	66%			
incorrect explanation heat causes temperature to rise		12%		
Other reasoning		16%		
No explanation		2%		4%
Change in internal energy (ΔU)				
correct or partially correct explanation				
Temperature increases	20%			
Using the first law equation	22%			
incorrect explanation				
Increasing pressure causes an internal energy to increase	15%			

Table 7.11 (continued)

Reasoning	Answers			
	Positive*	Negative	No answer	Zero
Other reasoning		14%	9%	2%
No explanation	12%			6%

For the second part of the prediction sheet, students had to justify three thermodynamic quantities of the system-work, heat transfer and a change in internal energy after students observed the demonstrations. In general students answered correctly that all three quantities are positive and provided correct explanations. However, several students provided incorrect reasoning as follows:

Increasing pressure pushes water out

A few students overlooked a change in volume causing the work done by the system to be positive. They thought that the pressure increased so that air pushed water to shoot out. This is similar to "pressure depending on temperature" reasoning that we found in students' explanation in the first part.

Heat transfer causes temperature to rise

Most students answered and explained heat transfer of the system correctly. They reasoned that heat transfers from an environment to the system because the system is at lower temperature than the environment. This type of reasoning agrees with a definition of heat that "heat is energy that is transferred from one system to another because of a difference in temperature" [105]. However, several students thought that heat transfer caused temperature to rise as follows:

"Air temperature goes up, so the heat transfer is positive."

A few students also used an equation $Q = mc\Delta T$ as part of their reasoning. This indicates that a few students might still think of "heat and temperature as the same thing" [106], "temperature is the amount of heat" [95] or "Heat is a quantity consisting of a change in temperature" [107].

Increasing pressure causes an internal energy to increase

When asking about the change in internal energy of the system, many Thai students answered correctly that the change in internal energy was positive but they provided incorrect explanation. They related pressure with an internal energy. These were students who also used "pressure depends on temperature" reasoning in the first part of the prediction sheet. They related pressure with temperature, and then they connected pressure with an internal energy.

Therefore an instructor needs to clearly explain that an increase in temperature does not necessarily imply an increase in pressure because it depends on external conditions. The instructor can use a constant pressure situation, as shown in Figure 7.6, to work out and confirm his/her point. Pressure of a gas inside the system relates with a force exerted on a piston. It is easier to understand why pressure stays constant even when temperature increases. Also it is easier for an instructor to explain the situation of constant pressure in term of a free body diagram, as shown in the Figure 7.6. The forces acting on the piston are the same, so the force from air pressure has to be the same.

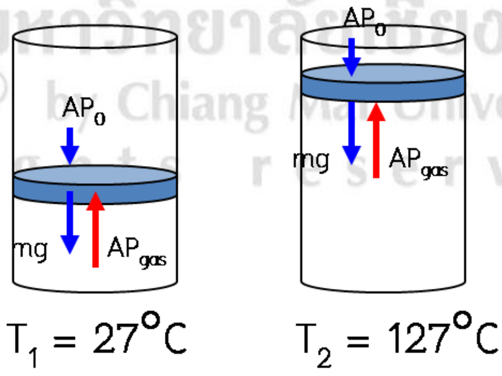

Figure 7.6. A situation of constant pressure with an increase in temperature

7.5.2 Student surveys

Student surveys were administered at the end of the thermodynamic module and included 4 items asking students to rate ILDs as the most favorite, the least favorite, understand the most and understand the least. The student responses were analyzed and plotted comparatively, as shown in Table 7.12. Majority of students thought that the pee-pee boy ILD were their most favorite and they understood it the most. They also provided some responses that

"Interesting to see practical application of physics."

"It was fun and easy to understand the 1st law."

"Very well explained after attempting to hypothesize the reason. Made a lot of sense about the expansion of air."

These results from both parts of the survey indicated that students found the pee-pee boys ILD to be exceptionally interesting and they learned about the first law of thermodynamics as well. Therefore, the pee-pee boys ILD is a stimulating and engaging teaching materials for the first law of thermodynamics.

Table 7.12 Student opinions on pee-pee boys interactive lecture demonstration (ILD).

ILD	Students opinion			
	Most favorite ILD	Least favorite ILD	Understand the most	Understand the least
Pee-pee boys	70%	6%	48%	4%

7.6 Physics education results for movable syringe demonstration

From analyzing student responses on the worksheet, only incorrect predictions were reported and discussed as follows.

