Science and Mathematics Education Centre

The Influence of Multiple Representations and Attitudes to Learning on the First year Non-Physics Majors' Conceptual Understanding

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published by any person except where due acknowledgement has been made.

Signature:

Date: December 2012

Abstract

The study described in this thesis was conducted in a university in Australia with non-Physics majors studying Introductory Physics over three semesters. The main theme in this thesis was to study the relationship between students' use of multiple representations, their attitudes towards learning Physics and their conceptual understanding. The assessment in the Physics unit was designed to encourage students to represent their knowledge with as many representations as they could. Two multiple representational questionnaires on the topics of thermal physics and optics were developed to assess students' conceptual understanding and for their learning. In addition, three attitude-related surveys - Physics Motivation Survey, Expectation Survey and Experience Survey - were administered to measure students' attitude towards learning Physics.

Phase One of the study focused on observing the lecturer and tutors' representations in class and accordingly, developing the multiple representations questionnaire prior to its first trial. In Phase Two, the revised multiple representations questionnaires were administered as the second trial, and a marking key was developed for the questionnaires. In addition, three attitude-related surveys were administered in the first trial to clarify students' attitudes to learning, because some inattentive learning behaviours were observed in Phase One.

Phase Three was the most productive phase because this phase built on what was learned from Phases One and Two. Based on the results of Phase Two, the multiple representational questionnaires testing thermal physics and optics were revised and administered in a third trial, and the three attitude related surveys were given the second trial. In addition, in Phase Three, the time spent on different representations used by the lecturer was recorded. These data were used to obtain further understanding of the relationship between multiple representations, students' attitudes to learning Physics and students' conceptual understanding. Also approximately 50 % of the student cohort (n = 70) was interviewed.

In Phase Three, the results of post-tests of the multiple representational questionnaires showed that students' marks varied considerably on the zero to three scale; however, the average mark of all representations, number of different mode representations presented in each question improved significantly based on both on t-tests and effect size compared to their pre-tests. It was speculated that the improvement was due to the effect of the lectures and tutorials that were designed to make students explicitly more aware of the different ways they can represent their knowledge. Besides, it was found that the time of teaching in one representation had no significant correlation with students' improvement of mark in that representation.

During the interviews, students were able to provide more elaborate and richer explanations than on their written responses alone because they were able to clarify their written responses. Students had more opportunities to confront cognitive conflicts when the interviewer reminded students about the mistakes they made in the questionnaire or in their oral explanation. The research showed that students' prior knowledge (e.g., representational, referent and conceptual knowledge) was important to make the best use of multiple representations.

The three attitude-related surveys had high Cronbach alpha reliabilities and were generally effective in measuring students' attitudes and unit learning experiences. Based on students' responses to the three surveys, their attitudes towards learning Physics was positive in spite of some assessment anxiety, and they reported positive experiences during the semester. Students' expectations of the unit they attended had medium correlation($r=0.37$ in thermal module, $r=0.38$ in optics module) with their conceptual understanding. However, the careless attitudes observed by some students may have limited their learning with multiple representations. We recommend further study examining the causes of students' learning attitude and learning behaviour, and how these causes interact with each other to influence students' conceptual understanding while learning physics with multiple representations.

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CHAPTER 1

Introduction

1.1 Overview of this Chapter

In this thesis, multiple representations of physics concepts and students' learning attitudes to physics were the two topics to be investigated. The research background on multiple representations used in students' learning and assessment is introduced, followed by literature review of students' attitudes related to their learning outcomes. The methodology used in this thesis, namely a case study approach, is briefly described here with more details in Chapter Three. Also in this chapter, the rationales for the study, the research questions, the significance, ethical issues and limitations of the research are described. Finally, an overview of this thesis is provided to introduce the coming chapters.

1.2 Learning and Assessment Using Multiple Representations

In recent years, there has been an increasing amount of research discussing the effects of teaching and learning with multiple representations. Although there is growing recognition that students have to understand and link different representations in learning to think and act scientifically, this task is not easily achieved. There are many factors which can influence the effect of students' learning with multiple representations. For example, Cook (2006) and Seufert (2003) have argued that students' prior knowledge is a key factor in multiple representational learning. To summarize these factors, Ainsworth (2006) provided a conceptual framework (DeFT –Design, Functions, Tasks) for considering teaching and learning with multiple representations. In her paper, Ainsworth illustrates how the effectiveness of multiple representations can be evaluated taking into account the three phases: the design parameters of representations, the functions that representations provide for learning, and the cognitive tasks which have to be undertaken by learners. Nevertheless, before forming more solid principles for using multiple representations in instruction, more research studies are needed to verify the effectiveness of multiple representations from the three phases.

A related construct to learning with multiple representations is higher-order thinking. If science courses are going to involve students in higher-order thinking, then students need to be able to construct arguments, ask questions, make comparisons, establish causal relationships, identify hidden assumptions, evaluate and interpret data, formulate hypotheses and identify and control variables (Osborne & Dillon, 2008). Earlier, Black and William (1998) suggested alternative forms of assessment which emphasize student reasoning rather than knowledge acquisition. To achieve the goal of assessing students' multiple abilities in science learning, many tasks can be designed in the process of teaching. Treagust, Jacobowitz, Gallagher, and Parker (2001) embedded different tasks such as pre-tests, asking questions of students, conducting experiments and activities, writing tasks, drawing diagrams in the instruction on the topic of sound to Grade 8 students. The research showed that students' understanding was more effectively assessed with multiple representations rather than one representation. In our research, to assess students' conceptual understanding more objectively, we have developed multiple representations questionnaires which assess students' conceptual understandings of several key physics concepts using multiple representations. The questionnaires were also used for students' learning as a take home assignment, so we had the opportunity to understand how the multiple representations in the questionnaire worked during students' learning concepts.

1.3 Students' Attitudes towards Learning

The importance of students' attitudes (e.g. motivation, expectations) towards learning Physics has been well documented by research in the past years. Frequently, students' attitudes towards learning Physics has a positive correlation with academic achievement and conceptual understanding but this is not always the case. Furthermore, Nieswandt and Shanahan (2008) found that motivation can influence students' goal structure in learning and Redish, Saul, and Steinberg (1998) showed that the students' expectations and their actual experiences on a Physics course can impact what they learn from the course. As noted by Tobin, Seiler, and Walls (1999), if students lack motivation to learn, it is difficult to engage students in the instruction. Indeed, instruction in science classes should not only take into account cognitive abilities but also students' attitudes toward the subject. Park (2007) stated that instructors need to think about the components of students' conceptual development relating to logical structure, rational process and affective aspects. Since the importance of students' attitude toward learning should not be neglected in the science classroom, more research to examine the relationship between students' attitude and their learning is needed.

1.4 Research Methodology Used in this Thesis

This case study was conducted at a university in Australia, over three semesters. Each semester was defined by a research phase; therefore, the first semester was the first research phase and so on. In Research Phases One and Two, the students studied the same units, Physics A and Physics B, which are designed for non-Physics major students. In Research Phase Three, one more unit, Physics C, was included and all students were non-Physics majors. The theme of study in Research Phase One was how multiple representations can be presented in Physics; the main task was to design and develop multiple representations questionnaires based on classroom observations and meeting with Physics experts. In Research Phase Two, the students' attitudes towards learning was added to the main themes of research; the main tasks were to develop the multiple representations questionnaires and a marking key, and to find out how best to solicit students' representations. The questionnaires in this phase were mainly used for assessment of learning. Further, the trial administration of three surveys -the Physics Motivation Survey (revised from Science Motivation Questionnaire), the Expectation Survey and the Experience Survey was the other focus of the tasks. In Research Phase Three, the final version of the multiple representations questionnaires and the attitude and motivation surveys were administered. The multiple representations questionnaires in this phase were mainly used for assessment for (and as) learning. In addition, we obtained richer data by expanding our methodology to include student interviews. To summarize, the flowchart shown in Figure 1.1 summarises the three research phases, identifies the main tasks and informs where the details are provided in the thesis. Also, timeline charts of main tasks for each research phase are provided as shown in Figure 1.2, Figure 1.3 and Figure 1.4.

Research Phase One

Theme: Development of Multiple Representations Questionnaires

- Classroom observation—observed lecturers' and tutors' representations
- Developed and administered multiple representations questionnaires—to test the questionnaires
- Met with Physics experts—discussed teaching experience, research data and future research in the next research phase
- Details are presented in Chapters 3 and 4

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Research Phase Two

Theme: Trialing of Multiple Representations Questionnaires and Attitude Surveys

- Developed and administered multiple representations questionnaires—to test the questionnaires
- Developed the marking key for the multiple representations questionnaires
- Administered Physics Motivation Survey—to test the reliability of the survey and to know students' motivation
- Administered Expectation Survey and Experience Survey—to test the reliability of both surveys and to know if students' experience could meet their expectation
- Details are presented in Chapters 3 and 4

⇩

Research Phase Three

Theme: Administration of the Final Versions of the Multiple Representations Questionnaires and the Attitude Survey Instruments

- Developed and administered multiple representations questionnaires—for students' learning and for assessing their conceptual understanding
- Classroom observation—observed the time of different representations used by lecturer and tutors
- Interviewed students
- Details are presented in Chapters 5 and 6
- Administered Physics Motivation Survey—to test the construct validity, the reliability of the survey and to know students' motivation
- Administered Expectation Survey and Experience Survey—to test the reliability of both surveys and to know if students' experiences could meet their expectations
- Interviewed students
- Details are presented in Chapter 7

Figure 1.1 The theme, main tasks and where the details are provided in this thesis for each research phase.

