CHAPTER 2

Theoretical Background

This chapter contains the theoretical background and details of: student thinking model, methods for probing student thinking, two-tier multiple choice question, model analysis, thermodynamics understanding, and interactive lecture demonstration. More details are described in the following sections.

2.1 Student thinking model

Since 2011, it has been exploring, investigating, and surveying the new approach to teching in physics. The essential of a new approach was to improving students to overcome their naïve ideas and misconceptions in physics. The examination used to checking students' understanding and proving the success of the teaching methodology. It has been helping students overcome their naïve ideas. The process of replacing a naïve ideas and misconceptions with a scientifically acceptable knowledge is called conceptual change. Many science educators offered various definiftion of conceptual change. Stella Vosniadou proposed that conceptual change is a process that a person construct their model in order to organize new knowledge with the pre-existing knowledge. This process is an on-going one, so as a result a person mental model is enhance [12]. Eduardo F. Mortimer proposed that the process of conceptual change seem to be difference depending on different context and sometime the process can take place without previous knowlwdge [13]. Michelene T.H. Chi and Rod D. Roscoe considered that conceptual change is repairing of misconceptions and reassignment concept to correct categories [14]. Andrea A. Disessa concluded that conceptual change restructure a person or in this case students pre-existing knowledge and most of these knowledge are consider to be misconception [15]. Jonas Ivarsson, Jan Schoultz, and Roger SÄLJÖ proposed that conceptual change is the allocation of learning implements which is going on common level. Misconceptions do not assist a resolution in conceptual change [16].

However, the principle of conceptual change was established in the early 1980 by Posner, Strike, Hewson, and Gertzog [17].This theory is found on Piaget's early studies of children's explanations of natural phenomena. According to the theory of conceptual change, there are two different phases to be used of conceptual change in science. The first phase is called central commitments which are define problems, indicate strategies, and specify criteria for solution. Thomas S. Kuhn calls central commitments these "paradigms" and paradigm-dominated research "normal science". [18]. Normal science operates within set of shared beliefs, assumptions, commitment, and practices. Irme Lakatos labeled scientists' central commitments as their "theoretical hard core" and suggest that these commitments originate "research program" designed to apply and preserve conceptual change from pre-existing knowledge [19]. The modification of the first stage of conceptual change called assimilation. Assimilation refers to "the use of existing concepts to deal with new phenomena" [17].

The second stage is scientific revolution or change of research program. Then the students have to replace or reorganize their central concepts. This more deeply than conceptual change, called accommodation [17]. Such conceptual changes are a part of progress and development of science. From the conceptual change theory, Posner et al. formed a correlation between the kinds of conceptual changes needed to be made by students learning and Kuhn explained the theory of conceptual change. They proposed that students need to experience fundamental conceptual change when it comes to understanding scientific concepts. They need to change their pre-concepts with the new concepts through instruction. Posner et al. provided conditions to bring a conceptual change in students, several necessary conditions are

1) The students have to be dissatisfaction with their obtainable concepts.

2) The new concepts have to be clear.

3) The new concepts have to appear initially plausible.

4) The new concepts have to explain and predict more completely.

The four following conditions are common to most case of accommodation. Since its commencement, the conceptual change model (CCM) has been generally considered and accepted as principal, but it has been concern about evaluation.

Ping-KeeTao and Richard F. Gunstone offered the pattern of conceptual change which is represented in Figure 2.1. Students could change their own concepts to scientific concepts in one context, but keep their conception in another. The students' conceptual change is also unsteady and dependent to framework [20].

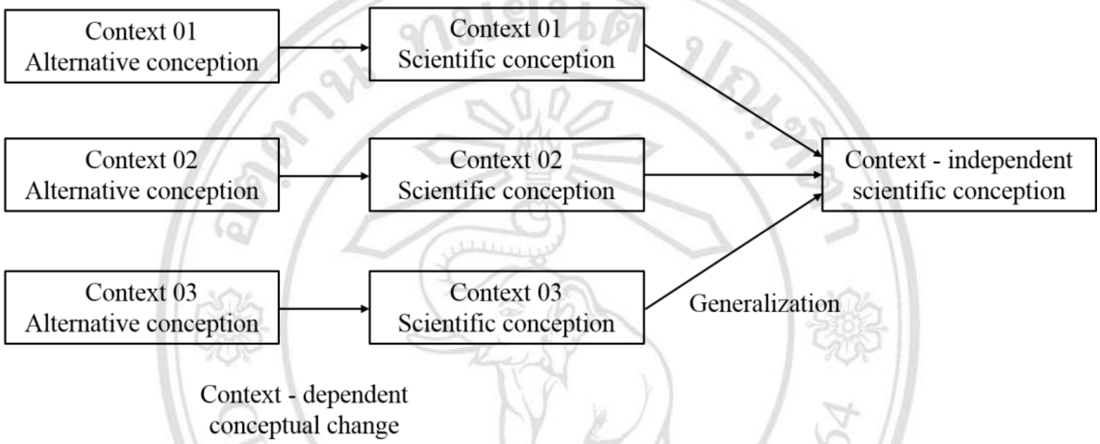

Figure 2.1 The process of conceptual change

Kenneth A. Strike and George J. Posner restated some aspects of the theory more clearly and made several corrections in the theory [17]. There are principle adjustments imposed on conceptual change theory:

1) A various kind of issues have to be bring into explanation in conceptual change.

2) Existing scientific concepts and misconceptions are parts of students' conceptual change. So they have to be seen in interface with others.

3) Misconceptions can exist in different technique of representation and different marks of combination.

4) The development of conceptual change is required.

5) The collaboration of conceptual change is required.

