CHAPTER 6

Physics Education Research Methodology

From previous chapter, three experiments were described and explained physics principle behind Seebeck effect, thermodynamics of rubber band, and fog in the bottle. In this chapter, methodologies in physics education research (PER) aspects were described. A section 6.1 describes the process of developing a thermodynamics conceptual survey (TCS). Model analysis approach in analyzing data from TCS was described. Then a development process of interactive lecture demonstrations (ILDs) is included in a section 6.3-6.5. Finally, a section 6.6 is about an evaluation of student thermodynamics concept.

6.1 Thermodynamics conceptual survey

Students' understanding of thermodynamics has been the subject of considerable investigation in the physics education literature. The relevant content of literature is very large because of the integration of physics education, which combines chemistry education, mathematics education, cognitive psychology and education. There are many methods which are using to investigate students' thermodynamics understanding such as interview, questionnaires, and multiple choice questions. In this study, Thermodynamic Conceptual Survey (TCS) was used to identify student's understanding thermodynamic. The TCS is a 35 items, multiple choice survey consist of two content parts. First, it consisted of temperature, heat transfer, and ideal gas law. Second, it consisted of the thermodynamics process and the first law of thermodynamics [89]. The concept areas of TCS are shown in the Table 6.1.

Table 6.1 The conceptual areas of TCS [89]

Topics		Items
Part 1	1) Temperature and heat transfer	1, 2, 3, 4, 5, 6, 7
	2) Ideal gas law	
	2.1) Isobaric process	8, 9, 10, 11, 12
	2.2) Adiabatic process	13, 14, 15, 16
Part 2	3) The 1st law of thermodynamics	
	3.1) Adiabatic process	17, 18, 19
	3.2) Isobaric process	20, 21
	3.3) Isothermal process	22, 23
	3.4) Isochoric process	24
	3.5) Cyclic process	26, 27, 28, 29, 30, 31
	3.6) P-V diagram	25, 32, 33, 34, 35

In 2011, the TCS was administered to 106 first-year students taking a fundamental physics I at Chiang Mai University. They took 45 minutes to complete the test. The result of TCS was analyzed for identifying students' misconceptions in thermodynamics. There are many methods for analyzing the data from a multiple-choice test. In this study, model analysis method was used to prove students' misconception. The detail of this method was described in the next section.

6.2 Model analysis

In this part of this study, the main objective is to obtain students' misconceptions by analyzing multiple-choice questions using the model analysis. In this analysis, students who use alternative concepts in answering multiple-choice questions are defined to be in a "mixed model state." The main algorithm of model analysis aims to determine probabilities of students' using dominated alternative concepts and uses student responses to construct a class density matrix. The matrix is solved for eigenvalues and eigenvectors. Finally the class model plot is then constructed and class model states before and after-instruction are compared. In order to use the model analysis effectively, it have to follow these steps that are shown in the Figure 6.1.

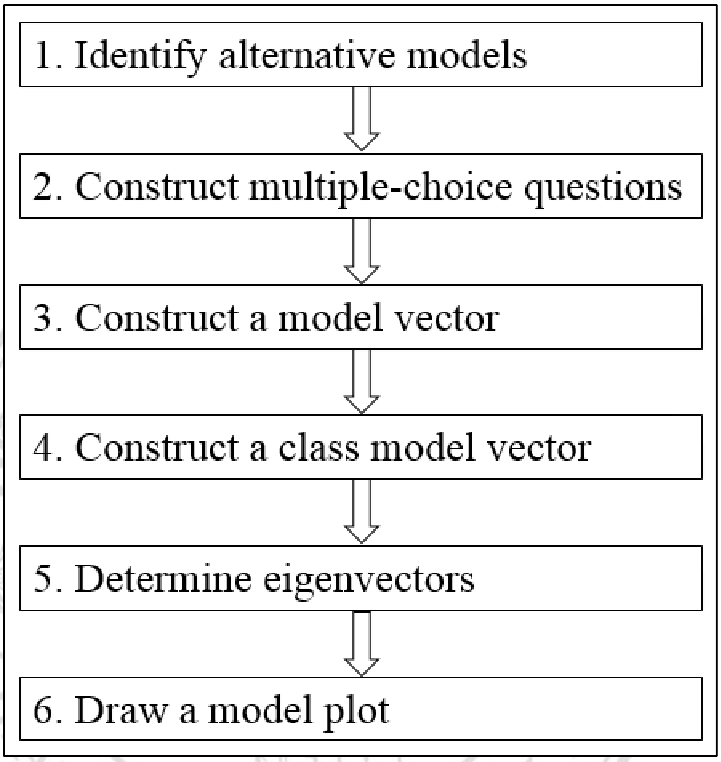


Figure 6.1 The model analysis procedure

Alternative models are investigated and identified through conducting well-structured research and analyzing student interviews. The models often used by most students are corroborated and classified so that these models are reliable for a general population of students. The knowledge of alternative models is then used in designing a multiple-choice test. Distracters are developed from interview data and designed to activate alternative models. The multiple-choice questions have to be tested in order to determine validity and reliability. For example, it can identify the following models as student responses to the TCS questions involve three physical models

Model 1: Appropriate use of the ideal gas equation $PV = nRT$ (Correct)

Model 2: Often relate pressure (P) with temperature (T) (Incorrect)

Model 3: Other ideas and incomplete answers. (A null model)

After identifying common models, it related these models with student responses from TCS and construct a model vector. The basic algorithm of model analysis starts with a linear vector Q_k that characterizes a student's responses with a vector in a linear "model space" representing the individual's probabilities of using different models in answering a set of questions. Each common model is associated with an element of an orthonormal basis, e_n as shown in Figure 6.2. This supports the fact that different mental models can have similar features.