7.6.1 Temperature caused pressure to increase

Most students made correct prediction on question 1, as shown in the Figure 7.7.

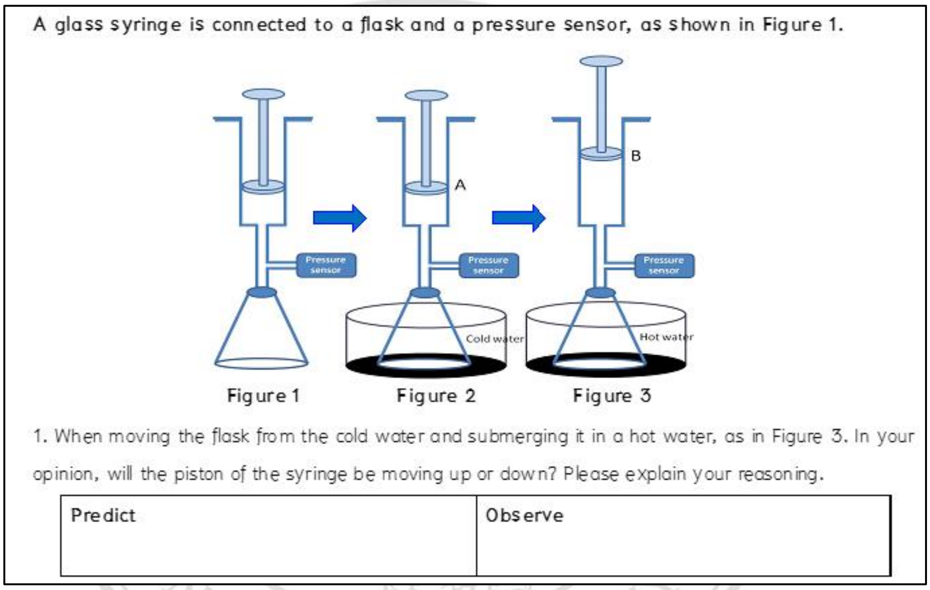

Figure 7.7 An example of prediction sheet on question 1 [93].

Also most students (51%) provided correct explanation. About 44% did not provide an explanation. The rest provided incorrect explanation. They explained that temperature increased as the flask was placed in hot water and this caused pressure to increase as well. Therefore the piston was pushed up.

7.6.2 Difficulties with pressure graph

About 94% of students made incorrect prediction on pressure graph. An example of an incorrect response is shown in Figure 7.8 Students provided interesting reasoning resource in making their predictions. The reasoning can be divided into two types.

Pressure depends on temperature

Students about 28% thought that pressure changes when temperature changes. They misunderstood that pressure is directly proportional to temperature. Therefore, they plotted the graph similar to the one shown in Figure 7.8.

Pressure depends on volume

Students about 53% thought that pressure changes when volume changes. They explained that the volume of syringe increased, the pressure decreased.

Therefore, they plotted the graph opposite to the one shown in Figure 7.8.

The finding is similar to results from previous studies, called linear casual reasoning [89]. This difficulty in reasoning with multi-variable also found in mechanics when students were dealing with kinematic variables—position, velocity, acceleration, and time [89].

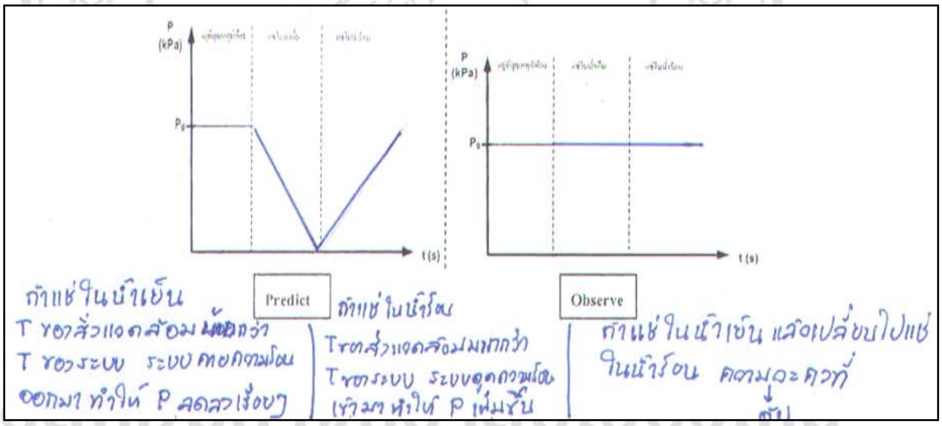

Figure 7.8 An example of student's incorrect prediction on pressure graph.