Duit et.al found that there is a large gap between theoretical knowledge and classroom practices. They argued that teachers are not well advised about conceptual change issue and do not use the suggested teaching approaches for encouraging conceptual change in the classroom [21]. Mariana G. Hewson and Peter W. Hewson commented that the teaching strategies based on conceptual change process was affect to the learning of scientific conceptions. The result shown a significantly larger improvement in scientific conceptions than traditional instruction [22]. According to research finding, the development of CCM is the result of work by many science educators, teachers, and other professionals of education. Some of those who have contributed to developing and implementing the CCM are shown in the Table 2.1

Table 2.1 The conceptual change model (CCM)

Revealed by	year	Instructional Procedure
Nussbaum and Novick [23]	1982	There are four elements of teaching sequence that based on the Piagetian notion of accommodation. 1) Exposing students' preconceptions in preparation for conflict through their responses to a devised event. 2) Making students aware of their individual preconceptions and exposing other students' contexts. 3) Making conceptual opposition by trying to describe a improper event. 4) Guiding and encouraging accommodation and creation of a new conceptual model.
Solomon [24]	1983	The learning scientific concept strategy consists of six steps. 1) Preparation: The teaching process has tools and concepts precedes the intervention can be drawn on. 2) Initiation: an open-ended question is assigned. 3) Acting on following step: expressing problems or hypothesis, preparation and doing experiments, creating

Table 2.1 (continued)

Revealed by	year	Instructional Procedure
		surveying, theoretical discussions, and preparation of decision. 4) Discussion in a class meeting. 5) Evaluation with science: classroom conclusions are compared to similar past theories or new ideas. Differences are specified and discuss on the possible reasons of the changing. 6) Reflection: students are considered particular questions or difficulties which a have arisen and stimulated to remember on the process of performance.
Cosgrove and Osborne [25]	1985	The creative learning model is concerned with the existing conception. This process has following four steps. 1) Teacher requires to understand students view, scientists view, and his or her own view. 2) Students have change to explore the content of the concept. 3) Students discuss the conceptions of their own view with their peers and teacher presents the scientist vision. 4) Students have change to appliance of new ideas through context.
Champagne, Gunstone, and Klopfer [26]	1985	There are 6 strategies relates the principle of interaction to support conceptual change. 1) Preparation for teaching, there are demonstration, laboratory exercise, problem solution, reading text. The teaching provides the description for the students. 2) Each student employs to analysis and states the concepts,

Table 2.1 (continued)

Revealed by	year	Instructional Procedure
		propositional knowledge and variables of the physical situation. 3) Students present their analyses and discuss with each other. 4) Each student explained his or her analysis and modified by other students whose analyses are basically in agreement. 5) Two students or group of students with differing views begins to prove others of the validity of their concepts. 6) The concepts developed recovering distinct, and essential statements and propositions are specified apparently. Student is certainly thinking of his or her analysis of the condition of interesting.
Rowell and Dawson [27]	1985	There are six steps involved teaching approach. 1) Student established the ideas which are considered relevant to the problem situation. 2) Students were discussed and their ideas are retained for subsequent consideration in a "paper memory". 3) Students were told that a present theory can solve the problem and their help shall be required both in construction and evaluation later against the options that they have suggested. 4) The new theory is existing by relating it with basic knowledge. 5) Each student applies the new theory to problem solution for indicate its construction. The part of this procedure must

Table 2.1 (continued)

Revealed by	year	Instructional Procedure
		be written work to offer a second memory. 6) Each student relates the memories from step 1 and step 5 and the ideas is examined class.
Clement, Brown, and Zietsman [28]	1989	The teaching strategy establishes four steps. 1) By using a target question, the student's misconception comparing to the topic under consideration is made obvious. 2) Students were suggested a case which is viewed as analogous and appealing to their intuitions by teacher. This case is termed as simply an anchor or anchoring example. 3) Students were asked to make an obvious relation between the anchor and target cases in a challenge to found the analogy relation by the teacher. 4) The teacher attempts to discover a bridging analogy or a series of bridging analogies when the student does not accept the analogy.
Stavy [29]	1991	There are two types of framing of conflict between ideas. 1) A conflict between an actual physical and a certain physical reality related to a child's cognitive structures. 2) A conflict between the same realities related to two different cognitive structures. They made use of second type of conflict in evolving teaching strategy.
Carey [30]	1991	There are three process that can be change concept: *replacement, differentiation,* and *coalescence.* 1) Replacement, a pre-concept is replaced by another concept, because the two concepts are generally dissimilar

Table 2.1 (continued)

Revealed by	year	Instructional Procedure
		that the appreciation of one concept overwrites the existence of the other. 2) Differentiation, the pre-concept separates into two or more new concepts that replace the original. These new concepts can be inadequate to the pre-concept or to each other. 3) Coalescence, involves two or more pre-concepts integration into a single concept that replaces the originals.
Chin and Brewer [31]	1993	In this teaching method, the students contribute in a procedure of learning process such as the following seven steps: 1) Consideration of a physical result which is unknown. 2) The result was predicted. 3) Invent challenging theoretical explanations to sustain the predictions. 4) Result was observed. 5) Modify challenging theoretical descriptions. 6) Evaluate descriptions. 7) Restate the prior steps with dissimilar data.
Stepans [32]	1994	There are 6 stages that provide a context to improve conceptual change learning. 1) Students were awareness their own preconceptions by thinking and making predictions before any activity begins. 2) Students expose their views by sharing to smaller groups and then with the whole class.