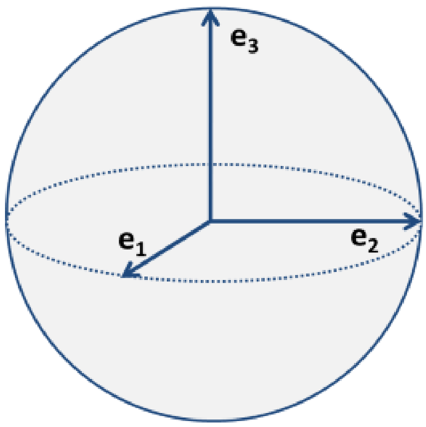


Figure 6.2 A model space consisting of three orthogonal model vectors e_1, e_2 and e_3 [90]

For example, the vector Q_k for this k[th] student is

$$Q_k = 0.57\begin{bmatrix}1\\0\\0\end{bmatrix} + 0.29\begin{bmatrix}0\\1\\0\end{bmatrix} + 0.14\begin{bmatrix}0\\0\\1\end{bmatrix} = \begin{bmatrix}0.57\\0.29\\0.14\end{bmatrix} \tag{27}$$

Here, the three elements "0.57," "0.29," and "0.14" indicate the frequencies of applying three different models, respectively.

The individual student model states constructed from step 3) were used to create a "density matrix," which is then summed over all students. The off-diagonal elements of this matrix retain information about probabilities of using different models of individual students. For example use the square root of each element in Q_k to form a new vector V_k,

$$V_k = \begin{bmatrix} \sqrt{0.57} \\ \sqrt{0.29} \\ \sqrt{0.14} \end{bmatrix} = \begin{bmatrix} 0.75 \\ 0.54 \\ 0.37 \end{bmatrix} \quad (28)$$

Now take an outer product of V_k with a transpose of itself V_k^T ($V_k \times V_k^T$) to get a matrix, namely, the "density matrix" (D_k) for each individual student.

$$V_k = \begin{bmatrix} n_1^k \\ n_2^k \\ n_3^k \end{bmatrix} \quad (29)$$

and
$$V_k^T = \begin{bmatrix} n_1^k & n_2^k & n_3^k \end{bmatrix} \quad (30)$$

$$D_k = V_k \times V_k^T = \frac{1}{m}\begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{bmatrix} \quad (31)$$

For this study, it used seven questions of TCS (Question number 9-15) which are involves three models, so m = 7. For example it can rewrite a density matrix (D_k) for each individual student as

$$D_k = \begin{bmatrix} 0.11 & 0.09 & 0.08 \\ 0.09 & 0.08 & 0.06 \\ 0.08 & 0.06 & 0.05 \end{bmatrix} \quad (32)$$

Next, take an average over all the students to obtain a class density matrix (D), as in equation (33) where N is the number of students.

$$D = \frac{1}{N}\sum_{k=1}^{N} D_k \quad (33)$$

Depending on how students use different models, the class density matrix may display different numbers. The class model density matrix retains important structural information about the individual student models which are otherwise lost if it only sum over the model vectors. By analyzing this matrix, it can study the features of the models used by the students in the class. After obtain the class density matrix, there determined its eigenvalues and eigenvectors by using a Math lab analysis software. The eigenvalues and eigenvectors give information not only how many students got correct answers, but also the class model state which represents a dominant model used by the class. If a large eigenvalue is obtained from a class model density matrix, it indicates that many students in the class use a similar model to answer the questions. On the other hand, if several small eigenvalues are obtained, it implies that students have no strong mental models. Bao and Redish [70] also invented an easy way to represent the class model state with a model plot. The model plot, as shown in Figure 6.3, is a two-dimensional graph to represent the class use of the two models. A class model state can be represented as a point in a two-dimensional space in which the two axes represent the probabilities that a representative student in the class will use the corresponding models over the whole set of expert equivalent questions of the probe instrument. The state is represented by a point that it refers to as the class model point on a plot with $P_2 = \sigma_\mu^2 v_{2\mu}^2$ as the horizontal component and $P_1 = \sigma_\mu^2 v_{1\mu}^2$ as the vertical component. In order to describe the different regions of the plot, there are separate the plot by drawing two straight lines from the origin with slopes equal to 1/3 and 3 respectively. There also draw the line corresponding to the condition P_1+P_2=0.4. With these lines, there separated the model plot into four regions: the model 1 region, model 2 region, mixed region, and secondary model region. When a class has a primary model point in model 1 region (or model 2 region), it suggests that statistically the students in the class have similar model states which have a dominant component on model 1(or model 2). When a class has a primary model point in the mixed region, the students in the class often have predominantly mixed model states**.** The secondary model region represents model states with small eigenvalues, which reflect less popular features of the class behavior. The model plot presents much information about the student model states on the same graph. There can also put the pre-model and post-model states from different classes together on the same plot, making it much easier to see the patterns and shifts of the different class model states.