When students have to consider multi-variable problems, they tend to reduce numbers of variable and reason in a linear logic. In this case, they considered the situation that there are two thermodynamic variables changing—temperature and volume. As seen from the results, most students only used volume to consider pressure and ignored temperature. Some students considered only temperature in order to predict pressure.

7.7 Physics education results for evaluation of thermodynamics concept

In this study, the data analysis of TDT was divided into two 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 7.13) and test reliability (as shown in Table 7.14). Secondly, each item was analyzed and linked to alternative conceptions in thermodynamics, as shown in Table 7.15. 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.

7.7.1 Descriptive Statistics

In this analysis, student responses to each item were considered to be correct only if both tiers were correct. In Table 7.13, all groups had higher scores on post-test compared with pre-test.

Table 7.13 Descriptive statistics of student responses on TDT

Parameter	Statistic							
	2012		2013		2013-3rd		Overall	
	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	2.2	1.9	2.0	2.3	2.4	1.5	2.1	2.0

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 7.14 displayed reliability of TDT compared with acceptable values.

Table 7.14 The reliability of TDT with a range of statistics *(N = 109)*

Reliability	statistics	Acceptable	TDT
Internal consistency	KR-20	KR-20 ≥ 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 ≥ 0.70 [108]. The reliability, in term of Cronbach's alpha (α), for the content tier was acceptable for criterion-referenced tests [109]. 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 [110]. These results indicated that TDT has acceptable reliability or this test is reliable.

7.7.2 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 7.15.

Table 7.15 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 [95].	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) [96, 97].	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 [98].	Q5C(G)	25.69	2.75
AC4) Temperature as an indicator for a change in internal energy [95].	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 [98].	Q7C(F)	16.51	4.59
AC6) Temperature increase caused the pressure to increase [99].	Q9A(G)	49.54	20.18
The second law of thermodynamics			
AC7) According to the second law the entropy of the system must increase [100] for any spontaneous process [101].	Q11A(E) Q14A(E) Q15A(E)	28.44 51.38 38.53	36.70 58.72 26.61

Table 7.15 (continued)

Areas of concepts	Content (reason)	% TDT responses	
		Pre-test	Post-test
AC8) An increase (decrease) in entropy means an increase (decrease) in temperature [102].	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 [94].	Q13C(F)	33.03	45.87

Note: Content-reason Q1B (F) = Q1, content response is "B" and reasoning is "F".

%TCS2.2 = percentage of the total sample who chose the content-reason combination.

7.7.3 Alternative concepts of the thermodynamics

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 7.9. 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.

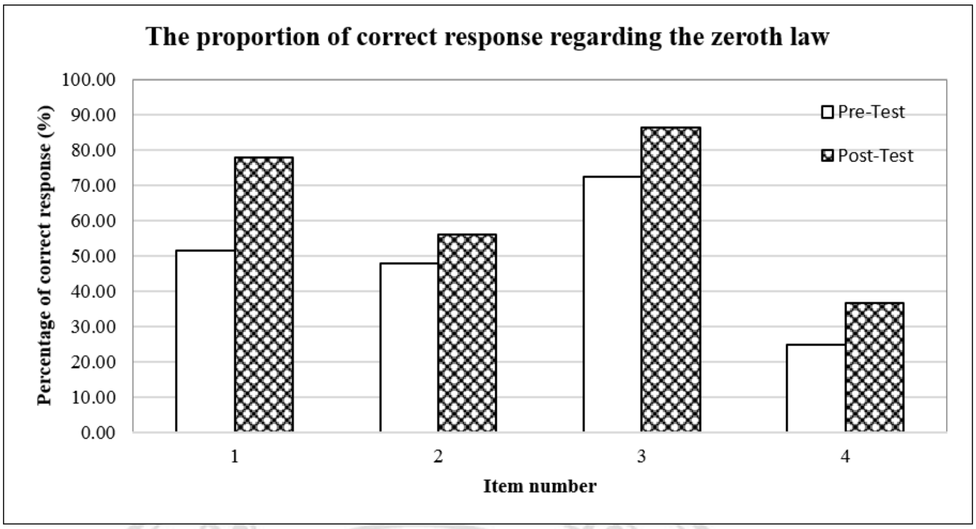

Figure 7.9 The proportion of correct responses regarding the zeroth law

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 [95] and their views that heat and temperature are the same [106].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/substance? Water in this case, then the heat transfer is equal"

"[S04]: The heat transfer doesn't 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" [99]. 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 (7.34% in post-test and 9.17% in pre-test). All students in the interview answered and reasoned correctly.