Table 2.1 (continued)

Revealed by	year	Instructional Procedure
		3) Students confront their views by testing and discussing them in small groups. 4) Students work to resolving engagements between their concepts and their observations, thus new concept was accommodating. 5) Students cover the concept by making the connections between the concept learned in the classroom and other situations. 6) Students are encouraged to go beyond and difficulties of their choice related to the concept.

By comparing these models, their differences were observed, but there also participate four common characteristics. First, all models recognize that student's prior knowledge affects the students' capability to correctly learn a new concept. So students' prior knowledge about a concept must become obvious in an initial stage. Second, all models suppose that students resist changing their preconceptions. That means a strategy that encourages students to change their preconceptions towards scientifically acceptable must be conceived. Third, the process of conceptual change is time consuming and includes multiple steps so planning must take carefulness. Finally, all these models implicate that students must participate actively in the classroom.

2.1.1 Conceptual change teaching strategies

Davis J. offers a new concept that there are incorrect will cause in conceptual change, because students have depended on their preconceptions to understand in their domain [33]. Arons, McDermott, and Vosniadou & Brewer showed that students who are open to scientific concepts would transfer their previous mental models entirely, because these models are grounded in a long experience. They will try to change their previous conception when they are opposed to the new concept, but they may still merge both to form a new context [34, 35, 36]. In science education research various instructional strategies have been suggested to encourage conceptual understanding and investigate conceptual change among students. We tend to include for three strategies.

1) Cognitive Conflict: there are three researchers proposed the facet of this strategy. Posner et al shown that cognitive conflict strategies are aligned with the theory of conceptual change in that their common goal is to create the four conditions required for conceptual change [17]. Duit explained that when the teacher clearly provides evidence or positions in conflict with students‘ mental models in order to create a state of cognitive conflict or disequilibrium [37]. Davis offered that students must become dissatisfied with their current conceptions and accept an alternative notion as intelligible, plausible, and fruitful [33].

2) Concept Substitution: Grayson established another instructional approach to create conceptual change. This strategy is appropriate when students express a native idea that is correct when explaining observed phenomena, but rather limited in terms of lack of appropriate knowledge about the specific science term suitable for the observed phenomena [38]. In this strategy students' correct idea is being protected, but by substituting the correct scientific term instead of the "naive" term students use to explain the scientific phenomena [39].

3) Physics-by-Inquiry Tutorials: Shaffer and McDermott proposed a strategy that uses a set of laboratory-based instructional modules, collectively entitled Physics by Inquiry [40]. Their approach is that the direct experience of using laboratory equipment encourages students to make the necessary mental commitment for conceptual change, by guiding them through the process of constructing a conceptual model for a particular concept from direct ―hands-on experience with this equipment [41].

2.1.2 Conceptual change model for instructional design

As previous section, many conceptual change strategies through which students change their alternative conceptions towards scientific accepted ideas exist. Among these conceptual change strategies, there have chosen to implement the Conceptual Change Model (CCM) for instructional design, developed by Joseph I. Stepans [32].

Stepans's conceptual change model is based on Posner et al.'s (1982) theory. It begins with clearly revealing the students' individual preconceptions about a concept, causing them to commit to a prediction and share explanations as a group before working with materials. As a result, they become actively engaged in challenging their existing ideas. Stephan's CCM consisted of 6 stages. It's an activity-center, constructivist teaching and learning strategy that places students in an environment that encourages them to identify and challenge their own preconceptions and those of their peers, then work toward resolution and conceptual change [32, 42]. It also models collaboration and the kind of activity and thinking processes typical of scientific inquiry [32]. An outline of the CCM as shown in Figure 2.2.