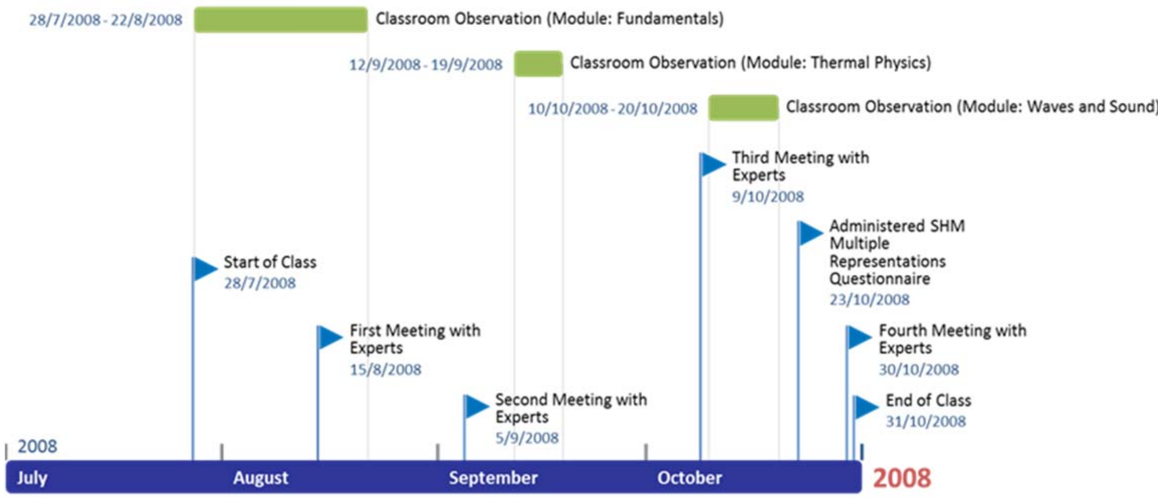


Figure 1.2 Timeline Chart of Main Tasks for Research Phase One

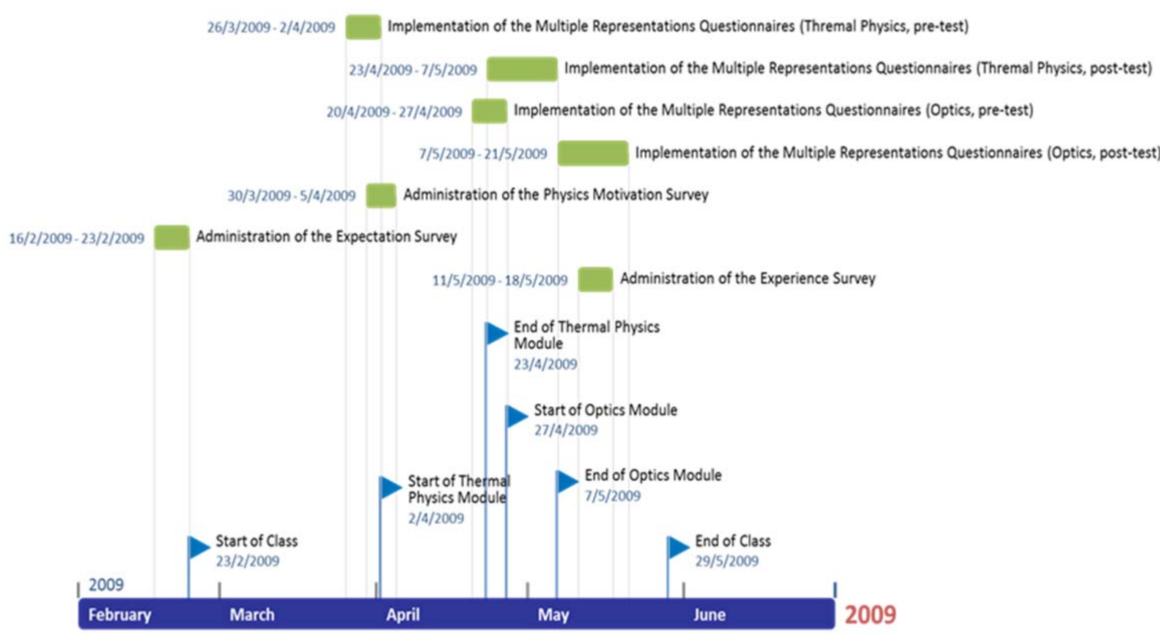


Figure 1.3 Timeline Chart of Main Tasks for Research Phase Two

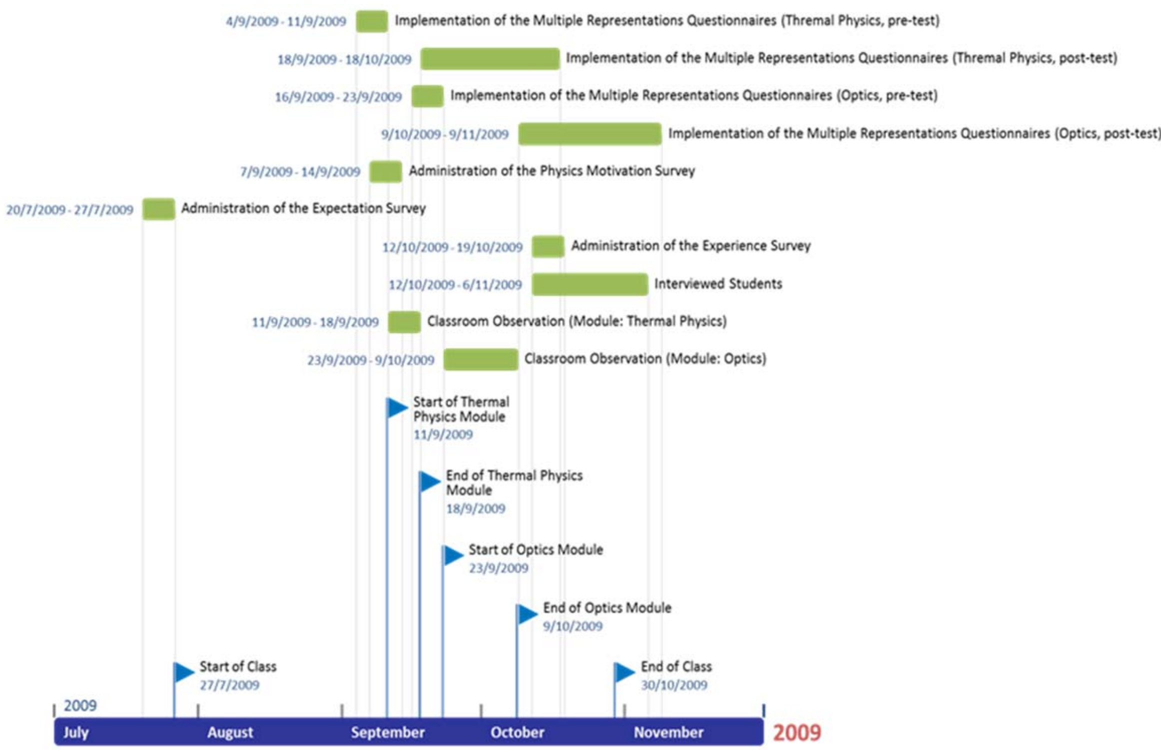


Figure 1.4 Timeline Chart of Main Tasks for Research Phase Three

1.5 Rationale for the Study

The conceptual understanding of many students enrolled in university introductory Physics courses has been doubted for years and needs to be further researched. This case study not only can contribute an understanding of first year students' conceptual level in introductory Physics, but also to an understanding of, and under what conditions, the multiple representations can or cannot help students' learning. Furthermore, due to having observed unit students' inattentive behaviour in class, this study investigated how students' attitudes towards learning influenced their conceptual understanding, which has not been well researched with non-Physics majors.

This study also can contribute to the literature by showing how a multiple representations questionnaire is developed for a specific university unit and topic, including the development of its marking key. In addition, the Expectation Survey and the Experience Survey used in this study having been developed from an Australian Teaching and Learning grant were deemed relevant for the student group.

The reliability and validity of the surveys were verified in this study. The Physics Motivation Survey was adapted for use with this group of non-Physics majors.

From the position of improving the Physics units, this study can help identify students' conceptual understanding and their learning attitudes. The developed multiple representations questionnaires provide another way for the instructor to assess the students' conceptual understandings and learning. Examining students' learning attitudes provides another issue in assessing students' learning, and can become a reference for the instructor's teaching.

1.6 Research Aims and Research Questions

In this case study, in order to become familiar with the Physics units A, B and C, which are taught every semester, the data collected during one research phase was analysed before the next research phase in the coming semester. As shown in Figure 1.1, the aim of Research Phase One was to develop multiple representations questionnaires and the aim of Research Phase Two was to trial the multiple representations questionnaires, to determine the reliability of the existing instruments for measuring attitudes towards learning and modify the existing motivation survey for studying Physics for this audience. Once the instruments were developed, designed and/or trialled and measured for acceptable reliability and validity, the aim of Research Phase Three was to answer the following research questions.

Research Question 1: What are students' evaluations of the use of multiple representations questionnaires in Optics and Thermal Physics?

Research Question 2: What were the levels of students' conceptual understandings based on the analysis of the multiple representations questionnaires in Optics and Thermal Physics and interview oral explanations?

Research Question 3: How did students perform when explaining their concepts using one representation on the Optics and Thermal Physics questionnaires?

Research Question 4: How well did students perform in their multiple representations with and without guidance on the optics and thermal physics questionnaires?

Research Question 5: What were the students' attitudes towards learning Physics?

Research Question 6: Is there any relationship between students' learning attitudes and the depth of students' conceptual understanding in optics and thermal physics?

1.7 Significance of this Study

This study will not only demonstrate how to develop multiple representations questionnaires and marking keys for two modules (Thermal Physics and Optics) from a first year university Physics unit, but also identify conditions in which multiple representations may or may not help students' learning. Furthermore, this study will explore how students' learning attitudes impact upon their conceptual understanding, and further verify the reliability and validity of the selected attitude related surveys. From a practical teaching experience, this study provides an opportunity to further improve the students' learning and instructor's teaching in the target modules, and seeks to provide different perspectives to assess students' learning (e.g. use multiple representations questionnaires, students' learning attitudes). Finally, this study tested Pierce's Model and Ainsworth's framework about how appropriate are the functions of multiple representations for analysing students' learning, and suggestions for future studies.

1.8 Ethical Issues

Ethics approval for this study was obtained as shown in Appendix 1.1. Prior to commencing the research, the participants were provided with information about the aims of this research, the background of the researchers, and the ways that students can contact the researchers. Permission for the use of audio-recording for interviewing students was obtained. In addition, the names of the student participants remain anonymous in any related publication to protect their identity.

1.9 Limitations of this Study

As with any research, there are some limitations in this study. Firstly, the sample was not randomly selected because students could decide if participate in our research or not. Besides that, the studied units were only one semester (one research phase) long. Although the samples were all non-Physics majors from research Phase One to research Phase Three, there were different students in each phase.

The second limitation is related to the research instruments used. In this thesis, we used four representations (written words, diagrams, formulae, coordinate graphs) to represent "multiple representations", and to assess students' conceptual understanding. However, students' conceptual understanding also can be represented by other representations (e.g. concept maps).We used multiple representations questionnaires to assess students' conceptual understanding, although not all concepts taught in class were tested in the questionnaire. Similarly, the attitude related surveys we selected did not assess all aspects of students' learning attitudes.

Third, some research methods (e.g. classroom observations, interviewing students) and data interpretation (e.g. interpret interview excerpts) were mostly conducted by one person. However, in order to achieve a high level of reliability and validity, the researcher and supervisors met on a regular basis to ensure consistency and confirm the data collection procedures. In addition, one of the supervisors sat in on several interviews with students. Finally, due to the nature of case study, the conclusion of this study may not apply to a different study background (e.g. in a different university). Namely the generalization (external validity) of this study has limitations.