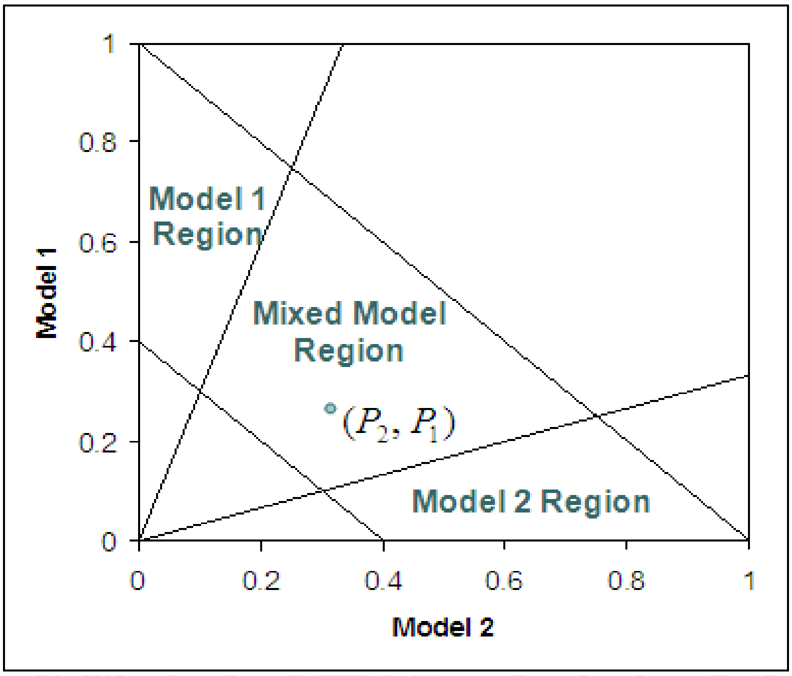


Figure 6.3 Model regions on model plot [90]

In this study, it used model analysis, a method to analyze student's knowledge states in a large class with multiple-choice questions. Model analysis can determine probabilities of students using alternative models. This information about student alternative conceptions in the thermodynamics concept will be used to improve an instruction. For this study, it used interactive lecture demonstration (ILDs) for improvement of thermodynamics concept. The full detail of ILDs was described in the next section.

6.3 Physics education for development of Interactive Lecture Demonstrations (ILDs)

This section describes processes of physics education research (PER) for development of interactive lecture demonstration (ILDs), originally consisted of eight steps [91] However in this study, we used a shorter version of ILDs using a Predict-Observe-Discuss-Synthesize (PODS) learning cycle. These ILDs have been used for over a decade to engage students in large class and to improve their conceptual understanding and deep learning in many topics such as mechanics, optics, heat, electric circuits. ILDs in this study is based on three experiments, including Seebeck effect demonstration, thermodynamics of rubber band and fog in the bottle demonstration. Furthermore, it also used two demonstrations as pee-pee boy demonstration and isobaric demonstration for ILDs supplement. This development process of ILDs was conducted in the following sequence as shown in Figure 6.4 below:

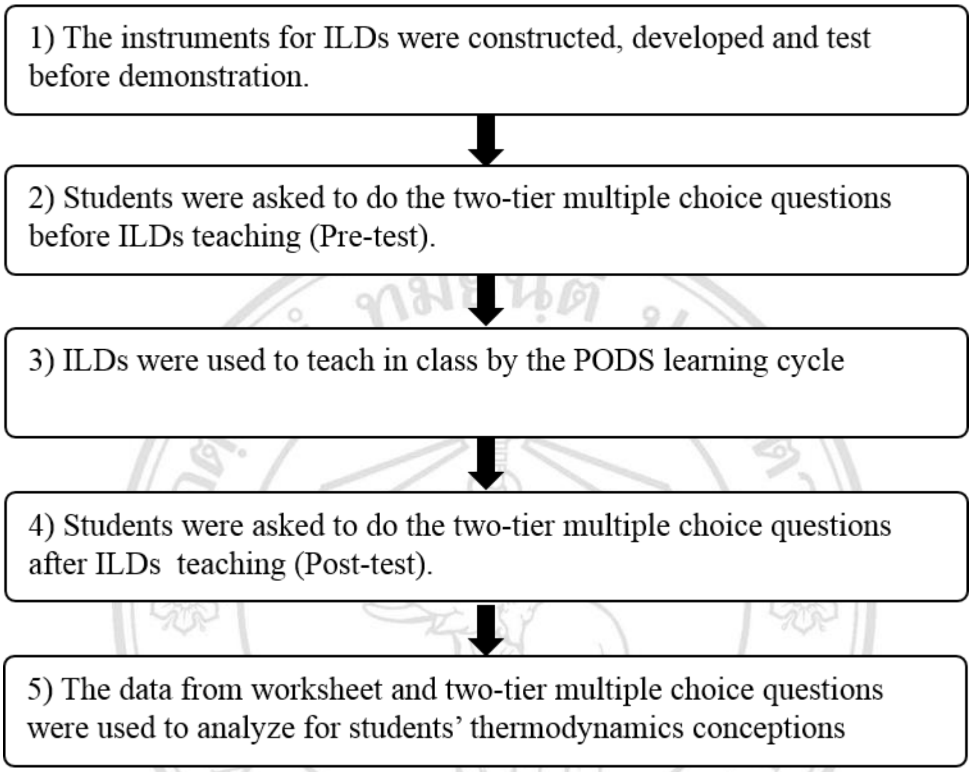


Figure 6.4 The sequence of developing ILDs

This part of the study aimed to develop thermodynamics interactive lecture demonstrations. These are helpful in engaging students to construct correct thermodynamic concepts and to connect physics principles with the real situations. Each demonstration was designed to take up about 30 minutes class time with PODS techniques to deliver active-learning instructions. The PODS learning cycle encourage students to learn from any contradiction between their predictions and observations that could be resolved during the discussion phase [92]. Students then synthesize their newly learned ideas and conclusions into the more general framework of their physics knowledge. However, some naïve students should be use some background information in the form of previous knowledge to increase their confidence to make a prediction rather than just making a random or uninformed guesses. The background information is a backup for students to use logical reasoning to make their predictions, so. Each activity starts with the classroom discussion to retrieve student thermodynamics conceptions of each experiment. Students then are asked to predict what is going on before the demonstration getting start. Students have to predict and write down their predictions in their worksheet. Then, students observed the experiment, collected the data and write down in the worksheet. They also discussed and shared their data to each other. After that students discussed with their peers, they worked on worksheet. In the synthesis phase, students have to think about the contradiction between their predictions and observations. Then, they concluded the results with their lecturer. The task for each ILD base on PODS is shown in the Table 6.2, Table 6.3, Table 6.4, Table 6.5, and Table 6.6.

Table 6.2 PODS for Seebeck effect demonstration

PODS sequence	Seebeck effect demonstration
P = Predict	Part 1: thermocouple - Students write the general information of thermocouple in the worksheet. - Students predict the relation between temperature differences versus voltage that generated by thermocouple. Part 2: thermoelectric module - Students write the general information of thermoelectric module in the worksheet. - Students predict the relation between temperature differences versus voltage that generated by thermoelectric module. - Students predict the relation between temperatures changing versus time after the thermoelectric devices operated.
O = Observe	Part 1: thermocouple - The thermocouple is operated and the digital voltmeter is then used to record a change in voltage for every minute and takes about 8.0 minutes. - Students are asked to write down data from the digital voltmeter

Table 6.2 (continued)

PODS sequence	Seebeck effect demonstration
	on their worksheet. Part 2: thermoelectric module - The thermoelectric devices are applied the power from AC adapter within a range of 0-15 V. - IR camera is used to collect the temperature of the cold-hot plate and also to record a photo for every 30 seconds. - Temperatures of the cold-hot sides are measured by two stainless steel temperature probes and connected to the LabQuest2 sensor system for collecting the data. -The digital voltmeter is measured the voltage generating by thermoelectric module. - Thermoelectric devices are operated for 10 times of each experiment. - Students write data collected from the sensor on their worksheet.
D = Discuss	Part 1: thermocouple - Students discuss and interpret trends of data with their peers and an instructor. Part 2: thermoelectric module - Students discuss and interpret trends of data with their peers and an instructor.

Table 6.2 (continued)

PODS sequence	Seebeck effect demonstration
S = Synthesize	Part 1: thermocouple - Students draw a graph between voltages versus temperature difference and calculate the Seebeck coefficient from thermocouple. - Students and an instructor conclude the conception of thermoelectric effect. Part 2: thermoelectric module - Students draw a graph between voltages versus temperature difference and calculate the Seebeck coefficient from thermoelectric module. - Students and an instructor conclude the conception of thermoelectric effect.

Table 6.3 PODS for thermodynamics of rubber band

PODS sequence	Thermodynamics of rubber band
P = Predict	Part 1: determination of a constant value of rubber band - Students write down general information of rubber band such as length and cross section area. - Students predict the relation between mass addition and mass reduction to rubber band with the elongation. Part 2: thermodynamics potential change - Students write the general information such as length, cross section area of rubber band. - Students predict the relation between tension due to temperature change, and tension due to length change.

