CHAPTER 1
INTRODUCTION

1.1 Background

Since the 1970's, there has been significantly increased number of systematic investigations into students understanding of physics. A large number of empirical studies completed in the past three decades could be categorized into three areas in terms of their primary emphasis: research about student conceptual understanding and reasoning; research about student problem solving; and research about student attitudes and beliefs (McDermott & Redish, 1999). Investigation of student difficulties in conceptual understanding have been more comprehensively documented than both about student problem solving and about beliefs and attitudes. Many of the researches into student conceptual understanding have been in classical physics such as kinematics, Newtonian dynamics, electric circuits, thermodynamics, work and energy, and geometrical optics.

In that period, some physicists found that there existed a great difference between what was taught and what was learned (McDermott, 1993). Since then, systematic investigations done by physicists about how students learn physics have been growing in number and sophistication. Forming a new community and building a new area in physics, researchers have gained deep insight both into students' difficulties understanding physics and into how to help students learn more effectively (McDermott & Redish, 1999).

At the same time, the goal of learning physics has also been examined and challenged by the needs in the 21st century workplace. Some of various Physics Institutes (Rebello & Zollman, 2005) often suggest some common skills that the real world workplace wants employees in science and engineering to have: for example, knowing how to learn, scientific investigation skills, problem solving ability, communication and teamwork skills, and others. Therefore, the goals of physics education research are varied and different. Some focus more on understanding of physics knowledge, some emphasize developing procedural skills to meet the needs of the workplace, and some do both until students' attitudes and beliefs. In fact all of these attributes refer to how to design learning systems as a main focus of discourses about learning physics, including learning materials, instructional strategies, instructors, classroom implementations, and so forth.

Recent research in learning and teaching physics strategies has increased greatly (Rebello & Zollman, 2005). Some researchers have investigated traditional methods of learning, while others have developed and assessed techniques such as hands-on experiments and interactive computer visualizations. Over the past ten years a number of researchers have been involved in these efforts, especially in the modern physics field. Their work is now showing some good results that can help us understand how to teach quantum physics and, perhaps, other abstract scientific concepts (Zollman, 1999; Asikainen, *et al*, 2005)

Many physics educators state that physics is not considered very attractive and interesting as an alternative to study for many students even though the technology that we are using in everyday life is a consequence of research in physics, especially quantum physics topics (Zollman, Rebello, & Hogg, 2002). Actually, quantum physics could be a very attractive field but students perceive quantum physics as very abstract and conceptually difficult, so that they generally have a weak level of the understanding of quantum physics. In terms of assessing students difficulties in quantum physics, several conceptual surveys have been developed, though most are appropriate for advanced undergraduate and beginning graduate students since they address topics such as the calculation of expectation values, or the time-evolution of quantum states (Baily & Finkelstein, 2009). Wuttiprom *et al* (2009) reported that students had the most difficulty with six questions which they classified as *interpretive*; for example, the two survey items with the lowest percentage of correct responses ask whether, “according to the standard interpretation of quantum mechanics,” light (or an electron) is behaving like a wave or a particle when traveling from a source to a detector. The authors reported that only ~20% of students chose the correct response for each of these two questions.

Quantum physics can be built on a classical base theory, using many classical concepts and so can be rich in representations. If student understanding is weak in these areas, the learning of quantum physics may still be difficult (Bao & Redish, 2002). Although quantum physics is representationally very rich but it seems almost certain that traditional teaching ignores these richness. Student ability to build different kinds of physics representations for quantum physics can help them understand and use key physics concepts. Therefore, quantum physics lectures based on multimodality or multiple representations is an alternative way to enhance students’ understanding of quantum physics concepts.