1.10 Thesis Overview

There are eight chapters in this thesis. The first chapter and last chapter are introduction and conclusion, respectively. Chapter Two is the literature review for this study, and it discusses the related literature on the topics of learning and assessment with multiple representations, students' attitudes toward learning Physics, and learning and teaching of introductory Physics. Furthermore, the theoretical framework is also introduced in this chapter. Chapter Three includes the methodologies used in each research phase, which describes the research aims and questions, research methods, research instruments and data analysis procedures. Chapter Four presents the results of data analysis in research Phase One and Two, discussions of the results are also made in this chapter. As for the results and discussions of Research Phase Three, they are divided into three chapters (from Chapter Five, Six and Seven) because the data obtained in this phase were much richer than those in the other two phases and comprise the main point of the study. In Chapter Five, the focus is on responding to the Research Questions 1 and 2. Students' evaluation of the multiple representations questionnaires are provided, and students' level of conceptual understanding is also discussed according to their questionnaire answers and their oral explanations. Responding to the Research Question 3 and 4 is the whole content of Chapter Six, where we demonstrate which functions of multiple representations students used, important factors affecting students' learning and the helpfulness of guidance for students' learning with multiple representations. Chapter Seven is about students' learning attitudes, which relates to the Research Questions 5 and 6. The validity and reliability of the selected attitude surveys and the level of the subjects' learning attitudes based on Likert's scale are presented and discussed. We also attempt to determine the relationship (if any) between students' learning attitudes and their conceptual understandings by conducting the correlation test and discussing the causes of, and threats to, students' attitudes to learning. In Chapter Eight, we conclude our findings by briefly addressing each research question. This is followed by the implications for future instruction with multiple representations, and recommendations for improving the target units, instruction and research.

CHAPTER 2

Literature Review

2.1 Introduction

For many decades, there have been many research studies focusing on students' alternative conceptions. After more and more students' alternative conceptions had been identified, attention changed to how to teach in such a way to change those students' alternative conceptions to scientific ones. However, students' conceptual change is not an easy task, and more and more factors have been concerned and their effects on students' conceptual change have been considered (Duit & Treagust, 1998; Duit & Treagust, 2003).These factors include students' attitudes, students' use of multiple representations, contextual factors and so on. Up to now, those concerns still need more research to verify their functions and roles in student learning.

In this chapter, we review literature related to multiple representations, students' attitudes towards learning Physics, learning introductory Physics and specifically learning the topics of thermal physics and optics. Also, two theoretical frameworks that inform this study, Ainsworth's DeFT framework and Peirce's triadic model, are introduced. Last, the relations between the research questions and the literature that we review are illustrated.

2.2 Multiple Representations Used in Teaching, Learning and Assessment

Various representations are used in different instructional settings, yet they can be generally categorised as descriptive, figurative, mathematical, experimental, and kinaesthetic representations(Tytler, Prain, & Peterson, 2007). Each representation has its own features and advantages, for instance, diagrams are suitable for presenting and explaining laboratory equipment (Chittleborough & Treagust, 2008). Although one representation has its own advantage in instruction, multiple representations may create more benefits. Many papers describe the advantages that multiple representations can bring(e.g. Ainsworth, 1999; Galili, 1996)but it is not easy for learners to gain those advantages. Learners usually cannot make use of multiple representations effectively (van Someren, Reimann, Boshuizen, & DeJong, 1998) and multiple representations need to be handled carefully in instruction (Ainsworth, 2008).

Multiple representations pose more cognitive demands on learners at the same time (Waldrip, Prain, & Carolan, 2006); for example Schnotz and Bannert(2003) claimed that in order to integrate verbal and pictorial representations as a mental representation, learners need to experience the process of information selection and information organisation, parsing of symbol structures, mapping of analog structures as well as model construction and model inspection. To form a mental representation with coherent knowledge structures while learning with multiple representations requires the learners to have high cognitive and metacognitive skills (T. Seufert, 2003).To consider those cognitive issues, Ainsworth (2006)developed a framework including three main aspects, namely design of representations, function of representations and cognitive tasks undertaken by the learners, which can be referred to when multiple representations are used in instruction. With this framework, more research is required to explore the effects of multiple representations on learners.

Although multiple representations have different effects on different learners, fortunately, the ability to use multiple representations can be taught and students educated to use them (Chandrasegaran, Treagust, & Mocerino, 2007, 2008). However, a teacher or tutor for students learning multiple representations is usually necessary (Chittleborough & Treagust, 2008; Tytler, et al., 2007) so they can gain support in forming coherent knowledge structures (T. Seufert, 2003), especially for those who learn in an unfamiliar domain (Reif & Larkin, 2006) and those with low prior knowledge (Kozma & Russell, 1997). Ford (2008) proposed that the teacher should play a role of critique while students learning, pointing out problems or inconsistencies that students make and modeling their knowledge claims to scientific ones. Besides, in a timely way the teacher can clarify students' representations, and accordingly guide students' reasoning and the conventions in their different representations (Waldrip, Prain, & Carolan, 2010).Ainsworth (1999)raised the question when is the proper timing for the teacher to help students relate different representations? When learners fail to link the multiple representations by themselves, they do need the teacher's help. However, if they begin to succeed in the link, the help should be faded out. Tytler, et al. (2007) further pointed out that it takes time for students to develop concepts using multiple representations. Therefore, students' concept learning with multiple representations needs teacher's help and patience.

One of main issues considering learning with multiple representations is to integrate them. Many studies show that learning with integrated representations leads to better performance or knowledge than learning with non-integrated representations(e.g. Chandler & Sweller, 1991; van der Meij & de Jong, 2006). Integrated representations can help learners relate or translate the different representations. Nevertheless, Bodemer, Ploetzner, Feuerlein, and Spada (2004) emphasized the integration should be done by the learners themselves, otherwise the learners do not necessarily learn better.

Another main issue is student-generated representations. From a science teaching perspective, in order to cultivate students' competence of interpreting, integrating and reproducing multiple representations within or across topics, it is essential to involve not only authorised (or justified), but also student-generated representations (Tytler, et al., 2007). If students only participate in teacher-designed activities, their opportunities of learning may be constrained (Greeno & Hall, 1997). Investigating students' representations is a way to access their mental representations (Halloum, 1996), and it can become a starting point for instruction (Hubber, 2006; Hubber, Tytler, & Haslam, 2010). Waldrip, et al.(2010) pointed that students' representations can be a tool for judging and developing their understanding. From the angle of learners, they not only can use their representations to record initial and new thinking, to scaffold understanding(Tytler, Peterson, & Prain, 2006), but also to explore science ideas (Dufresne, Gerace, & Leonard, 1997; Tytler, Haslam, Prain, & Hubber, 2009; Tytler, et al., 2007).Furthermore, it was found that letting students generate representations can increase their ownership of their work, and raise the students' learning motivation and creativity (Hubber, 2005; Waldrip, et al., 2006). In short, students should learn to use their representations to think, predict and make their claims (Giere & Moffatt, 2003), and the knowledge developed in this way is more durable than in the way of just using teacher's representations(Waldrip, et al., 2010).

In other aspect, few studies focused on assessment using multiple representations. Rosengrant, Etkina, and Van Heuvelen (2007) pointed there were two trends when studying students' problem solving using multiple representations: one was to study how question formats influence students' performance, and the other was to study how students use multiple representations when they solve problems. For instance, Dufresne, et al. (1997) suggested a question format which explicitly asked students to solve the problems step by step could involve students to use the different representations and during the process of students' problem solving, teachers should play an active role. (2006) found that based on their interviewing students, and students' exam responses, high-achieving students could use one representation to evaluate the result gained from other different representation. However, this kind of research, namely assessment of, for or as learning using multiple representations, is quite limited so far.

In this thesis, we developed integrated, student-generated representational questionnaires to review and assess students' learning of the observed Physics units. Besides, we sought to examine the difference in students' cognitive learning in the condition with and without a tutor's instant guidance. Lastly, by applying Pierce's Model (1931) and Ainsworth's framework (1999) about functions of multiple representations to analyzing students' representations, we examine what factors are important , and which functions students used during their learning.

2.3 Students' Attitude towards Learning Science

Students' attitudes influence their learning performance and this aspect has attracted many researchers' attention. For instance, Shrigley (1990) argued that a moderate correlation can be expected between learners' attitudes and their ability scores. Halloun (1997)investigated college students' views about science and discovered that the students who had more expert-like views had better performance in their courses. With a different result, Jurisevic, Glazar, Pucko, and Devetak (2008) found that there is no strong correlation between knowledge test results and motivation in pre-service primary school teachers. It is controversial to determine to what degree the correlation exists between students' learning attitudes and their academic performance, and even more difficult, to prove there is a causal relationship between them. A proper description of the relationship of the two is that they link in a complex interaction (Osborne, Simon, & Collins, 2003).

However, research has generally shown that learning attitudes play an important role in the process of learning. Pintrich, Marx, and Boyle (1993) proposed that students' motivational beliefs can facilitate or hinder their conceptual change. Another similar paper presented that students' beliefs about conceptual knowledge would affect their conceptual evolution(Hammer, 1994b). Hammer (1994a)also argued students' beliefs about Physics may limit their development of knowledge and abilities. Barmby, Kind, and Jones (2008) suggested students' learning attitudes should be emphasised while they learn science at school. The importance of learning attitudes also applied to females. Hazari, Tai, and Sadler (2007) found that when females have more confidence after they study introductory Physics, there is a greater chance for them to further study more Physics. Besides, there are more and more innovative technological tools used in instruction, but they have confronted a problem that students may lack motivation to learn(Pintrich, 2003). Chu, Treagust, and Chandrasegaran (2008) indicated that students' beliefs of Physics knowledge and interest in learning Physics dominate over students' previous Physics experience in their conceptual development.

Since students' attitude toward learning science is important, the issue of how to measure students' attitude has been given attention in this study. Many instruments have been developed to measure students' attitude toward science or mathematics, however, every instrument has different definitions and scales about attitude (Leder, 1985). Besides, the methods used to measure attitude can be various such as subject preference studies, attitude scales, interest inventories, subject enrolment, and qualitative methodologies (Osborne, et al., 2003), each method can only measure one aspect of individual's attitude (Petty, Wegener, & Fabrigar, 1997; Potter & Wetherell, 1987). Osborne, et al.'s article (2003) further mentioned that just a few studies tried to use the method of interview to explore students' attitudes.

Blalock et al., (2008) reviewed and evaluated 66 science attitude instruments distributed in 150 published articles from year 1935 to 2005, and found that most instruments had single study usage and lacked psychometric evidence. As Gardner

(1995) stated that a good instrument should be internally consistent and unidimensional, more evidence showing the reliability and validity of the existing instruments is needed. Also, more studies checking the generalizability of the instruments (e.g. used in different disciplines) are necessary (Pintrich, 2003).

In the aspect of measuring students' attitude towards learning Physics, Colorado Learning Attitudes about Science Survey (CLASS) (Adams et al., 2006), Maryland Physics Expectations Survey (MPEX) (Redish, et al., 1998), Views About Sciences Survey (VASS) (Halloun & Hestenes, 1998), Epistemological Beliefs Assessment for Physical Science (EBAPS) ("Epistemological Beliefs Assessment for Physical Science (EBAPS) items,") are well-known instruments but they measure different aspects of students' attitudes toward Physics or learning Physics. Regardless of the difference, once the instrument has high validity and reliability, it can be accepted for use in studies. The instruments mentioned above also have been used for different research or instructional purposes in the classroom.