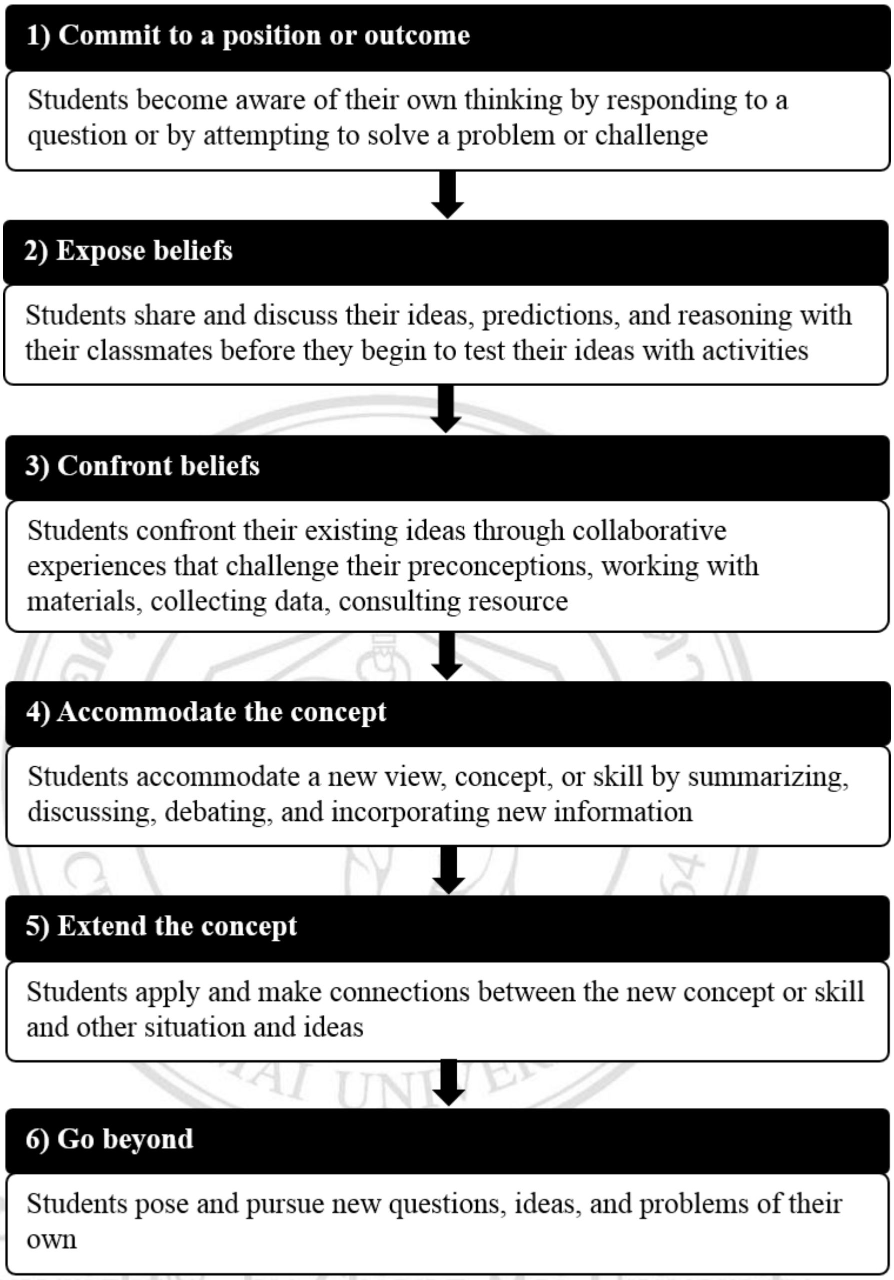

Figure 2.2 The stage of Conceptual Change Model (CCM)

Furthermore, Stepans's CCM is designed to substitute active student collaboration within the classroom. Students communicate with each other and the teacher, to find information and solutions to their questions and to discuss their findings and understandings. Also, through active association, students learn to evaluate and regard each other's concepts. The results of many studies indicated that collaborative learning significantly influences learning outcomes and has been associated with gains in such variables as achievement, thinking skills, interpersonal skills, and attitudes toward school, self, and others [43, 44, 45, 46].

2.1.3 Student memory working

According to the CCM, it is necessary understanding how the brain organize the information and how the memory is worked. There are two main memory types that using in learning and thinking. First, working memory is the main part in processing information, preserving the appreciate information. It has a limit capacity. George Miller proposed that working memory only hold five to nine (seven plus or minus two) units of information [47]. If it has more than seven units, the data was lost. It is easily overloaded if too many unit of information are processing in at one time. Tim Shallice presented that the working memory contains the separate auditory and visual component [48].Second, long term memory is an unlimited capacity and can storage information over a long period of time. From previous research, it focus on the association between working memory and long term memory as shown in the Figure 2.3.

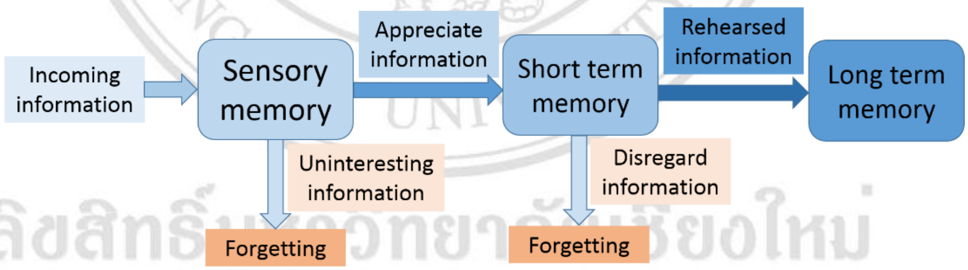

Figure 2.3 The association between working memory and long term memory

The memory model consisted of a sensory memory, short term memory (one component of a larger working memory), and long term memory. In coming data was first registered in sensory memory. A limited amount of an appreciate information was passed into short term memory whereas the disregard information was forgetting. Because of short term memory was capacity limited, the information was temporary keeping for further processing. The information in short term memory was decayed after two seconds if it is not practice [49]. The review information was encoded and storage in the long term memory. The rehearsed information was store in the long term memory. The information in long term memory could be recover at any later time and unlimited capacity.

2.1.4 Cognitive description of students' knowledge

Cognitive has many descriptions with respect to their structure. The cognitive structure is related to the model of the mind which is characteristic of human behavior. It can be conclude that the characteristics of human ascribe to the brain are called knowledge, ideas, ability. The cognitive description also refers to the human behavior interpretation and characteristics of situation as shown in the Figure 2.4 [50].