Table 6.3 (continued)

PODS sequence	Thermodynamics of rubber band
O = Observe	Part 1: determination of a constant value of rubber band - Students observe and collect the data from the experiment. Part 2: thermodynamics potential change - Students observe and collect the data from the experiment.
D = Discuss	Part 1: determination of a constant value of rubber band - Students discuss trends of data with their peers and an instructor. Part 2: thermodynamics potential change - Students discuss the data with their peers and instructor.
S = Synthesize	Part 1: determination of a constant value of rubber band - Students calculate the elongation of rubber band. - Students draw the graph of length and extension of rubber band. - Students calculate the area between the curves and compare the area under curve for each cross section area. - Students and a lecturer conclude the relation between A constant and the dimension of rubber band. Part 2: thermodynamics potential change - Students plot a graph between force versus length, tension and temperature. - Students calculate Helmholtz free energy, the change of entropy, and the change of internal energy. - Students and a lecturer conclude a conception of thermodynamic potential change in a system of rubber band.

Table 6.4 PODS for fog in the bottle demonstration

PODS sequence	Fog in the bottle demonstration
P = Predict	- Students write the general information of experiment. - Students predict the result of experiment.
O = Observe	- Students observe and write the data from measurement.
D = Discuss	- Students discuss trends of data with their peers and a lecturer.
S = Synthesize	- Students calculate the final parameter of gas such as pressure, volume, temperature, and work done by the gas. - Students and lecturer conclude the conception of fog formation in the bottle.

Table 6.5 PODS for pee-pee boys demonstration

PODS sequence	Pee-pee boys demonstration
P = Predict	- Students write the general information of experiment. - Students predict the result of experiment. It consist the comparative of water shooting from each doll.
O = Observe	- Students observe and collect the data from the experiment.
D = Discuss	- Students discuss the data with their peers and lecturer.
S = Synthesize	- Students respond and reason the results of the experiment on their worksheet. - Students and lecturer conclude the results from pee-pee boy demonstration.

Table 6.6 PODS for movable syringe demonstration

PODS sequence	Movable syringe demonstration
P = Predict	- Students write the general information of experiment. - Students predict the result of experiment as the graph between pressure change and time.
O = Observe	- Students observe and collect the data from the experiment.
D = Discuss	- Students discuss the data with their peers and lecturer.
S = Synthesize	- Students draw the graph between pressure and time from the results of experiment. - Students and lecturer conclude the results from the isobaric process.

The "Fog in the bottle" demonstration, the "Pee-pee boys" demonstration, and the "Moveable syringe" demonstration were used as ILDs to teach a large class for the fundamental physics course. These demonstrations were suitable for teaching the first year physics course. The demonstrations were conduct by a lecturer and a teaching assistant. Students were observed and learned by using PODS learning cycle.

The Seebeck effect demonstration was used as ILD to demonstrate a more complicated thermodynamic concept in a small classroom for the second year materials science students who enrolled a physical properties course. The demonstration also had a compatible worksheet for students to complete and follow the PODS cycle. The students also completed a conceptual multiple choice test after the instruction.

For the last demonstration, the "Thermodynamics of rubber band" demonstration was used as an experiment for an advanced laboratory course for the third year physics students. Students did this experiment themselves and the lecturer role was a facilitator to provide equipment and brief thermodynamics principles relating to the experiment. The students designed the experimental procedure and collected data themselves. The supplemental demonstrations including the "Pee-pee boys" demonstration and the "Moveable syringe" demonstration are described in the following sections.

6.4 Pee-pee boys demonstration

A clay ceramic doll, called a pee-pee boy can be found in most Chinese tea shops and used for testing if water is hot enough for making tea. Figure 6.5 shows a picture of a pee-pee boy and when hot water is poured over it.

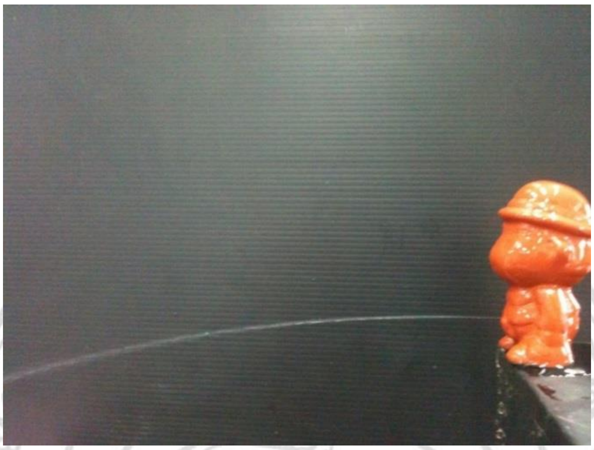


Figure 6.5 Pee-pee boy after pouring hot water on it.

To fill the doll with water, there have to submerge the doll in hot water. Air inside the doll will expand and air bubbles emerge from a hole in front of it. Then the pee-pee boy is placed in a container filled with room-temperature water. The air pressure inside the doll is much less than atmospheric pressure, so the water will be pushed into the doll. If the doll has been filled with enough water, then about 80% of the doll will be submerged under water. The doll will partly float in the room temperature water because there is some air trapped inside the doll. The doll is then ready to use as a rough thermometer for checking whether water is hot enough for making tea. For this experiment, it constructed the pee-pee boy from the glass as shown in the Figure 6.6. The glass doll can be seen through inside and the water inside the doll can easy to observe.