An appropriate measures of attitude used in this study is the Physics Motivation Survey revised from Science Motivation Questionnaire(S. M. Glynn & Koballa, 2006), and two surveys used as a pre and a post test. The pretest is an Expectation Survey and posttest is an Experience Survey (Kirkup & Mendez, 2009). The Science Motivation Questionnaire was developed in recent years and was applied to a different discipline - in this study, Physics - to assess its generalizability. The Expectation Survey and the Experience Survey were newly developed and needed more evidence to verify their validity and reliability. In this study, the validity and reliability of the three attitude-related surveys were tested in research phase two, and with the acceptable results, we used them to discuss the relationship between students' learning attitudes and their conceptual understanding in research phase three.

2.4 Learning and Teaching Introductory Physics

The competence of the Physics knowledge held by students taking introductory Physics has been questioned. For instance, Van Heuvelen (1991) found that introductory physics students cannot reason about physical processes qualitatively but rather in their minds, there are just a few facts and equations for them to randomly search for solving a problem. Similarly, Prosser, Walker, and Millar (1996)stated that just a few first year students tried to understand how the major principles work or apply their knowledge to the real world when learning Physics. Lin (1982)pointed out that most students studying introductory Physics knew that physicists work from general principles when solving problems, but they still worked from special cases. In the same article, many students stated the reason why they had such inappropriate learning behavior was because they did not have enough time; further, this article commented that assessment tasks are the main factor to drive students' learning.

It is true that Physics teachers have to take more responsibility than the students to help students understand Physics (Lasry, Finkelstein, & Mazur, 2009). Teachers have to observe students' situation of learning and if students have inattentive learning behaviours, teachers have to find out the reason behind the behaviour and try to prevent it from happening again. In the case study of this thesis, introductory Physics students' inattentive learning behaviours were observed and the possible reasons behind the behaviours are inferred. Besides, in order to try to improve students' competence of Physics, multiple representations were used in teaching and learning, and their effects on students' conceptual understanding are discussed.

2.5 Teaching and Learning in the Topic of Thermal Physics and Optics

In earlier ages, there were a large number of studies focusing on students' alternative conceptions in the area of thermal physics and optics(Fetherstonhaugh & Treagust, 1992), and students' alternative conceptions before and after instruction had been identified. For instance, in the area of thermal physics, students usually could not tell the difference between heat and temperature (Alwan, 2011; Eylon & Linn, 1988; Kesidou & Duit, 2006; Wiser & Amin, 2001; Yeo & Zadnik, 2001), and the concepts of heat and internal energy usually confused students (Warren, 1972).Besides, students had difficulties learning heat transfer and thermal equilibrium (Georgiou, Sharma, O'Byrne, Sefton, & McInnes, 2009; Paik, Cho, & Go, 2007). Within the concept of heat transfer, the difference between the rate of heat transfer and the amount of heat transferred could not be recognized (Miller et al., 2006). In addition, specific heat capacity was another concept with which students usually had difficulty (Jasien & Oberem, 2002). To help challenge students' alternative conceptions, many efforts have been made. Prince, Vigeant, and Nottis (2009)developed inquiry-based activities for undergraduate engineering students and found those activities were effective for conceptual change. Tanahoung, Chitaree, Soankwan, Sharma, and Johnston (2009) stated that a computer program Interactive Lecture Demonstrations was helpful for improving students' understanding of heat and temperature. There are other studies trying to use different teaching methods (Kinnear, 2005; She, 2003) or computer programs (Özmen, 2011; Zacharia & Olympiou, 2011) to promote students' conceptual change and they seemed to be able to change students' misconceptions to some extent.

Similarly with thermal physics, many research studies have identified students' alternative conceptions about light and its properties (Cavell & Jones, 1995). Students usually hold alternative conceptions of "seeing" (perception of light) (Andersson & Kärrqvist, 1983; Cavell & Jones, 1995; Eylon, Ronen, & Ganiel, 1996) and of images (Galili, 1996; Galili, Bendall, & Goldberg, 2006). Indeed, optics is one of the most challenging topics in Physics (Mzoughi, Herring, Foley, Morris, & Gilbert, 2007) because this domain cannot be understood by tactile experience or concrete frames of reference (Heywood, 2005). Galili (1996) pointed that students could not tell "matter-based" concepts and "process-based" concepts when learning optics and this may affect students to change their misconceptions. To help students' conceptual change, many approaches have been implemented including different teaching models(Dedes & Ravanis, 2009), teaching modules (Cavell & Jones, 1995; Fetherstonhaugh, 1990)and computer programs (Blanquet, Walrand, & Cardinael, 1983; Eylon, et al., 1996; Reimann, 1991).Within these trials, one key element in learning this topic is drawing ray diagrams. Ronen, Eylon, Rivlin, and Ganiel (1993) stated that the use of ray diagrams is a main representation for communication in this domain. However, students do not readily accept this representation. Goldberg & McDermott (1987) mentioned that students struggled in drawing and interpreting ray diagrams. As a result, multiple representations are important when students learn these topics. For the reason that learning with multiple representations can decrease the possibility of wrong interpretation of any representation when they are interpreted individually (Galili, 1996), our course in the target units focused on teaching with different representations. To help students learn using different representations was also the emphasis on the developed questionnaires, and we tried to use everyday situations instead of formal settings in the questionnaires in order to help us approach students' real conceptual understanding (Kolari & Savander-Ranne, 2000).

2.6 Theoretical Framework

2.6.1 Pierce's Triadic Model of a Sign System

Pierce (1931) presented a model which shows how one representation makes meaning (See Figure 2.1). This model explains representation of sign (e.g. word, image, graph, etc.) makes meaning (e.g. concept, idea, theory, etc.) via referring the referent in world (e.g. physical object, experience, artifact, situation, process, etc.). Concept, representation and referent are the three main elements of the model, and are closely linked to each other, which implies better conceptual understanding needs better representational and/or referent knowledge. Carolan, Prain and Waldrip (2008) noted that the model implies learners need to understand or explain concepts in science by using their current cognitive and representational resources. Waldrip, et al.(2010) further explained that in this model, every new interpretation of a representation re-activates this triad, and adds new understanding to the existing understanding. Therefore, if students can recognize and link each element of the triad, they can interpret and construct scientific meaning and processes. If they can map the links between the three elements of the triad in different mode representations, they can gain deeper understanding.

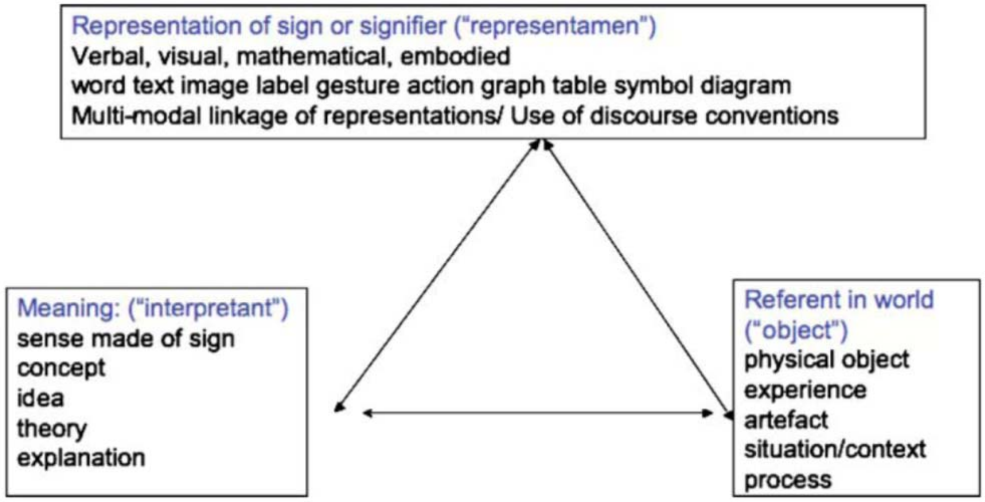


Figure 2.1 Pierce's Triadic Model of a Sign System

2.6.2 Ainsworth's DeFT (Design, Functions, Tasks) Framework

This DeFT framework was proposed by Ainsworth(2006)in order to design an effective way for teaching and learning with multiple representations. Three phases in the framework are discussed, which respectively are (a) Design Parameters – including the number of representations employed, the way that information is distributed, the form of the representational system, the sequence of representations and support for translation between representations. (b) Functions – the functions of an appropriate representation (computational offloading, re-representation, graphical constraining), and the functions of multiple representations (complementary roles, constrain interpretation, construct deeper understanding). (c) Cognitive Tasks undertaken by learners – when learning with a representation, learners should understand the form of representation, the relation between the representation and the domain. Also, learners may need to understand how to select an appropriate representation and construct an appropriate representation. On the other hand, when learning with multiple representations, they may need to understand how to relate representations.

In this thesis, we examine if the functions of multiple representations that Ainsworth proposed could fit in the practical situation. In the above DeFT framework, there are three main functions that multiple representations can provide. Firstly, complementary roles, and this can be discussed in two ways, complementary processes and complementary information. Each representation has its own computational process to represent the same concept, for example, we can use coordinate graphs, animations or written words to represent the motion of constant acceleration. Which ones are suitable for learners really depends on the learner's conceptual preferences, the tasks to be done, or the problem to be solved. This is the function of complementary processes which multiple representations can have. The latter one is complementary information. Take the example of constant acceleration. If just the coordinate graph is provided to learners, learners will not know how the accelerating object looks like, unless the animation is provided. In this case, the animation provides complementary information.

The second function that multiple representations can support is to constrain interpretation. It also can be divided into two categories. One is constrained by familiarity, which depends on the individual learner. To explain the concept in more detail, the unfamiliar representation can be constrained by another familiar representation, which makes the concept represented more clearly. The other type of constraining interpretation is constrained by inherent properties. A classic example to explain this is if there is a written description "A dog is beside a tree", which cannot show the dog is in the right hand side or left hand side of the tree. However if a picture depicting the situation is shown, it will be clear presenting the position of the dog. The inherent property of the picture constrains the interpretation of the written description.

Last but not least of the main functions of multiple representations is to construct deeper understanding, which can be described in three aspects. The first is extension. Extension means the knowledge learned when learning from a familiar representation to an unfamiliar representation. The second is relation, meaning the knowledge which relates two different, familiar representations, but just in the surface features of the two representations. Usually it is the basis for the third aspect, abstraction. Abstraction is a mental entity showing a deep understanding of a concept. The mental entity can relate or translate (compare advantages and disadvantages of different representations) between multiple representations of the concept. Finally there is one thing worth mentioning, that is the three main functions do not necessarily exist alone, on the contrary, they normally co-exist.

Ainsworth (1999) further pointed that this taxonomy (the functions of multiple representations) can help instructors establish the goals of using multiple representations and translation between the representations plays a crucial role to determine if the goals can be reached. It is necessary that learners can relate different representations if they want to use the functions of constraining interpretation and constructing deeper understanding. Although translating between representations is not easy (Schoenfeld, Smith, & Arcavi, 1993), it is still worth our effort to learn the ability.