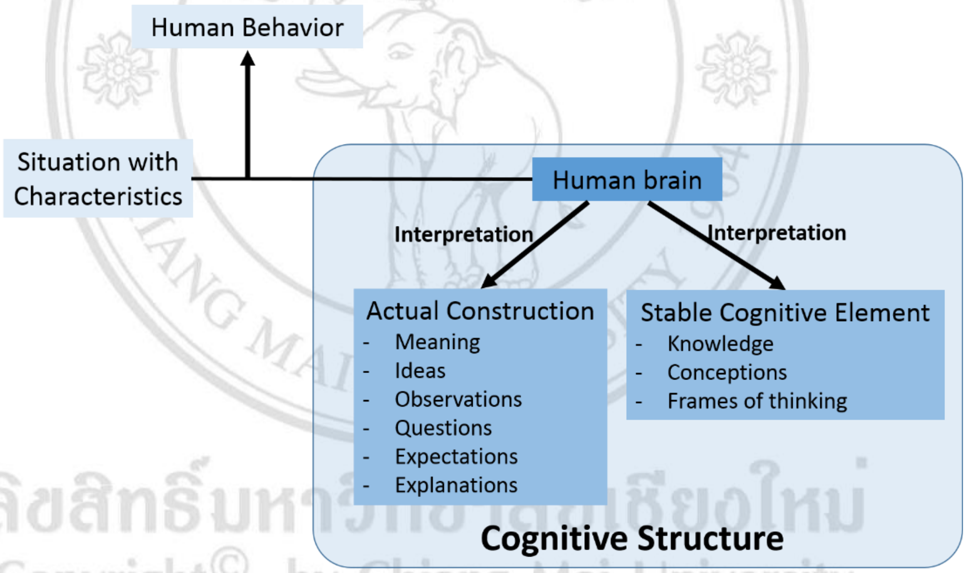

Figure 2.4 The cognitive structure description

Actual constructions are mental representations which are constructed in the order of ten seconds such as meaning, ideas, observations, questions, expectations, and explanations. The stable cognitive elements considered to be stable from hours to months or years such as knowledge, conceptions, and frames of thinking [51].

Minstrell explained that students attempted to understand the physical knowledge in the term of facets of knowledge. Facets express the individual students' understanding and incorporate with several concepts. Facets of knowledge can be group with the same idea which called scheme of knowledge [52]. Scheme of knowledge is less dependent on the context and can be used to construct the mental model. It assumes that mental model are constituted with difference scheme which are build up from propositional representation. Students can received the information from three difference stages which are enactive stage, iconic stage, and symbolic stage. Enactive stage represents through movement and action on the object which obtain the experience. Iconic stage represents through image from perceptions on object which using as thinking process. Symbolic stage represents through words, languages to express students' thinking [53]. The mental model has a procedure to construct as shown in the Figure 2.5.

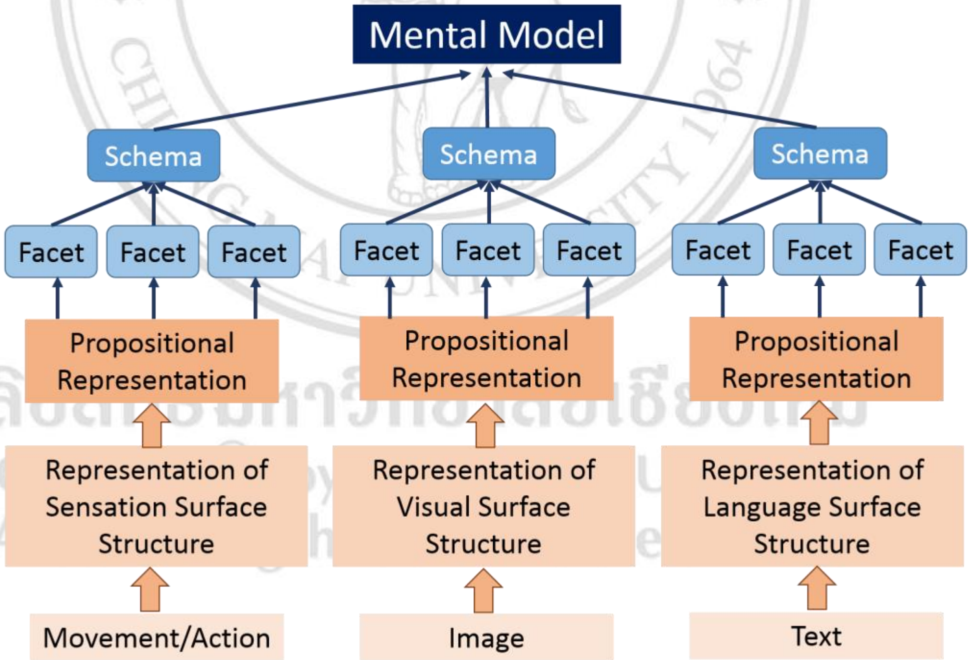

Figure 2.5 The mental model construction

In this way, mental model compose of different schemas which are build up from several propositional representation. Because of a mental model has this characteristic so, there refer to it as a physical model. A physical model may or may not agree with current community agreement view of physics.

2.1.5 Cognitive resources for teaching

For this work, it is important to know the knowledge and thinking about students' conception that they bring into the class. It helped to understand students' misconception that make the misunderstanding and helped to design the new improve teaching and evaluation. Furthermore, it is the normal resources of students' knowledge for construct and develop their knowledge. There are three ways for cognitive resources for teaching:

1) Basic naïve conception

A basic naïve conception referred to misconception or alternative conception and found on the order of 20% or more of total students. It defined as the particular of mental model. The naïve conception help to understand the students' understanding for construct more scientific and productive concepts. Much of physics education research has been to present the common naïve conception as shown in the Table 2.6. The main usefulness of a basic naïve conception is construction and development of teaching methodology.

2) Facets and schemas of knowledge

As diSessa points out [54] that there is many figure of facets which consist of the mental model and they are more complicated of schema of knowledge. This complication is concerned with the ascending of abstract reasoning onto the variety of physical knowledge. The analyzing of facets and schemas helped for understand the sorts of students' reasoning. If there can collect the correct students' reasoning, there can help students reorganize their previous knowledge and build more complete and correct their understanding. Furthermore, it can helped instructor to understand students' thinking model.

3) Active learning resources

The common requirement of teaching is to know that students are actively involved in learning. From the previous research found that students must balance receiving knowledge with using knowledge when they learned above the lowest levels of pre-knowledge so the active participation and involving are necessary to active the process information [55]. Active learning can provide a feedback to instructors for teaching improvement.