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 7.10. When performing item analysis, four alternative concepts were found.

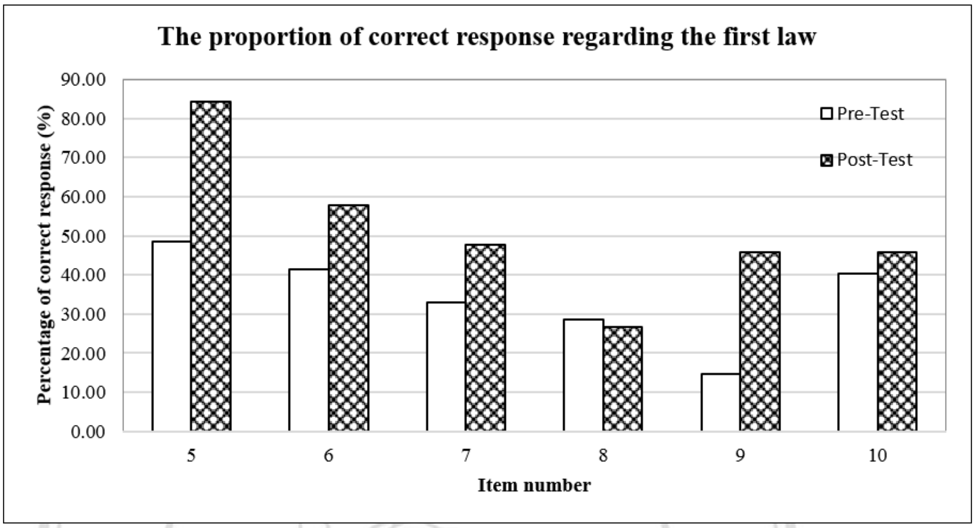

Figure 7.10 The proportion of correct responses regarding the first law

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 [89, 104, 111]. This concept was rooted from a concept of work from 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 [104]. 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 [89, 99, 104]. 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 [99, 104]. 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 [99]. This AC is quite hard to change, as about 20% of students still held this view after instruction.

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 7.11. When performing item analysis, three alternative concepts were found.

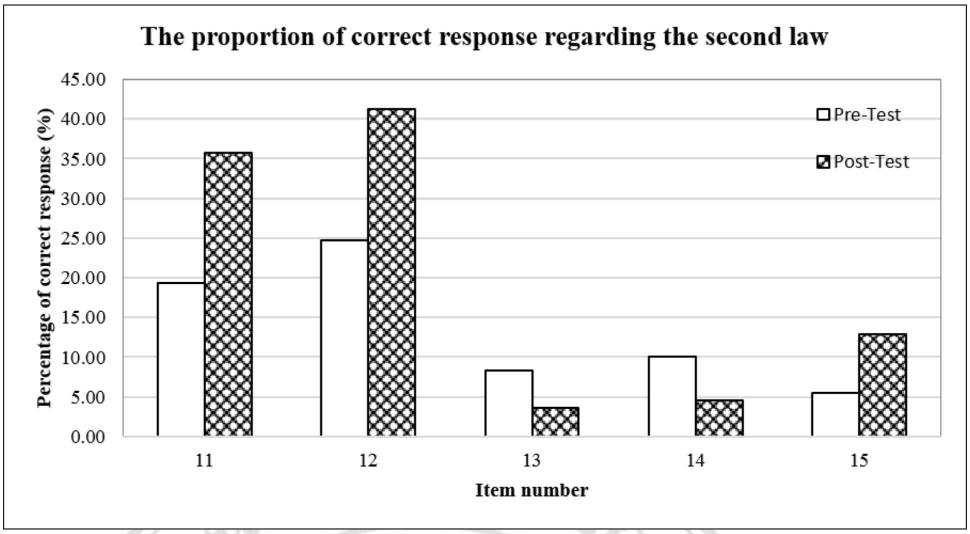

Figure 7.11 The proportion of correct responses regarding the second law

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.”

Meltzer (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 6 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. 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.