Cook, Wiebe, and Carter (2008) stated that in order to make multiple representations functional, the learners have to first know how to select appropriate representations for learning. After the selection, learners have to understand each representation, including its format and computational characteristic. The second step, learners have to relate each representation to the domain knowledge and the connection makes the learner have a superficial understanding of the concept. The last step is that learners will have an abstract mental entity, which integrates the domain knowledge and each representation, allowing the learner relate or translate between the different representations. Discussing functions of multiple representations cannot be separated from discussing the learners' cognitive state.

2.7 Conclusion to this Chapter

Although the advantages of students' multiple representations in instruction have been discussed in some studies as mentioned above, more evidence is needed to show how they benefit learners. Therefore we developed multiple representations questionnaires to help students learning in thermal physics and optics modules. In order to know if the questionnaires are beneficial for students learning, we had to notice students' evaluations of the questionnaires (Research Question 1), and students' level of conceptual understanding based on the pre and posttests in the questionnaires (Research Question 2). By analyzing the data of interviewing students, we obtained further understanding of students' performance and the important factors when they learned a concept with one representation in the multiple representations questionnaires (Research Question 3). In addition, we tried to find the possible causes of students' positive and negative performances, and verify the advantages of receiving a tutor's guidance as described in the former section when students learn with different representations (Research Question 4).

The relationship between students' learning attitudes and their conceptual understanding needs more research to clarify, and we need to use effective surveys to measure students' attitudes to learning physics. We demonstrated the validity and reliability of our effective surveys for the potential users while we used them to quantify our students' learning attitudes (Research Question 5). With the correlation analysis of the quantitative data, we further used interviews, the method which was rarely used in former studies, to investigate the relationship between students' learning attitudes and their conceptual understanding (Research Question 6).

CHAPTER 3

Research Methodology

3.1 Introduction

In this chapter, the research methodologies, including research questions, research methods, research instruments, procedure for data analysis, and threats to reliability and validity used in Research Phases One, Two and Three, are described sequentially. Each of the three phases were researched in chronological order and represented one full semester of research. The research methodology in Phase Two was developed from the research results in Phase One, and the research methodology in Phase Three was developed referring to the results in Phases One and Two. In Phase One, the focus was to develop a questionnaire which can assess students' conceptual understanding of multiple representations in Physics. Afterwards in Phase Two, students' attitudes towards learning Physics and their motivation were investigated in addition to further development of and administration of the multiple representations questionnaire. Finally in Phase Three, the validity or reliability of the selected attitude surveys and motivation questionnaire was measured and the relationship between multiple representations, learning attitudes and conceptual understanding was investigated.

3.2 Research Design for Phases One, Two and Three

Merriam(1988) stated that although the term case study is well-known to most people, there is little agreement on what constitutes case study research. Anderson (2004) indicated that case studies are suitable for educational situations which do not easily allow tight control or experimental manipulation. A case study is also suitable for applying in a little known or poorly understood situation (Leedy & Ormrod, 2005). Examining university students' use of multiple representations in the units observed was unfamiliar, so a case study was considered to be a reasonable design for conducting this research.

In a case study, extensive data were collected and multiple sources of evidence were used to analyse a specific instance. Besides, the researcher begins to analyse data at each stage of the data collection (Anderson, 2004); (Leedy & Ormrod, 2005). Merriam (1988) also proposed that by conducting a case study, a theory can be tested or built. In this case study, we analysed the data before the next research phase (the next semester) began, and Pierce's model and Ainsworth's DeFT framework was tested for their validity to analyse students' multiple representations.

3.3 Research Methodology in Phase One: Development of the Multiple Representations Questionnaire

In Phase One, investigating multiple representations was the main theme of the research, and required the design of suitable multiple representations questionnaires for the observed Physics units. Consequently, firstly we wanted to know what kinds of representations the lecturer or the tutors used in class. To achieve these goals, multiple representations used in observed classes were recorded and analysed. We designed the first version of the multiple representations questionnaire and administered it to students and obtained feedback for the next research phase.

Consequently, the aims in Research Phase One were to:

- Identify what multiple representations had been used in the target classes.
- Design suitable questionnaires which can assess the level of conceptual understanding of students' multiple representations in the target classes.
- Identify if the selected units were suitable for the development of the multiple representations questionnaire in the next research phase.

3.3.1 Research Procedures

Studied Units

This Phase One study was conducted in the Unit A and Unit B for non-major Physics students in the Department of Applied Physics. Unit B contained three different modules—Fundamental Principles, Thermal Concepts, and Waves & Sound; Unit A contained these three and three extra modules—Electricity, Optics, and Atomic & Nuclear Radiation. Phase One focused only on the modules of Fundamental Principles, Thermal Concepts, and Waves & Sound in both Units A and B. There were 50 students enrolled in Unit B, and 114 students enrolled in Unit A. The total number of students enrolled in both Units was 164. The period of this Phase One study was one semester in 2008.

Participant-observations

In Research Phase One, all lectures (20 sessions) and half tutorials (16 of 32 sessions) of the three modules, Fundamental Principles, Thermal Concepts, and Waves & Sound, were observed with the researcher as a participant observer (Leedy & Ormrod, 2005), and one session was 50 minutes. The researcher sat with students to observe the lectures and tutorials, and most students did not know the identity of the researcher. The target of the participant-observation was which representations the lecturer and the tutors used.

Meeting with Experts

The functions of meeting with experts were to discuss how the research study was going, and to plan for the next step. Meetings with three experts were held on a monthly basis. The three experts come from the field of Physics or Science Education. One of them is a professor in Science Education, and the other two are an associate professor and a teaching fellow in Physics. The latter two also taught in the lectures and tutorials of Units A and B. There were four meetings held during the semester and in every meeting, the main issues were noted as dot points by the researcher.

Developing and Administering SHM Multiple Representations Questionnaire

In the end of the classroom observation on the multiple representations used by the lecturer and tutors (in the end of Waves and Sound module), a SHM (Simple Harmonic Motion) Multiple Representations Questionnaire was designed. In the questionnaire, students were asked to present their understanding with the representations used in lectures and tutorials, including words, pictures, formulas, coordinate graphs, calculations, in order to know how well students' understanding of this topic after the class instruction, and to know how well students performed their knowledge using those different representations. The outcome could provide some feedbacks to instruction and our development of the multiple representations questionnaire. The questionnaires were distributed in the last tutorial class of Waves and Sound module in Unit B when SHM had been taught in earlier lectures. The questionnaires had already been checked by experts (the same people in our meetings) for content before being distributed to students. For the reason that some questions would give hints on answering the others, the questionnaire was divided to two parts (Questionnaire no.1 & no.2, as shown in Appendix 3.1). Questionnaire no.1 was answered before no. 2.

3.3.2 Data Collection Instruments - Multiple Representations Questionnaire

The purposes of designing the multiple representations questionnaires in the research phase were to know students' knowledge level after lectures and tutorials and how they used multiple representations to present their understanding. The questionnaire was divided into two parts: questionnaire no.1 and questionnaire no.2. In questionnaire no.1, we wanted to know without providing any question context, what students had already known by using different representation (word description, picture, formula and coordinate graph). In contrast to questionnaire no.1, questionnaire no.2 provided richer question context, which gave the information of formulas relating to SHM (Simple Harmonic Motion), coordinate graphs with two labelled axes. Besides, to know students' ability to calculate, there were two questions needing students to calculate without a calculator. All questions in questionnaire no.1 and questionnaire no.2 were related to simple harmonic motion.

3.3.3 Data Analysis Procedures

In order to know the quantity and quality of students' multiple representations in the questionnaire, a tally table of all representations that each student used and students' responses in each representation were used for questionnaire no.1 and questionnaire no.2. Also students' responses in the questionnaire were reviewed by the researcher and three experts in the regular meeting and the quality of students' responses were discussed.

3.3.4 Threats to Reliability and Validity

The multiple representations questionnaire was distributed in the last tutorial of that module, therefore students may not have had enough time to review and study the related content in the questionnaire, which would influence their performance in the questionnaire.

3.4 Research Methodology in Phase Two: Trialling the Multiple Representations Questionnaire and Attitude Surveys

In Research Phase One, a preliminary understanding of target units had been obtained through classroom observations, discussion in meetings, and the multiple representations questionnaire. The first understanding included how to improve the multiple representations questionnaire and we observed some inattentive students' learning behaviour in the classroom. In this research phase we redesigned the multiple representations questionnaire, and distributed it to more students to determine its suitability. Furthermore, three surveys related to students' attitudes towards learning Physics were distributed to further examine if their learning attitude was the possible cause of the observed inattentive learning behaviours. Besides, for the purpose of marking students' representations in the multiple representations questionnaire, which represented their understanding of tested concepts, a marking key for different representations was developed and applied in this research phase.

The research aims for Phase Two which guided this study were to:

- Design and implement suitable questionnaires which can effectively assess students' Physics conceptual understanding using multiple representations (word descriptions, diagrams, formulae, coordinate graphs) in the target units.
- Develop the marking key for assessing different representations in the multiple representations questionnaire.

- Determine the students' conceptual performance in the redesigned multiple representations questionnaire based on the developed marking key.
- Trial the questionnaire students' attitude towards learning Physics in the target units.

3.4.1 Research Procedures in Phase Two

Participants

In Phase Two, the units were the same as Phase One, the case study was conducted in Unit A and Unit B in the same university in Australia with Physics non-major students comprising 82 in Unit A and 67 in Unit B. The program for Unit A required students to take six modules, namely, Fundamental Principles, Thermal Physics, Waves and Sound, Electricity, Optics, and Atomic and Nuclear Radiation. The students in Unit B only were required to take Fundamental Principles, Thermal Physics, and Waves and Sound.

Based on a careful examination and subsequently changing and solving the problems which happened in Phase One, a new questionnaire which assesses students' understanding of Thermal Physics and Optics using multiple representations was designed and distributed to students. In addition, after observing students' inattentive learning behaviours in class during Phase One, we investigated students' attitudes toward learning Physics, with the Expectation Survey and Experience Survey (pre and posttest respectively) (Kirkup & Mendez, 2009), and the Physics Motivation Survey (revised from Glynn and Koballa's Science Motivation Questionnaire (2006)), which were distributed to students in Phase Two.

Redesign and Implementation of the Multiple Representations Questionnaires

During Phase One of the study, the questionnaire assessing students' understanding of SHM (Simple Harmonic Motion) with multiple representations was designed preliminarily and given the first trial. In the first trial, problems from students' responses to the questionnaire were identified such as the definition of each representation was not clear to students. Therefore in Phase Two, the disadvantages of the first version questionnaire were improved. However in this phase, Thermal and Optics module were selected as the subjects of the multiple representations questionnaire. The idea that we selected the two modules was from the conclusion of the meeting in Phase One, which suggested that for the four modules – Thermal Physics, Waves &Sound, Optics, and Atomic &Nuclear Radiation – more time was needed to research them all. Subsequently, we selected two modules, Thermal Physics and Optics. The module Waves &Sound was taught between the modules of Thermal Physics and Optics. We did not want students to feel rushed in answering the multiple representations questionnaires about Waves & Sound; therefore the Waves &Sound module was not considered. As for the module of atomic and nuclear radiation, it was the last module in the unit schedule and after teaching the module, the students do not come to the university and usually stay at home to prepare for the final examination. It was not good timing for students to participate in the research activity at this time; subsequently the module was also removed from our research.