Figure 6.6 The glass pee-pee boy after pouring hot water.

This study contains three objectives. The first one is to show a demonstration of thermodynamics process which can be approximately to be an isobaric process using an exotic example, in this case pee-pee boys. The second objective is to identify types of reasoning that students gave in this example. The third objective is to display student preference when using the pee-pee boy in Interactive Lecture Demonstration (ILD) for the first law of thermodynamics. The equipment of this experiment consist of the four pee-pee boys with gave the code for A, B, C, and D, hot water, cold water, room temperature water, and the IR camera as shown in the Figure 6.7.

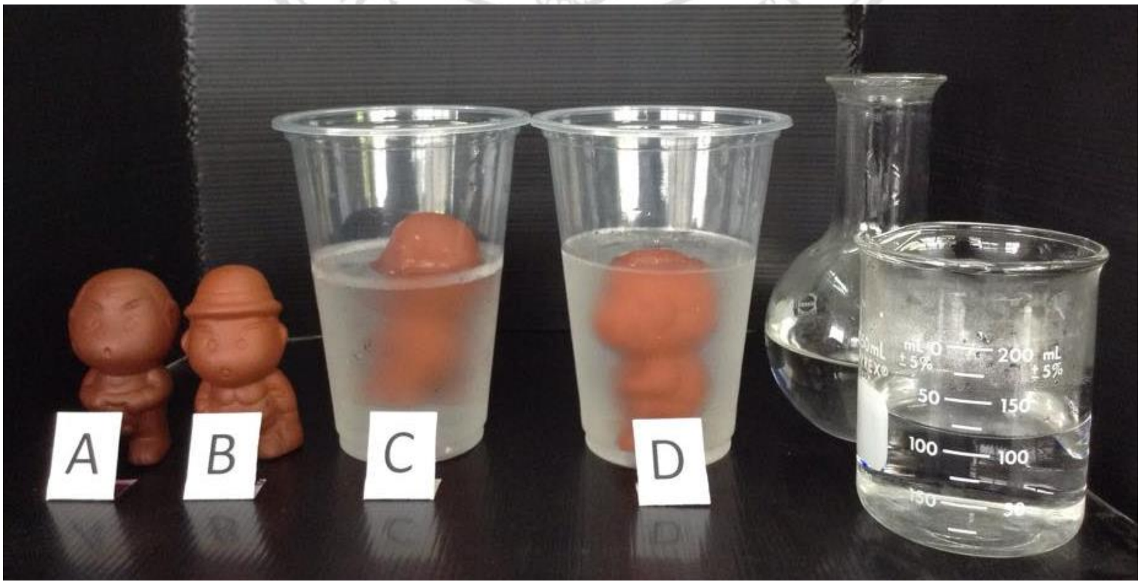


Figure 6.7 Pee-pee boys for ILD setup.

There are four ceramic dolls with different conditions. Ceramics dolls A and B contain room temperature water whereas ceramics dolls C and D containing room temperature were submerged in ice-cold water. Then, hot water was pouring on ceramic doll A and C and room temperature water was pouring on ceramic doll B and D. There IR camera was used to show the temperature of gas inside the pee-pee boys as shown in the Figure 6.8.

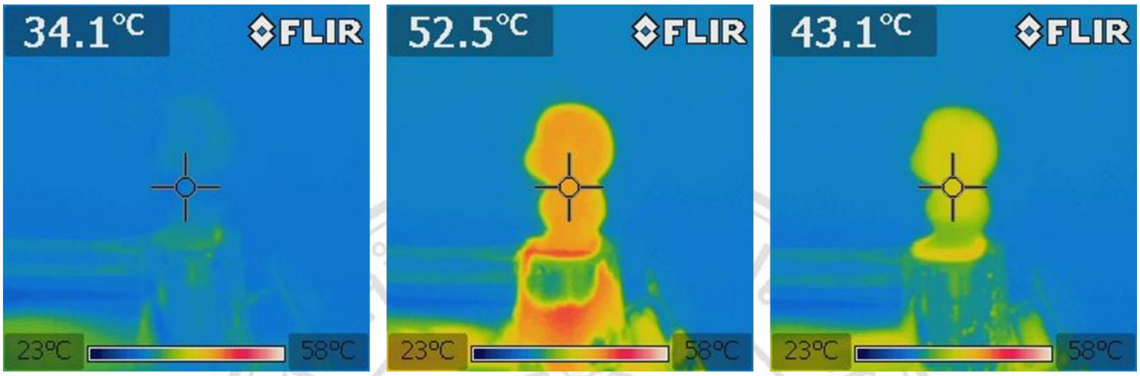


Figure 6.8 The IR photo of pee-pee boys demonstration.