2.2 Methods for probing student thinking

Students' thinking is an important part of Conceptual Change Model (CCM). It helped an instructor to characterize student views about knowing, learning and assess the relation of this views to accomplishment in physics course. In this study, it used a general method for probing student thinking are using questions. Questions are a valuable teaching tool and the most used of teaching technique. They employed to improve students' understanding, making them listen carefully, breaking down their thinking critically [56]. It seems to explore the categories of questions in the form of questions are defined in Table 2.2.

Table 2.2 The categories of the form of questions

Form	Definition
1) Factual	Questions which invited a pre-determined answer
2) Speculative	Questions which invited a reaction with no pre-determined event, often opinions, theories, imaginings, and thoughts
3) Process	Questions which invited students to formulate their understanding of learning processes/explain their thinking
4) Procedural	Questions which related to the establishment and management of the lesson

In this study, it focused on probing questions, which are a type of open-ended or higher order questions that not only extend students' knowledge beyond factual recall and repeating learned skills, but also force students to apply old knowledge to explore and build up new concepts and procedures. The characteristics of probing questions were related to the purpose of teaching. It follows as the indicators of probing questions were:

1) To advance pupils to express their knowledge or intellect
2) To advance students to clarify, justify, interpret, or exemplify their knowledge or intellect
3) To provides opportunities for each student (rather than just some students) to express their understanding

Studies about questioning show that probing questions can used to clarification, justification, and confirmation questions to extend and continue student thinking [57].

There are several method to collecting data by using the questions. The main instruments are interviews, questionnaires, and multiple choice questions. These different method can supplement validity and dependability of data. The detail of each method is described in following subsection.

2.2.1 Interviews

Interviews are widely employed means of collecting qualitative data and are to reveal existing knowledge in the form of answers [58]. It provides in-depth information pertaining to participants' experiences and vantage points of a particular case. Oft times, interviews are coupled with other forms of data collection in order to supply the researcher with a well-rounded collection of data for analyses. It has two forms of interviews which are person-to-person and group interview. There are the strengths and weaknesses of the interview as shown in the Table 2.3

Table 2.3 The strengths and weakness of the interview

Strengths	Weakness
1) Good for measuring attitude and content of interesting	1) Expensive and time-consuming are conducted in the person-to-person interview
2) Allow to probing and provide in-depth information	2) Data analysis was time-consuming and depend on the experience of the interviewer.
3) Moderately high measurement validity of well-built and well-interview protocol	
4) Useful for exploration and confirmation	

It can be categorize the types of interviews by using the structure of interviews. The two types of interviews were classified by Patton and Burns that can be illustrated and compared in the Table 2.4

Table 2.4 The two types of interviews

Types of interview		Detail
Patton	Burns	
1) Closed, fixed response interview	1) Structured interview	- The questions are determined with practically fixed order
2) Structure opened-ended interview		
3) Interview guided approach	2) Semi-structured interview	- The topics and questions are specified, but they can reworded in any sequence based on the state of affairs - The collected information can subsequently be compared and contrasted - The data collection is quite systematic and conversational
4) Informal conversation interview	3) Unstructured interview	- Conducted without any predetermined questions and without any guild - The questions emerge from the natural flow of conversation

The semi-structured interview is the most favored type of audience. It is pliable and allow the interviewee to provide more information than the other aces. Usually, the interview can be read in two ways. There are tape record, and taking notes. The significant issue in any interview is the type of the questions that are utilized.

2.2.2 Questionnaires

Questionnaires are the primary sources of obtaining data. The questionnaires are three types which are closed-ended questionnaires (structured), opened-ended questionnaires (unstructured), and a mixture of closed-ended and opened-ended questionnaires. There are advantages and disadvantage of questionnaires as shown in the Table 2.5.

Table 2.5 The advantages and disadvantage of questionnaires

Advantages	Disadvantages
1) They are the efficient way of collecting data on a large-class.	1) Sometime, the answers are inaccurate and questionable.
2) They are a time efficient style of accumulating data for many pupils.	2) Some question may cause misunderstanding.
3) Closed-ended questionnaires are easily be studied in a straight manner.	3) Wording of questions might affect the responses.
4) They are cost efficient.	

Therefore, it is better that mixture of closed-ended and opened-ended questionnaires to complement each other. That is helping the interviewer to explain any unclear questions and to know the conditions under which the questionnaires were filled out.

2.2.3 Multiple-choice Questions

Multiple-choice questions are commonly used because they allow instructors to quickly quantify varying degrees of knowledge in their classroom and determine what students thinking from instruction. A number of multiple-choice questions have been developed addressing many different areas of physics. These tests are typically used to determine what difficulties students have with specific content and to evaluate teaching practices and curriculum [59]. Multiple-choice questions are objectively graded, and statistical methods can be applied to the resulting data. It can be given to large numbers of individuals at one time, providing larger sample sizes and increasing the generalizability of the results, and using less time intensive than interviews. Whereas, multiple-choice questions cannot probe deeply into what students are thinking. It suggested that some students may be correct answer without actually understanding the material presented which showed that students who chose the correct answer were not necessarily able to provide acceptable explanation. However, the purposes for multiple-choice questions are different from the traditional instruction that using to grade students. A major difference is in the use of results from qualitative research studies in the development of the distractors for the multiple-choice questions, detail and time dedicated to the development of individual items. It can be using to ascertain students' initial and final knowledge states and evaluate teaching, teaching methods and curriculum. In terms of evaluating teaching, it can be used to determine a new teaching method can improve the quality of teaching. Well-multiple-choice question can be designed to provide diagnostic information to the student and instructor regarding common misconceptions or other areas of difficulty. An instructors can be used to evaluate new activities to help students overcome these misconceptions. Multiple-choice tests are valuable in that they are objectively graded and can be given to many students in a relatively short amount of time [59].