As an importance comparative view, many novice chemistry teachers struggle to translate their domain understanding into an effective teaching practice. Because experienced teachers’ thinking is not always shared with beginning teachers, this can result in novice teachers not fully understanding how the complex process of teaching and learning occurs (Ballet, Kelchtermans, & Loughran, 2006; Loughran, *et al*, 2001). Similarly, students' thinking is not often adequately explored within the classroom. We utilized an approach (Waldrip, Prain & Carolan, 2010) that conceptualizes facilitation of student learning in terms of Roberts' (1996) "trialogue", a three-way reciprocal linkage between teacher, student and content knowledge. In this paper, we suggest that exploration of students' thinking combined with teacher facilitation can lead to improved student understanding of the challenges entailed in representing concepts and processes in chemistry. This exploration entails teacher recognition that students' thinking often diverges from the teacher's expert domain knowledge, and that there is a need to make explicit students' thinking around representational adequacy to facilitate learning. In many classrooms, the teacher is seen as the source of knowledge, and teaching is characterized as timely imparting of this knowledge. We see that it is important for students to generate their own understandings (Ehrlen, 2009; Creagh, 2008) through making representations of their emerging understandings, including drawing, modeling, discussions, tables, graphs, multi-media products, role plays, and photographs, in a process of guided inquiry.

There is growing agreement that learning concepts and methods in science entails understanding and conceptually linking different representational modes (Ainsworth, 1999; Saul, 2004). Students need to be able to understand different representations of science concepts and processes, translate them into one another, and understand their co-ordinated use in representing scientific explanations. Student learning and engagement can be enhanced when students identify links between their own and authorised multiple and multimodal representations of science concepts and processes. diSessa (2004) suggested that secondary students are capable of discerning criteria by which an effective representation can be judged, criteria such as:

- Adequacy, in that all relevant information is shown.
- Conciseness, with a focus on pertinent points and avoiding distraction.
- Comprehensibility, in that a representation is self-sufficient in making its claims clear.
- Alignment, in that linkages between different parts of a representation are shown clearly.
- Conventionality, in that accepted conventions are observed.

He pointed out that judging the value of a representation is complex and content-dependent, where fit for purpose is also an important element in effectiveness. In comparing how expert chemists and chemistry students construct and use representations, Kozma (2003) noted that students had difficulty translating between representations, and connecting them. Kozma and Russell (2005) proposed a five stage conceptual structure of representational competence. It is clear that they are seeing high-level competence in using representations as a thinking tool to be used for more re-interpretive thinking.

Multimodality refers to the integration in science discourse of different modes to represent scientific reasoning and findings (Waldrip, Prain, & Carolan, 2006). The same concepts is re-represented through different forms or “multiple representations” in verbal, numerical, visual, or actional modes. A focus on multimodal thinking and representation encourages students to coordinate their different representations of scientific knowledge. Ainsworth (1999) stated that learner engagement with expert-generated representations could support learning in three ways. These are (a) when the new representation complements past understanding by confirming past knowledge, (b) the new representation constrains interpretation by limiting the learners' focus on key conceptual features, (c) the different representations enable learners to identify an underlying concepts or abstraction across modes or within the same mode of representation.

There are several innovative ongoing research and educational projects, especially on visual representation of quantum physics. For example, Zollman, Rebello, & Hogg (2002) have integrated quantum physics as a part of introductory level physics with developed Visual Quantum Mechanics (VQM) visualization materials. Based on the preliminary results VQM material is suitable for the teaching of quantum physics also for novice physics students or engineering students. Also Robblee, Garik, & Abegg (1999) have achieved good learning results by using Quantum Science Across Disciplines (QSAD) software in the upper secondary school teacher education. Based on the results of these studies it seems that different kinds of computer based visualization techniques can enhance the students' understanding of quantum physics.

Furthermore, we can predict that students who learn in a multiple-representation environment would show a greater improvement in understanding quantum physics concepts than students who learned in a single-representation environment. In addition, we expect instruction environment based on multiple representation effects to be particularly strong for (1) high-achieving student understanding and solved quantum physics problem in rich formats of representations, (2) using appropriate strategies for solving physics problems. Thus, in the science class, students should be able not only translate language about the topic between science and everyday language in the text-dominant classroom, but also have experience at re-representing the concepts discussed across the various modes used within the topic (Gunel, Hand, & Gunduz, 2007).