The results of water shooting out from each pee-pee boy were observed. Students were asked to complete the worksheet and provide their reasoning or explanation about the observed situations. From students' class evaluation, most students found this demonstration to be interesting. It is also easy to setup for teaching with ILD in the large lecture hall.

6.5 Movable syringe demonstration

This movable syringe ILD is a good example of an isobaric process with quasi-static expansion or compression under a constant pressure. This demonstration includes a use of a glass syringe because of its low wall friction. The syringe was connected to a flask and a pressure sensor, as shown in Figure 6.9. [93]

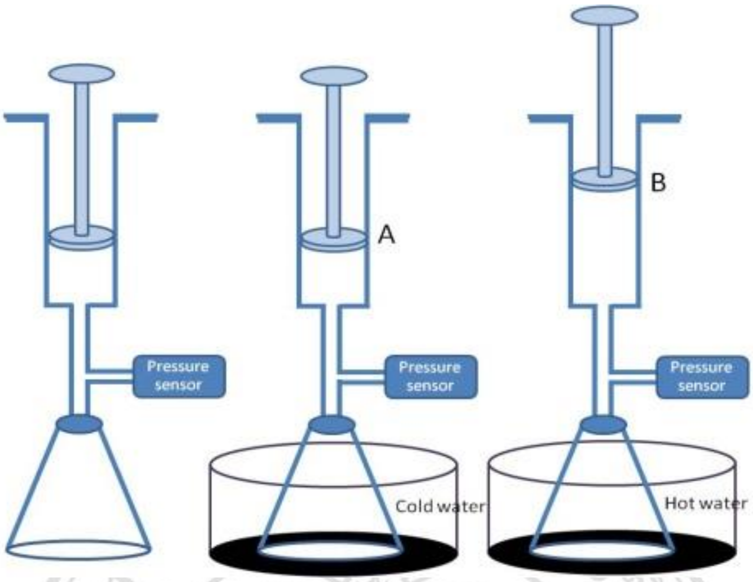


Figure 6.9 A demonstration setup of movable syringe [93].

The objectives of this study is investigated student understanding of an ideal gas law and the first law of thermodynamics in a context of isobaric process. The equipment of the experiment consist of the syringe, hot water, cold water, Pressure sensor, and the Vernier LabQuest interface. The experimental setup, as shown in Figure 6.9. The flask was place in cold water until the piston reached mechanical equilibrium. Then the flask was moved to hot water, the piston moved up and reached mechanical equilibrium at a larger volume. During the experiment, students were observed and asked to make predictions on the worksheet. In order to investigate student understanding of isobaric process, there were analyzed student prediction based on accuracy of their answers and their written reasoning.

6.6 Physics education for evaluation of thermodynamics concept

In order to evaluate students' conception in thermodynamics, a conceptual test has been developed in this study as well. Then, the test was implemented to diagnose students' conceptions in thermodynamics. Firstly, a two-tier Thermodynamic Diagnostic Test or TDT has been developed based on a previous Thermodynamic Conceptual Survey (TCS) [89] and results from interviewing students. Secondly, the TDT was administered to the first year students taking a fundamental physics course at Chiang Mai University (CMU) in 2012 and 2013.

The development of this TDT test used both quantitative and qualitative methods. The TDT was constructed based on one-tier questions from TCS. The development consisted of two phases with eight steps, as shown in the Figure 6.10.