Both Thermal Physics and Optics multiple representations questionnaires were distributed to students on two separate occasions as pre and post-tests. Pre-tests were distributed during the week before the module instruction started, and post-tests were distributed immediately after the module instruction had finished. In order to reduce the students' workload, the Optics Questionnaire in the post-test was divided to Questionnaire A and B (each has 6 questions), which were distributed to students randomly and evenly. The ways to distribute the questionnaires included distribution in class (lectures and tutorials), distribution in the reception office in Physics department (students went and took the questionnaire), distribution via email (students could ask the questionnaires from the researcher's email) and distribution through Blackboard (students could download the questionnaires from the Internet interface). Before the distribution, all questionnaires were checked by three experts to ensure the content validity and the suitability for students understanding the questions. There was no time limit for students to complete the questionnaire.

Administration of the Physics Motivation Survey

The Physics Motivation Survey was distributed in the sixth week of 12 tuition weeks to determine students' motivation in the middle of the semester. As with the multiple representations questionnaire, there were four ways to distribute the survey to students: through class, the reception office in Physics department, email and Blackboard. Before distributing the survey, the content of the survey had been reviewed by three experts to ensure it could be understood by students. There was no time limit for students to complete the survey.

Administration of the Expectation Survey and Experience Survey

To determine if there were any significant differences between students' expectations and their actual experience, the Expectation Survey and Experience Survey as pre and post-test were distributed to students. The Expectation Survey was administered in the orientation week (the week before lectures) and Experience Survey was distributed in the 10th week of the total 12 tuition weeks. The reason why the Experience Survey was not distributed right after the last tuition week was during that time, students were busy preparing for the final examination, and the rate of completing the survey would not be satisfactory. Again the ways of distribution were through class, the reception office in Physics department, email and Blackboard. Both surveys were checked by three experts before distribution to make sure students had no difficulty to understand the surveys. There was no time limit for students to complete the surveys.

3.4.2 Data Collection Instruments

Multiple Representations Questionnaire

There are two parts in each questionnaire (see Appendix 3.2 to 3.5): the first part comprises the instruction pages. Firstly, students were asked not to refer to any materials and not to discuss with other people in order to know the effectiveness of the class designed to teach with multiple representations on students' conceptual development. Besides, we had to make a statement letting students know that their serious participation was very important for them to get the Unit Assessment mark, so that we could have more valid students' responses. Next we requested students' personal information, including name, ID, unit of study and to which year he or she previously studied Physics at school. An example of each representation that we expected students to use was shown so that students can know what each representation looks like. Some of the formulas shown were expected to be used for explanation in the following questions. As a result students did not need to memorise the formulas. In addition, students were asked to present as many representations as they can in each question.

The second part of each questionnaire includes 12 questions in the Thermal Module questionnaire and also 12 questions in the Optics Module questionnaire. Most questions were selected from Hewitt(1998) and the lecturer's practice questions, with some questions added by the lecturer. As the questions were expected to be answered as many representations as possible, all questions are suitable to be answered using at least three different representations, with the exception of two questions in the optics questionnaire answered using two representations. Besides all questions were designed based on the topics taught in lectures (see Table 3.1 and Table 3.2) although they do not cover all. Not all the topics taught were suitable for designing questions to be responded with three or four representations.

Table 3.1 The Topics in Unit Outline and in the Multiple Representations Questionnaire (Thermal Physics Module)

Topics in Unit Outline	Tested Topics in Multiple Representations Questionnaire
· Heat and temperature	✓
· Temperature scales, conversions	
· Measurement of temperature	✓
· Thermal expansion, linear, volume	✓
· Absolute temperature	
· Kinetic theory of gases	
· Temperature and kinetic energy	
· Specific heat.	✓
· Calorimetry	✓
· Change of state, latent heat	✓
· Heat transfer by conduction	✓
· Heat transfer by convection	
· Heat transfer by radiation	✓
· Black body radiation, emissivity	✓

Table 3.2 The Topics in Unit Outline and in the Multiple Representations Questionnaire (Optics Module)

Topics in Unit Outline	Tested Topics in Multiple Representations Questionnaire
• Geometrical optics	✓
• Law of reflection, image formation	✓
• Index of refraction, Snell's law	✓
• Total internal reflection and fibre optics	
• Thin lenses, ray diagrams	✓
• Lens equations, Lens maker's equation	✓
• Optical defects of the eye and their correction	✓
• Resolving power of the eye	
• Magnifying glass, angular magnification	✓
• Compound microscope	
• Wave nature of light	✓
• Polarised Light	✓
• Scattering of light	✓

How everyday life context is essential in science instruction has been examined by many studies. For example, Enghag, Gustafsson, and Jonsson (2007) declared the connection between students' earlier life experiences and Physics being taught is necessary for students' meaning making. Chu et al. (2008) suggested that Physics concepts need to be connected to real life to help students' conceptual development. Furthermore, to avoid students memorizing the content of their textbooks to respond to our questionnaires as observed in Phase One, we used real life examples in most questions of the multiple representations questionnaire. After the above development, three experts reviewed each question before distributing to students.

There is one point which needs to be noted: the question format of the Optics Questionnaire in the post-test (see Appendices 3.4 and 3.5) was different from the one in pre-test (see Appendix 3.3). The reason why the question format had been changed was from the preliminary analysis of students' responses to pre, post-test in Thermal Module and pre-test in Optics Module, it was found that even though we asked students to answer the questions using as many representations as they can, most students responded the questions just using one representation, which was with a word description. Consequently, we only used the post-test style of questionnaire in Research Phase Three.

In order to approach the research aim and obtain more different kinds of students' representations, the representations which are suitable for solving each question were selected for students in the post test of Optics Questionnaire so there were separate spaces for word description, diagram, formula, coordinate graph. However, the contents of the questions were exactly the same as pre-test. In addition, in order to reduce the students' workload, the Optics Questionnaire in post-test was divided to Questionnaire A (see Appendix 3.4) and B (see Appendix 3.5), which were distributed to students randomly and evenly.

Physics Motivation Survey

The Physics Motivation Survey (see Appendix 3.6) was revised from the Science Motivation Questionnaire (SMQ), which was developed by Glynn and Koballa (2006). There are 30 Likert-type items in the SMQ and they were tested with science and non-science majors, showing the questionnaire is valid and reliable for use with these groups. Glynn, Taasoobshirazi and Brickman(2009) tried to establish the construct validity on the questionnaire and distributed it to 770 non-science majors. They used exploratory factor analysis and found those items can be categorised in five factors (intrinsic motivation and personal relevance, self-efficacy and assessment anxiety, self-determination, career motivation, grade motivation). Although the Physics Motivation Survey keeps the same number of items and factors, we changed the word "science" to "Physics" and some wording to meet the Australian examination system.

Expectation Survey and Experience Survey

The Expectation Survey (see Appendix 3.7) and the Experience Survey (see Appendix 3.8) were developed from a project funded by the Australian Learning and Teaching Council (Kirkup & Mendez, 2009). The Council held a project workshop in which 25 academics from 12 universities attended. In this workshop, "what constitutes good service teaching?" was suggested from the 25 academics so as to have a valid questionnaire. Based on the suggestions, the Expectation Survey and Experience Survey were devised by the project working party and were specifically devised for non-Physics majors. There are totally 13 items in each survey and the first 10 items are measured by Likert's scale, showing the degree of students' satisfaction of their expectation or experience. Item 11 and item 12 are multiple choice questions, of which item 11 asks students what final grade they are aiming for and item 12 asks students to which level they studied Physics in school. As for item 13, it is an open- ended question, asking students additional expectation in the Expectation Survey and additional experience or suggestions for the Experience Survey. However, neither instrument had measures of reliability prior to use in this research.

3.4.3 Data Analysis Procedures

Thermal and Optics Multiple Representations Questionnaires

Once we had students' multiple representations, a marking key was needed in order to measure their conceptual understanding based on those different types of representations. In Phase Two, I developed a marking key which was used by three experts to evaluate the responses of six selected students' questionnaires of Thermal-post and Optics-post respectively.

After the independent marking, the four markers met together to discuss any disagreements in each other's marking. Finally the markers came to the agreement that the inter-rater reliability was above 90% for each of the Thermal-post and Optics-post questionnaires. Also the marking key was revised (version two, see Table 3.2) during the discussion. In the final version of the marking key there were four different types of representations to be marked; the marking key for each representation can be divided to four scales: 0 is wrong, 1 is mostly wrong, 2 is mostly right, 3 is right. The details of the marking keys for each representation are shown in Table 3.3.

Table 3.3: Final Marking Key for Multiple Representations Questionnaire

Words	
0	Wrong
1	Mostly wrong with some correct parts
1	Right but very incomplete
2	Mostly right
3	Right and complete answer
Diagram	
0	Sketch not helpful to solve the question with or without labelling
1	Sketch partly helpful to solve the question with or without labelling
2	Sketch totally helpful to solve the question without labelling
3	Sketch totally helpful to solve the question with correct labelling
Formula	
0	Correct formula with wrong explanations of all variables
0	Correct formula but all variables are replaced with wrong numbers from the question
0	Wrong formula
1	Present one or some of correct formulas
1	Correct formula with incorrect formula(s)
1	Correct formula with wrong explanation of some variables
2	Correct formula only
3	Correct formula and apply the situation of the question to the key variables for explanation
3	Correct formula and variables are replaced with right numbers from the question
Coordinate Graph	
0	Wrong
1	Mostly wrong
2	Mostly right
3	Right

During the development of the marking key, the number of representations of the six students used in each question was also counted. What we were interested was if there was a significant difference in the number of representation in each question before and after the format of the questions changed. Because these six students had more total representations than other students in Thermal and Optics posttest, respectively, by analyzing their responses, we could observe the effect of format change on the number of representation in each question obviously.

In order to further understand students' level of conceptual understanding after Phase One preliminary research, in this phase students' representations in each pre and post-test of Thermal module was marked based on the final version of marking key. The grand mean of all responses in each representation with all responding students in pre and post-test, and the gain of the grand mean from pre to post test was calculated (see Chapter 4, Section 4.3.1).

Physics Motivation Survey

The data obtained from the Physics Motivation Survey were analysed based on the five factors (intrinsic motivation and personal relevance, self-efficacy and assessment anxiety, self-determination, career motivation, grade motivation) identified by S. Glynn, et al. (2009) from the Science Motivation Questionnaire. The mean and standard deviation of students' score in each factor was computed by the SPSS statistical software (version 17) to know their average degree of motivation. Besides, the reliability analysis was calculated with the SPSS statistical software to compare the result with Glynn, et al.'s findings (2009) (see Chapter 4, Section 4.3.2).