Besides understanding physics concepts, there is another goal in learning physics which is very important for students as the rising generation to meet their challenges and capitalize on their opportunities in future. Many instructors clearly fail in the "hidden curriculum" category to leave students with a positive attitude towards physics, especially for pre-service physics teacher students. This should be beyond simply "liking" physics; it encompasses an appreciation of how physicists think and operate, the value of physics as it applies to other fields such as engineering, biology, medicine, etc., and the applicability of physics to everyday life and various jobs in society (Brotosiswojo, 2001; Duda & Garret, 2007).

Therefore, the rich environment instruction of physics could help to achieve generic science skills that are required for everyday life and professional jobs. There are at least eight scientific generic skills which could be generated in learning physics, including ability in : (1) direct and indirect observation ; (2) sense of scale; (3) using symbolic language; (4) developing need for logical self-consistency; (5) developing logical inference ; (6) understanding causality ; (7) developing mathematical modeling ; and (8) developing concepts (Brotosiswojo, 2001).

Students' generic science skills could be built through learning physics that is encouraging higher order thinking process, like critical thinking. Therefore, critical thinking skills as a higher order thinking is considered an important variable in the process of students' learning science (Liliasari, 2007). Students' ability to think critically has become a major concern among educators and psychologists as they try to study the factors influencing the acquisition of thinking skills. Much recent research focuses on the relationship of several variables, the students' critical thinking dispositions, students' perceptions towards teachers' teaching approaches, the learning approaches students employ in the process of learning, and critical thinking skills as the learning outcome (Facione, 1995; Wan Sulaeman, Abdul Rahman, & Dzulkifli, 2007).

The development of critical thinking is an important step in achieving the goals of holistic education, not only through helping students gain knowledge but above all through ensuring that they think effectively. The learning of thinking skills will be even more meaningful when it is reinforced in the lessons taught. When thinking skills are infused and weaved into the lesson instruction, students are able to gain a deeper understanding of the content they are learning, resulting in meaningful and transferable knowledge (Ennis, 1996; Rutherford and Ahlgren, 1990; Costa, 1985).

As noted prior that many crucial aspects of systems of external representations and the meaningful transformation of information in learning physics related to thinking ability, therefore the physics instructional design based on multiple representation is believed to enhance students' thinking skills.

Facione, Facione & Giancarlo (2000) have hypothesized that skills in critical thinking is positively correlated with the consistent internal motivation to think; and, moreover, that specific critical thinking skills are matched with specific critical thinking dispositions. If true, these assumptions suggest that a thinking skill-focused curriculum would lead persons to be both willing and able to think.

This research has been done with focus on designing learning and teaching quantum physics with rich environment based on multimodal representation and its influence toward quantum physics concepts mastery, generic science skills, critical thinking disposition for pre-service physics teacher students.

1.2 Statement of Problem and Research Questions

The main problem of this research is how to design quantum physics instructional strategies based on multiple representation for enhancing concepts mastery, critical thinking disposition, and generic science skills. This study has attempted to answer the following research questions:

a) How do the students prefer certain physics representations before experiencing the unit of quantum physics instruction based on multiple representations?
b) How are the students' conceptions about quantum physics concepts before and after getting the unit of quantum physics instruction based on multiple representations?
c) What are the characteristics of quantum physics instruction designs based on multiple representations?
d) What are the different effects of the multiple representations-based instructions of quantum physics compared to the conventional instructions in enhancing concepts mastery, generic science skills, and critical thinking disposition?

e) What are the different effects of the multiple representations-based instructions compared to the conventional teaching method on pre-service physics teacher students to enhance re-representation skills?

f) How do the students use multiple representations when they encounter a quantum physics learning situation and solve quantum physics problem?

g) What are students' perceptions about teaching and learning quantum physics based on multiple representations?

1.3 Research Objectives

The primary purpose of this study is to design and descript the impact of an instruction strategy based on multiple representations on pre-service physics teacher students to quantum physics concepts understanding, critical thinking disposition, and generic science skills. An embedded mixed method will be used in this research. Furthermore, this study seeks to attain the following purposes:

a) to enhance quality of teaching and learning on quantum physics through multiple representation-based instructions

b) to enhance students' performance in quantum physics concept mastery

c) to develop students' generic science skills

d) to develop students' high order thinking skill, especially in critical thinking disposition

e) to supply examples of how pre-service physics teachers student design innovative instruction based on multiple representations.