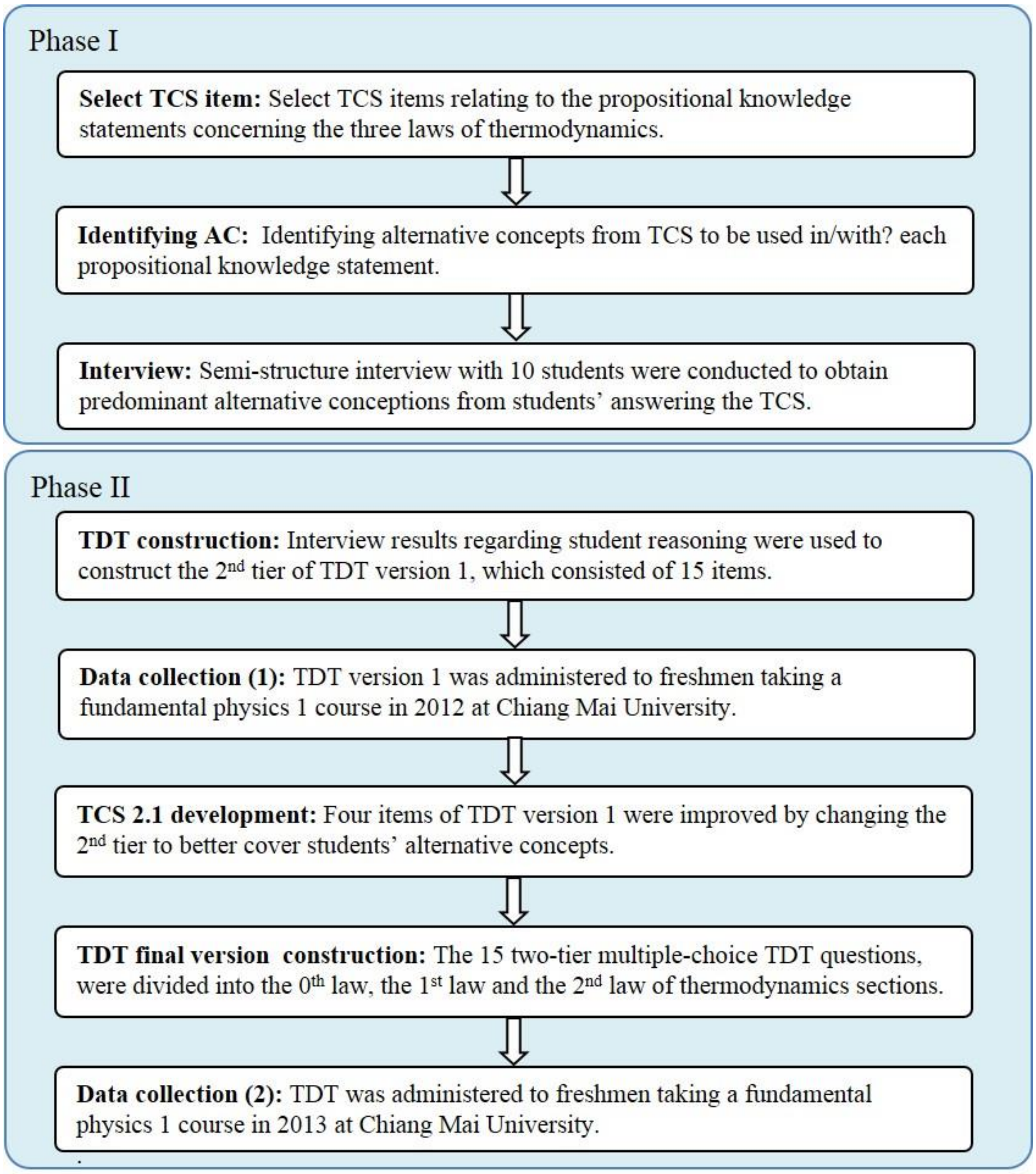


Figure 6.10 Diagram displaying steps in the TDT development process

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 [94]. 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 6.7.

Table 6.7 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 [95].	2,4
AC2) If there is heat transfer into (out of) an object, then its temperature increase (decrease) [96, 97].	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 [98].	5
AC4) Temperature is an indicator for a change in internal energy [95].	6
AC5) Heat transfer is independent of process, depends only on the initial and final states [98].	7
AC6) Temperature increase caused the pressure to increase [99].	9
The second law of thermodynamics	
AC7) According to the second law the entropy of the system must increase [100, 101].	11,14,15
AC8) An increase (decrease) in entropy means an increase (decrease) in temperature [102].	11,12
AC9) In the real process, the entropy of the system plus that of the environment remains the same [94].	13

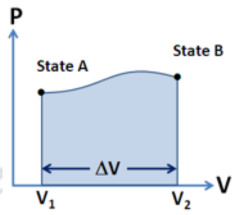
Identifying propositional knowledge, which is composed of four parts, syntactic (learning equations, vocabulary etc.) semantic (linguistic sense, how to use the vocabulary etc.), schematic (structural awareness, similarities and differences between categories) and finally there is strategic knowledge [103] 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 6.8.

Table 6.8 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
(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.	5

Table 6.8 (continued)

<table>
<tr><th>Propositional knowledge statements</th><th>Item</th></tr>
<tr><td>The more general expression for work done is: $W = \int_{V_1}^{V_2} PdV$



</td><td></td></tr>
<tr><td>(7) Internal Energy: U is energy stored in a system at the Molecular Level.</td><td>6</td></tr>
<tr><td>(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.

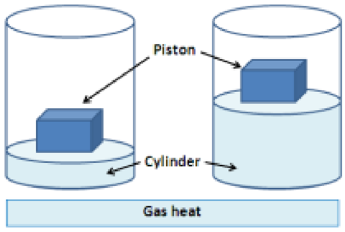
$$\Delta U = \Delta Q - \Delta W$$

when ΔU = change in internal energy, ΔQ = heat added to the system and ΔW = work done by the system</td><td>6</td></tr>
<tr><td>(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</td><td>7</td></tr>
<tr><td>(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 $Q = 0$</td><td>7</td></tr>
</table>

Table 6.8 (continued)

Propositional knowledge statements	Item
(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
(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

TCS2.1 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.

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

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) No change
D) Not determinable from the given information

Please indicate your reasoning:

E) System can be exchange energy to its surrounding.
F) No information is provided about the entropy changing of surrounding.
G) No information is provided of energy transfer between system and surrounding which is increase or decrease.
H) Temperature is increasing.

Figure 6.11 An example of TDT

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 6.9 [69].

Table 6.9 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 TCS2.1 and the feedback from TCS2.1 was used to develop the TDT.