2.3 Two-tier multiple-choice question

Physics education research employed various techniques to obtain information of student misconceptions. These techniques are 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 [60, 61, 62, 63]. 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. However, general multiple-choice questions have limitation in terms of providing in-depth information of students' reasoning. These are important data in helping physics education researchers understand characteristics of student misconceptions in a certain topics. Therefore, there is an emerging trend in science education to develop two-tier multiple choices in order to obtain more information about students' understanding. The two-tier multiple choices usually consist of content tier and reasoning tier. Many science education researchers found that the two-tier multiple choice questions provided significantly better results in terms of student misconceptions as compared with traditional multiple-choice questions [64, 65].

In physics education, many researchers also tend to construct conceptual surveys using two-tier multiple-choice questions. For example, the studies conducted with the two-tier test included a study of floating-sinking, buoyancy and pressure concepts (66], secondary students' understanding of wave [67], and student ideas of thermodynamics [62].

Treagust [68] stated that conceptual tests composing of two-tier multiple-choice questions had a potential to make a valuable contribution to the research of students' conceptions because the two-tier questions have two major benefits over typical multiple-choice questions. 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 for the second tier. Students' reasoning provides details of their alternative concepts. Secondly, they reduce measurement uncertainty from students' random guessing. Normally, students have 25% chance of guessing correctly in a question with four choices. In two-tier questions, students have to response correctly on both tiers, so they have 6.25% chance of guessing correctly.

Nonetheless, there were a few two-tier conceptual tests on topics of thermal physics. Therefore in this study, there developed, implemented and evaluated thermodynamic conceptual survey covering three fundamental laws of thermodynamics, called Thermodynamic Diagnostic Test (TDT). This test were modified from TCS 2.1, which is a conceptual test consisting of 15 multiple-choice questions [69].

2.4 Model analysis

It is a continuing effort among educational researchers to look for new ways to understand student learning process. However, it could not be measured directly because of learning is a complicated process. There can only model student ways of thinking and further improve our understanding of student learning. From physics teaching experiences, students sometimes even use contradictory ideas to answer similar questions and not consistent in solving problems. In many cases when a similar concept is presented under different physical contexts, students may have difficulties in identifying the correct physics. They tend to use pieces of knowledge that are induced by the surface features of the specific contexts. Therefore, students seem to function as if they hold a mixture of different models (a correct one and incorrect ones) without knowing the suitable situation in which to apply them.

From results of cognitive research, it may be of keen interest to see the student as always being in a consistent mental state. For pupils to gain a complete expert model, they necessitate to work through a process of conceptual change, as shown in Figure 2.6. The mixed state is seen as an important transitional stage for a student to achieve a complete favorable conceptual change in learning physics. Hence, measurements of such mixed states have significant values in assessment and education [70]. Students in this mixed model state (sometimes referred to as a hybrid model) often combine certain parts of their existing knowledge and the new knowledge. It is a solution of reconciliation to produce a locally-consistent model for two types of knowledge which are otherwise contradictory.

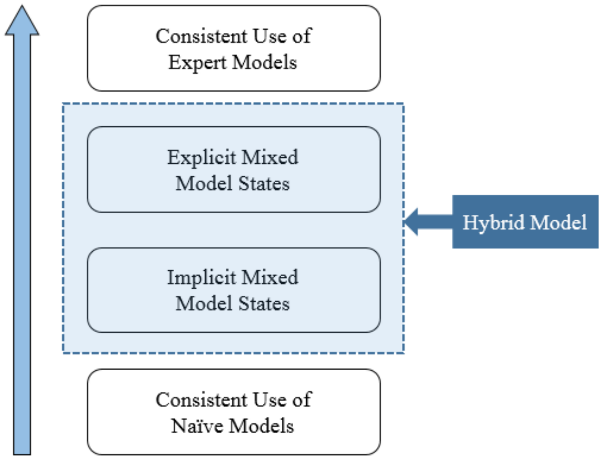

Figure 2.6 A process of model development leading to a conceptual change [71]

In physics education research, many research-based multiple-choice tests have been developed and often used to diagnose student conceptual understanding and to assess student learning. The multiple-choice tests are easy and economical to distribute and to grade, have objective scoring, and are agreeable to statistical analysis that can be applied to compare student populations or instructional methods. With traditional analysis, only correct responses from multiple-choice tests are used, and incorrect responses are disregards. Bao and Redish [70] proposed a new approach to analyze multiple-choice questions, call model analysis. This new approach uses all student responses to calculate a model state that students use to choose their answers.

The goal of model analysis is to determine probabilities of model trigger. In other words, this method presents a calculation of frequencies that students use different "models" in answering questions which probe similar concepts in different contexts. Model analysis method can be easily borne out on a spreadsheet or basic calculated program such as excel program and it is mathematically basic to calculate. The result is a more detailed picture of the effectiveness of teaching in a class than is available with analyses of results that do not consider the meanings of the incorrect responses chosen by the students. In this study, they've presented a way to analyze research-based multiple-choice questions, which can approach much richer information than classical test theory.

2.5 Thermodynamics understanding

Students' understanding of thermodynamics has been the topic 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, educational psychology and education.

It has been review the physics education literature on student misconceptions on thermodynamics. Various surveys have demonstrated that students have different ideas about heat and temperature from those obtained by scientists. Students can derive these estimates from their daily experiences and even from misrepresenting instructions in school. The review puts together the significant findings of the studies, summaries the misconceptions identified so far and the possible origins of these misconceptions. It has been proven that there are many misconceptions held by students. The following details are shown in the Table 2.6.