Expectation Survey and Experience Survey

Similarly to the Physics Motivation Survey, the mean and standard deviation of the first 10 items in Expectation Survey and Experience Survey were computed by the SPSS statistical software to know students' average level of their expectation and experience satisfaction, and a t-test was conducted to determine any significant differences in the average scores of the first 10 items between the Expectation Survey and Experience Survey. In addition, the reliability test was conducted on the first 10 items of Expectation Survey and Experience Survey to check the consistency of the 10 items (see Chapter 4, Section 4.3.3).

3.4.4 Threats to Reliability and Validity in Research Phase Two

There are some threats which may affect the reliability and validity of the research in this phase. First, since completing the questionnaires was not compulsory for students in the target units, some students were not willing to complete the questionnaires, which had a negative influence on the validity and reliability. Second, as discussed in the literature review, there are many different kinds of questionnaires that can measure different aspects of students' attitude toward learning science (or Physics). The Expectation Survey, Experience Survey and Physics Motivation Survey revealed some facets of students' attitudes but not all. Thirdly, students' marks in the multiple representations questionnaires were used to represent their conceptual understanding. However, the tested topics in the multiple representations questionnaires did not cover all topics taught in class (see Table 3.1 and Table 3.2), so there was some bias to use it to represent students' real conceptual understanding.

3.5 Research Methodology in Phase Three

Research Phase Three was the main phase of the study where we investigated students' conceptual understanding, multiple representations, students' attitude toward learning Physics, motivation for studying Physics and the relationship between them. Based on the results of Research Phase Two, the multiple representations questionnaire was further revised including format of questions, minor wordings in some questions and so on. Besides, in this phase we collected students' evaluations of the multiple representations questionnaire to make it more suitable for students' learning.

Some interesting findings in Research Phase Two needed to be clarified in Research Phase Three. First, although students had positive learning attitudes, the inattentive learning behaviours were still observed in Research Phase Two. The causes for the inattentive learning behaviours needed to be further examined. Second, despite of students' positive attitude to learning, they displayed a shallow conceptual understanding in the multiple representations questionnaires. What caused this phenomenon raised our interest to further investigate.

In addition, two main focuses in Research Phase Three study were to analyse the data using Pierce's Model (1931) and Ainsworth's framework (1999) about functions of multiple representations in order to identify what factors were important and which functions of multiple representations students used during their cognitive learning. In the process of analysis, Pierce's Model was used mainly for one representation, in contrast to Ainsworth's framework, specifically for multiple representations. The other focus was to investigate students' learning attitudes using the same surveys as used in Research Phase Two, and calculate their validity and reliability compared with any previous related literature.

Some new research methods were added in this phase. First, interviewing students was conducted in order to obtain deeper understanding of the research topics. Second, we recorded the time of different representations used by the instructor in lectures and tutorials to examine its correlation with students' conceptual understanding represented by each representation.

3.5.1 Research Questions for Phase Three

The following research questions were answered in Phase Three:

- Research Question 1: What are students' evaluations of the use of multiple representations questionnaires in optics and thermal physics?
- Research Question 2: What was the level of students' conceptual understanding based on the analysis of the multiple representations questionnaires in optics and thermal physics and interview oral explanations?
- Research Question 3: How did students perform when explaining their concepts using one representation on the optics and thermal physics questionnaires?
- Research Question 4: How well did students perform in their multiple representations with and without guidance on the optics and thermal physics questionnaires?
- Research Question 5: What were the students' attitudes towards learning Physics?

- Research Question 6: Is there any relationship between students' learning attitudes and the depth of students' conceptual understanding in optics and thermal physics?

3.5.2 Data Collection Instruments

Multiple Representations Questionnaires

In Research Phase Three, based on the analysis of the results of the second version questionnaire, the questionnaire again was revised to become the third version questionnaire(see Appendices 3.9 and 3.10). Not only some questions in the Thermal and Optics modules, but also the student information page and the instruction page were revised. The following are the details of those changes**.**

- Student Information Page

In Phase Three, more student information was asked such as "Major", "Gender","Howlong ago was your last Physics study undertaken at school?", "How often did you go to lectures in this Module?", "How often did you go to tutorials in this Module?". Responses to these questions were designed to know more about the students' study background, which were beneficial for data analysis and findings later.

- Student Instruction Page

In the second version of the questionnaire, students were not allowed to refer to any other materials (e.g. books, lecture notes) and discuss with other people when answering questions, therefore a couple of formulas which would be used in the following questions were provided in the instruction page. The formulas were provided because we did not think students needed to memorise the related formulas. In addition, there is a big difference between the Phase Two and Phase Three questionnaire. In Phase Two, no example question was provided and the four different representations (description using words, schematic diagram, formula, coordinate graph) shown in the instruction page do not relate to each other. On the contrary, the questionnaire in Phase Three does have an example question and the four different representations in the answer part do relate to each other, which symbolises the same concept.

- The Format of the Question

In Research Phase Three, the question format in the questionnaire (both Thermal and Optics module) is the same as that in the questionnaire of Optics post-test in Phase Two. In Phase Two, the change of the format in Optics post-test enables more students' to provide different kinds of representations than on Thermal pre, post-test, and Optics pre-test. By the reason, the format that reminds students to present with different representations in each question was kept in the questionnaires in Phase Three.

- Schematic Diagram Part

In the second version questionnaire, no "background diagrams" were drawn for students. "Background diagram" in each question shows the situation in which the question is describing and does not influence students' thinking about those concepts that the question is testing. Those diagrams just help students imagine and clarify the situation of the question. For example, in Thermal Physics questionnaire, a "background diagram" (See Fig. 3.1) was provided for the question "In winter, which makes you feel colder, sitting on a wooden chair or sitting on a metal chair?" The reason why we put the "background diagrams" is we found in Phase Two, students did not respond to the diagram part actively. Therefore in Phase Three, we put those background diagrams in most questions which were expected to attract more students' diagram representations for analysis of their conceptual understanding.

Figure 3.1: An example of “background diagram” for the question of sitting on a wooden and metal chair in Thermal Physics questionnaire

- Revision of the Questions

Some revisions of the questions in Thermal and Optics multiple representations questionnaires are shown in Appendix 3.11. Basically the tested concepts and the situation in the questions did not change. However, we revised some sentences and provided more specific information to make the questions more clear and understandable. For Phase Three, as for Phases One and Two, the questionnaires were reviewed by the lecturer and another two experts before distributing to students.

Physics Motivation Survey

The Physics Motivation Survey was almost same as the one used in Phase Two (see Appendix 3.12). None of the 30 items was revised but we asked two more questions about students’ personal information. One was students’ gender, the other one was to which year the student studied Physics at school in order to know more about each student’s prior Physics knowledge. The origin of the Physics Motivation Survey has been introduced in Phase Two methodology section, therefore we do not repeat here.

Expectation Survey and Experience Survey

Similar with Physics Motivation Survey, in this phase we did not revise the main items of the survey compared to the one in last phase. Instead, we added some questions relating to personal information, which included students’ gender, to which year students studied Physics at school, and how long ago students’ last Physics study at school (see Appendices 3.13 and 3.14).

Interview Protocol

The interview focused on the following topics: opinions for the whole unit, information relating to the multiple representations questionnaire, including evaluation of the questionnaire, how students made use of the questionnaire, the effectiveness of the questionnaire for students' learning, how the multiple representations developed students' conceptual understanding - were they helpful, confusing? Can students relate those representations?, attitudes towards learning with the questionnaire. In order to know more about the relationship between multiple representations and conceptual understanding, two specific questions with students' responses from the multiple representations questionnaire for each Thermal and Optics module were selected for exploration during the interview.

Worksheet for Recording Teachers' Representations

The worksheet (see Appendix 3.15) was used during classroom observation to record the time of different representations used by the lecturer or the tutors. In the first row of the working sheet, different modes of representations which may be used in class are listed in advance and each one has its own column to record the time session of the representation. Every working sheet was used for one class (around 50 minutes), and which unit, module and the date were recorded in the sheet. Besides, the total time of instruction (namely the total time of teaching or learning the content, not necessarily equals to the time of the whole class) was also recorded in the sheet.

3.5.3 Research Methods

Student Participants

Phase Three included students from Units A and B as in Phases One and Two and students from another Unit C who took three modules, Electricity, Optics, and Atomic & Nuclear Radiation. All students in the three units were non-Physics majors; enrolments were 160 students in Unit A, 57 students in Unit B, and 62 students in Unit C. The Thermal multiple representations questionnaire was distributed to Unit A and Unit B students, and Optics multiple representations questionnaire was distributed to Unit A and Unit C students. The activities of completing all attitude surveys (the Expectation Survey, Experience Survey and Physics Motivation Survey) and being interviewed were the same for students in all three units. As for recording the time of different representations in lectures and tutorials, in Thermal Physics module, we observed both Unit A and Unit B and in Optics module, we observed both Unit A and Unit C.

Redesign and Implementation of the Multiple Representations Questionnaire

Based on feedback from Research Phases One and Two, the third phase of the study, the topics of the multiple representations questionnaires were pre and post-test as in Phase Two study, namely Thermal Physics and Optics in order to see the growth of students' conceptual understanding. Pre-tests were distributed during the week before the module instruction started, and the post-tests were distributed immediately after the module instruction had finished. The channels of questionnaire distribution were in class (lectures and tutorials), in the reception office in Physics department (students went and took the questionnaire), via email (students could ask the questionnaires from the researcher's email) and through Blackboard (students could download the questionnaires from the Internet interface), as in Phase Two. All questionnaires were checked by three experts to ensure the content validity and the suitability for students' understanding the questions before distribution. There was no time limit for students to complete the questionnaire.

Administration of the Physics Motivation Survey

The Physics Motivation Survey was distributed in the seventh week of the total 14 tuition weeks to figure out students' motivation in mid semester. Same as multiple representations questionnaire, there were four ways to distribute the survey to students: through class, the reception office in Physics department, email and Blackboard. Before distributing the survey, the content of the survey was reviewed by three experts to ensure it could be understood by students. There was no time limit for students to complete the survey.

Administration of the Expectation Survey and Experience Survey

To determine if there were any significant differences between students' expectations and their actual experience, the Expectation Survey and Experience Survey as pre and post tests were distributed to students. The Expectation Survey was administered in the orientation week and Experience Survey was distributed in the 12th week of the total 14 tuition weeks. The reason why the Experience Survey was not distributed right after the last tuition week was during that time, students were busy preparing for the final examination, and this may decrease their intention to complete the survey. Again the ways of distribution were through class, the reception office in Physics department, email and Blackboard. Both surveys were checked by three experts before distribution to make sure students had no difficulty to understand the surveys. There was no time limit for students to complete the surveys.