1.4 Advantages of Research

The major contribution of this research is an innovative teaching and learning physics invention-based on multiple representations, a reasoning framework for analyzing and describing how students understand and use multiple representations in the context of quantum physics. The practical framework of this dissertation offers educators and researchers a technical language capable of describing students' (correct and incorrect) use of multimodal representations in quantum physics. Also, include that no study has investigated this unique combination of representations, reasoning framework including critical thinking and generic science skills.

The advantages of the research detail were following:

a) That is, this practical framework offers a new *vocabulary* for pre service physics teachers (definition of the relevant internal and external representation) and *grammar* (relationship between internal and external representation) for analyzing and describing students' quantum physics concepts mastery, critical thinking disposition, and generic science skills. It is useful for researchers and educators in three important ways: it synthesizes previous research into one coherent framework, it can be used as a diagnostic tool during instruction, and it can be used as a guide for future instruction and curriculum development.

b) Teaching and learning physics based on multiple representations where different modes serve different needs in relation to reasoning and recording scientific inquiry. In this way, mathematical, verbal, graphical, pictorial, simulation and others have been used individually and in coordinated ways to represent the knowledge claims of science discourse, with more recent technology which was invented as the investigation results of modern physics or quantum physics-mediated representations of science consistent with, rather than a deviation from, this evolution of science as a discipline.

c) By implication, students need to learn about the multi-modal nature of the representations entailed in scientific inquiry, and the different modes in which the same concepts in physics can be represented as part of students' general development of science literacy.

1.5 Definitions of the Important Terms

a) Multimodality refers to the integration in science discourse of different modes to represent scientific reasoning and findings (Waldrip, Prain & Carolan, 2006).

b) Internal representations can be defined as "individual cognitive configurations inferred from human behavior describing some aspects of the process of thinking and problem solving that formed mental configurations on students' minds (Lasry & Aulls, 2007).

c) External representations can be defined as "structured physical situations that can be seen as embodying physics ideas that stands for, depicts, symbolizes or represents objects and/or processes. Examples in physics include words, diagrams, equations, graphs, simulation, sketches, etc (Meltzer, 2005).

d) The representational mode is viewed as a cognitive mode that is dealing with the production of external representations of a learner's internal representation of an idea (Schnotz & Lowe, 2003).

e) Generic science skills: Fundamental skills that could be generated through innovation in learning science, such as a quantum physics class. There are eight indicators of scientific generic skills including: direct and indirect observation, sense of scale, using symbolic language, developing need for logical self-consistency, developing logical inference, understanding causality, developing mathematical modeling, and developing concepts (Brotosiswojo, 2001).

f) Critical Thinking Disposition: We propose to use the word “dispositions” as applied to humans to refer to characterological attributes of individuals. As such, a human disposition is a person’s persistent internal motivation to act toward, or to respond to, persons, events, or circumstances in habitual, and yet potentially malleable, ways. There are seven aspects of the overall disposition toward Critical Thinking: truth-seeking, open-mindedness, analyticity, systematicity, self-confidence, inquisitiveness, and cognitive maturity (Facione, Facione, & Giancarlo, 2000).

g) Multiple representations-based instructions: It is a kind of instructions strategy that involves multiple representations in concepts explanations. This means that in order to explain a concepts, a variety of external representations such as tables, graphs, pictures, symbols, equations, analogy etc. for comprehending the concepts are used (Kohl & Finkelstein, 2006)

h) Conventional-based Instructions: It is a kind of instructional strategy which used limitation of representations mode in learning and teaching physics concepts by a teacher or lecturer (Kohl & Finkelstein, 2006).

i) Quantum physics concepts is the physics subject matter concepts which describes the nature and behavior of matter and radiation, particularly at the microscopic level (Hobson, 2007). The main topics of quantum physics in this research are restricted to covering the: (1) Photoelectric Effect, (2) Bohr's Atom Model, and (3) Solution of the Schrödinger Equation for a 1 D Quantum Box System and the Hydrogen Atom.