Table 2.6 Identified students' misconceptions on thermodynamics

Identified Misconception	Students' age	Revealed by	year
The temperature of an object is related to its size. Heat is a form of energy. There are two types of heat, cold heat and hot heat. Heat is a material substance like air or steam.	6-13 year old	Erickson	1979 1980 1985
There is no difference between heat and temperature Temperature will change during melting or boiling Heat is hot, but temperature can be cold or hot	12 year old	Tiberghien	1985
Heat and temperature are the same Heat and cold are opposite and both are fluid materials Some substances are naturally colder than others	15 year old	Brook et al	1984 1985

Table 2.6 (continued)

Identified Misconception	Students' age	Revealed by	year
Heat transfer start and does not stop at once when the temperature equalized Heat is attracted by the cold body until heat and cold have neutralized Heat is not an extensive quantity, but an intensive quantity Air only cools other bodies if they are surrounded by air	15-16 year old	Duit and Kesidou	1988
Temperature is the amount of heat If two bodies are at the same temperature they have the same energy or heat Heat enters and leaves different materials at different ease Different materials attract heat or retain heat differently	15-16 year old	Kesidou and Duit	1993
The temperature of water could exceed the boiling point Objects at room temperature that feel cold have different temperatures Objects could get hotter than their surroundings Objects could have a certain quantity of heat in them	17-18 year old	Grayson et al	1995
Metals attract, hold, or absorb cold Conductors conduct heat more slowly than insulators Insulators absorb/trap heat Insulators conduct heat fast and heat leaves so insulators don't feel hot	12-14 year old Adults 19-45 year old Scientist	Lewis and Linn	1994

Research into student understanding of elementary heat and temperature concepts reveals that students incomplete idea about each concept. Additional, University students continue to confuse heat transfer and temperature, and also confuse both of these with internal energy and heat capacity. Students also have difficulties in correctly applying the state function concept that is of elementary importance in thermodynamics.

2.6 Interactive lecture demonstrations

Interactive Lecture Demonstrations or ILDs is an active learning in a lecture based model. [72] The ILDs was proposed by David Sokoloff and Ron Thornton [73] and had been used in several universities around the world, including Thailand. ILDs designed to engage students in learning process and convert the passive learning to active learning. ILDs consisted of eight steps, as shown in Figure 2.7.

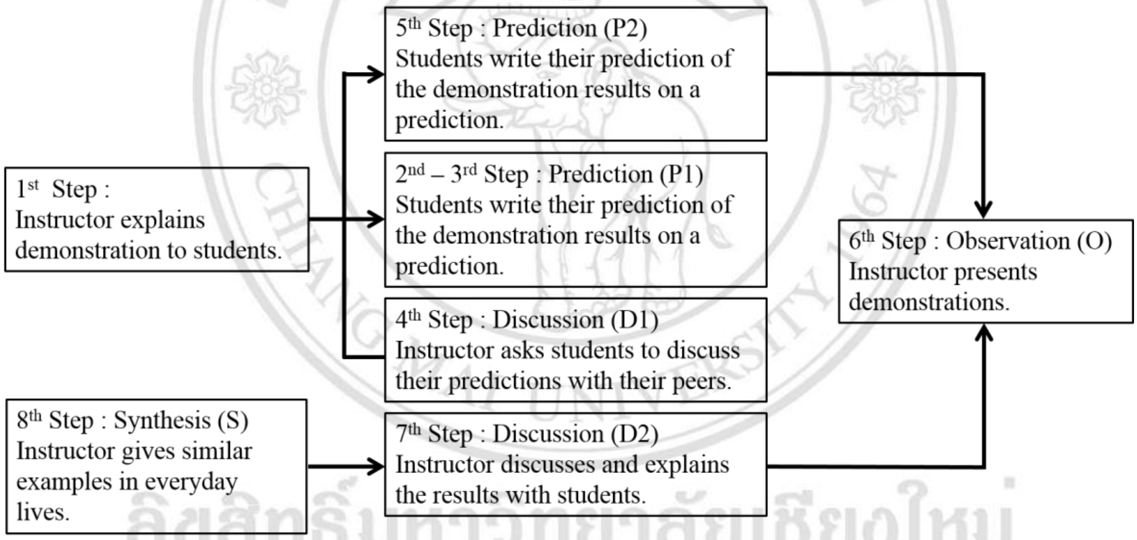

Figure 2.7 Interactive Lecture Demonstration Learning Cycle [10]

There had implemented ILDs in teaching thermodynamic topics at Chiang Mai University. There had developed five demonstrations including thermoelectric effect demonstration, thermodynamics of rubber band, fog in a bottle demonstration, pee-pee boys demonstration, and isobaric process demonstration. The content of ILDs that used to enhance the learning of thermodynamics concept were shown in the Table 2.7.

Table 2.7 Thermodynamics interactive lecture demonstration sequences

ILD sequence	Contents
Seebeck effect demonstration	- Seebeck effect - Seebeck coefficient of metal wire and thermoelectric module
Thermodynamics of rubber band	- Work done on the rubber band in stretching and contracting - The constant of the rubber band at constant temperature - Helmholtz free energy, internal energy, entropy of rubber band
Fog in a bottle demonstration	- Adiabatic process
Pee-pee boys demonstration	- Volume expansion - The first law of thermodynamics
Movable syringe demonstration	- Isobaric process

The details of each ILD were described in the next chapter. Seebeck effect demonstration was described in chapter 3. Thermodynamics of rubber band was described in chapter 4. Fog in the bottle demonstration was described in chapter 5. Pee-pee boys demonstration and movable syringe demonstration were describe in chapter 6.