Student Interviews

To gain a deeper understanding of students' use of multiple representations, interviews with students were conducted from the week after the Optics module finished (Thermal Physics module finished earlier than the Optics module), continuing for four weeks. Interviewing students was part of the research activities in this semester; however, students could decide whether or not they participated in the interview. The students who intended to participate in the interview made an appointment first and the interview was conducted in a quiet room. For the initial interviews, the interviewer was supported by a supervisor; afterwards there was only one interviewer and one interviewee, and the time for every interview was about 20 minutes. Besides, since we were interested in students' representations on the Thermal Physics and Optics multiple representations questionnaires, the students' completed questionnaires were present during the interview for the purposes of helping students recognise what they had done in the questionnaire, and for the purpose of clarifying some students' responses and thoughts. Also a semi-structure interview protocol was used for helping ask students questions and an audio recorder was used with students' permission.

Classroom Observations

In this phase, the time of different representations used by the lecturer and by the tutors was recorded in some classes. For Thermal module, three of five lectures, four of six Unit A tutorials, and three of six Unit B tutorials were observed. As for Optics module, three of five lectures, two of six Unit A tutorials, and three of six Unit C tutorials were observed. The duration of every one lecture or one tutorial was around 50 minutes, and all classes were observed by the same researcher. During the classes, a stop watch and a recording sheet were used by the researcher in order to record the time of different representations used by the lecturer or by the tutor. Here an emphasis should be mentioned, which is that during the observation, when the lecturer or the tutor asked the students to think or learn themselves (e.g. problem solving or group discussion), the representations appearing in the period were not counted because those were mainly student-generated representations.

3.5.4 Data Analysis Procedures

Multiple Representations Questionnaire

After having developed a marking key for the questionnaire in last phase, in this phase a unit tutor marked and counted all students' representations both in pre and posttest of each module, according to the marking key. When we had the marks and counts, we used SPSS statistical software to conduct the following analysis: t-test to compare each question: the marks in each modal representation, the average marks of all modal representations, and the number of representations in pre and posttest. Also, of the questionnaire students' attempts in each representation in pre and posttest were t-tested.

Physics Motivation Survey

The result of reliability test for this survey in Phase Two was acceptable, therefore we kept using it in this phase (see Chapter 4, Section 4.3.2). Since we collected enough samples to conduct exploratory factor analysis in this phase, the result of the analysis was compared with that in Glynn, et al.'s (2009) study. Physics Motivation

Survey was revised from Science Motivation Questionnaire (used in Glynn, et al.'s study), and the comparison could verify the construct validity with each other. Additionally, according to the new sorted factors, descriptive statistics (mean and standard deviation of each factor) was done in order to know students' motivation in the middle of the semester.

Expectation Survey and Experience Survey

Similarly, the results of the reliability tests for these surveys could be accepted, so in this phase they were used as our research instruments (see Chapter 4, Section 4.3.3). The first 10 Likert scale items of both surveys were calculated for their reliability, and mean and standard deviation to know about the level of satisfaction of students' expectation and experience. Besides, paired sample t test was conducted to determine whether or not students' experiences met their expectations.

Furthermore, an analysis related to above four surveys was conducted by SPSS software, namely analysing the correlation between the multiple representations questionnaires (students'average marks of all modal representations), the Physics Motivation Survey, the Expectation Survey and Experience Survey to help clarify the relationship between students' learning attitudes and their conceptual understanding. For the Physics Motivation Survey and Expectation Survey, one could be confirmed in its criterion validity by the other.

Interview Transcription Analysis

Due to the lack of manpower, 10 most informative interviewees, who had more content in their total responses than the others, were selected from all the interviewees by the interviewer after the interview activity, and their interviews were fully transcribed (see Appendix 3.16). Following based on the research questions, some categories were formed (e.g. questionnaire evaluation, learning attitude) as the "nodes" in the NVivo software, and using the "nodes", the analyser (same person as the interviewer) started to analyse the 10 interview transcriptions in the software. During the analysis, comments and new nodes were made if necessary.

Worksheet for Recording Teachers' Representations

The raw data in the working sheet were installed in the software Timeline Maker Professional. The timeline of each representation used by the lecturer or the tutor in a class was shown in a chart via the transfer by the software, so the distribution of used representations in every moment of the class could be seen clearly.

3.5.5 Threats to Reliability and Validity

In Phase Three, part of the research methodology was the same or very similar as the methodology in Phase Two. As a result, the threats mentioned in Phase Two still existed in the Phase Three research. Besides, since new research methods were added in Phase Three, new threats existed. They were as follows:

- While we marked the students' responses in the multiple representations questionnaire, if students gave no response, we did not give any mark in it, including not giving zero. Therefore, it was not counted into the marks representing students' conceptual understanding.

- Although many students liked to join the interview, we just had one interviewer. As a result, the time for each interview was limited. In addition, although 10 informative interviewees were selected for full transcription, it may not represent all students' opinions or situations.

- There was just one person to observe the time of each representation used by the lecturer or the tutor in class. Some subjective judgement in the time existed.

CHAPTER 4

Results and Discussion in Research Phase One and Research Phase Two

4.1 Introduction

In this chapter, we present and discuss our findings in Research Phase One first, followed by Research Phase Two. From the findings in Phase One, we present the kinds of representations used by the instructors in lectures and tutorials. We examine some students' responses to the preliminary developed multiple representational questionnaire and the main points discussed in our research group meetings are shown. After presenting those findings, discussions and some suggestions for improving the research design are made.

From the findings in Phase Two, we present the results of the second trial of the multiple representational questionnaire to identify not only the practicability of the questionnaire in the observed units, but also students' level of conceptual understanding. In addition, to infer the students' attitude towards learning, we present the reliability values of the Physics Motivation Survey, Expectation Survey and Experience Survey, based on the students' responses. Finally, discussions and suggestions on those findings are presented in the last section.

4.2 Results of Research Phase One: Development of Multiple Representation Questionnaires

4.2.1 Multiple Representations Used in the Lectures and Tutorials

All lectures (20 sessions) and half tutorials (16 of 32 sessions) of the studied modules were observed with the researcher as a participant observer. The lecturer and the tutors explained each topic or concept using as many representations as possible. The multiple representations used in the lectures were oral presentation, powerpoint computer software presentation, occasionally 3D entity demonstration (e.g. for the purpose of demonstrating friction, put a box on a desk and lift one side of the desk to slide down the box). The powerpoint software presentations included multiple representations of words, pictures, tables, diagrams, coordinate graphs, formulas, calculations, and animations. Oral plus powerpoint presentation were the most frequent methods used by the lecturer in the lectures.

As for the multiple representations used in the tutorials, hardcopy practice questions (which could be downloaded in advance), oral presentations, plus whiteboard demonstrations were the most common way preferred by the tutors of Unit A and B, respectively. The practice questions mainly included both conceptual and numerical features. Most of the time in both tutorials was spent solving those practice questions. However, the tutor of Unit B asked students more questions, which were related to the hardcopy practice questions, than the tutor of Unit A. In addition, in both units the representations on the whiteboard were tables, diagrams, coordinate graphs, formulas, and calculations. A 3D entity demonstration was rarely presented.

4.2.2 Multiple Representational Questionnaire on Simple Harmonic Motion

Five students enrolled in Unit B answered the SHM questionnaire. However, one student did not complete questionnaire no. 2. The responses to the questionnaire are shown in Appendix 4.1, and the five students are identified as student S1 to S5. Besides, to show the situation of the quantity of representations which students had used, two tally tables regarding questionnaire no.1 and questionnaire no.2 are displayed as Table 4.1 and Table 4.2. From the two tables, it can be discovered that most students were happy to present their knowledge using the representations requested. The quantity of their representations was satisfactory; however, the quality of their representations was on the contrary. A typical example of students' responses to questionnaire no. 1 is shown in Figure 4.1. According to the response in the figure, it can be noticed that in the written words representation, the student did not mention the main point "Hooke's law", which is the key element in SHM. Similarly for the student's formula representation, although some related formula had been written, the key formula "F=-kx" did not appear. As for the picture/ diagram representation, the direction of restoring force "F" (in the student's diagram "f") is wrong and there is no meaning in the student's graphical representation.

Looking at another example in questionnaire no. 2 (Figure 4.2), the student could not adequately draw the trend in the coordinate graph when given the related formula, indicating the relational knowledge from formula representation to coordinate graph representation needed to improve. Therefore overall, the students' conceptual understanding in SHM and some representational knowledge were limited.

Table 4.1: Tally for Unit B students' each and total representations in questionnaire no. 1 of the SHM questionnaire

Student ID	# of Representations Used	Representation Used			
		Words	Diagram	Formula	Coordinate graph
S1	4	√	√	√	√
S2	4	√	√	√	√
S3	4	√	√	√	√
S4	4	√	√	√	√
S5	3	√	√	√	
Counts in total	19	5	5	5	4

Table 4.2: Tally for Unit B students' each and total representations in questionnaire no. 2 of the SHM questionnaire

	# of Representation Used	Representation Used		
		Coordinate graph	Formula	Calculation
Student ID				
S1	1	√		
S2	3	√	√	√
S3	3	√	√	√
S4	3	√	√	√
S5				
Counts in total	10	4	3	3

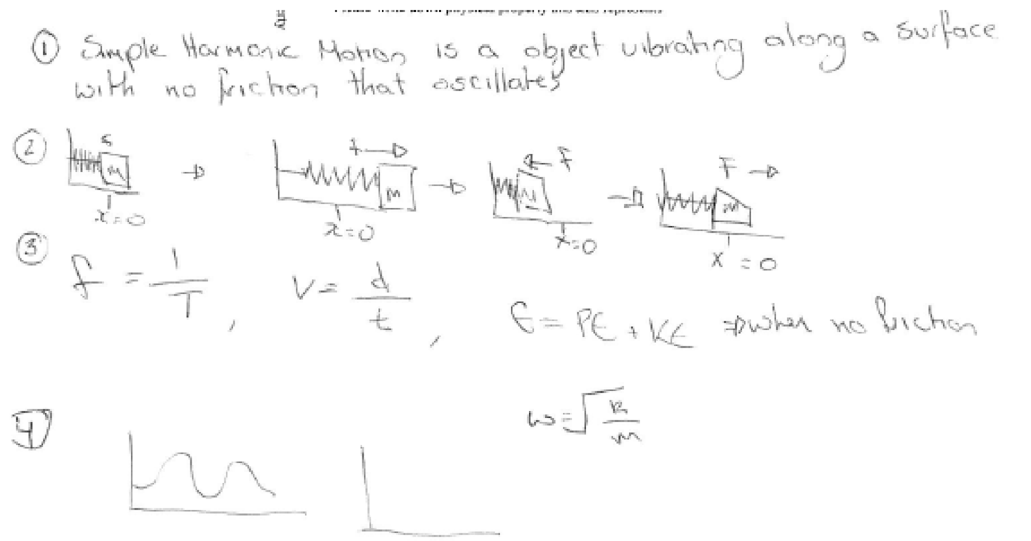


Figure 4.1: A typical example of students' responses to questionnaire no. 1 of the SHM questionnaire

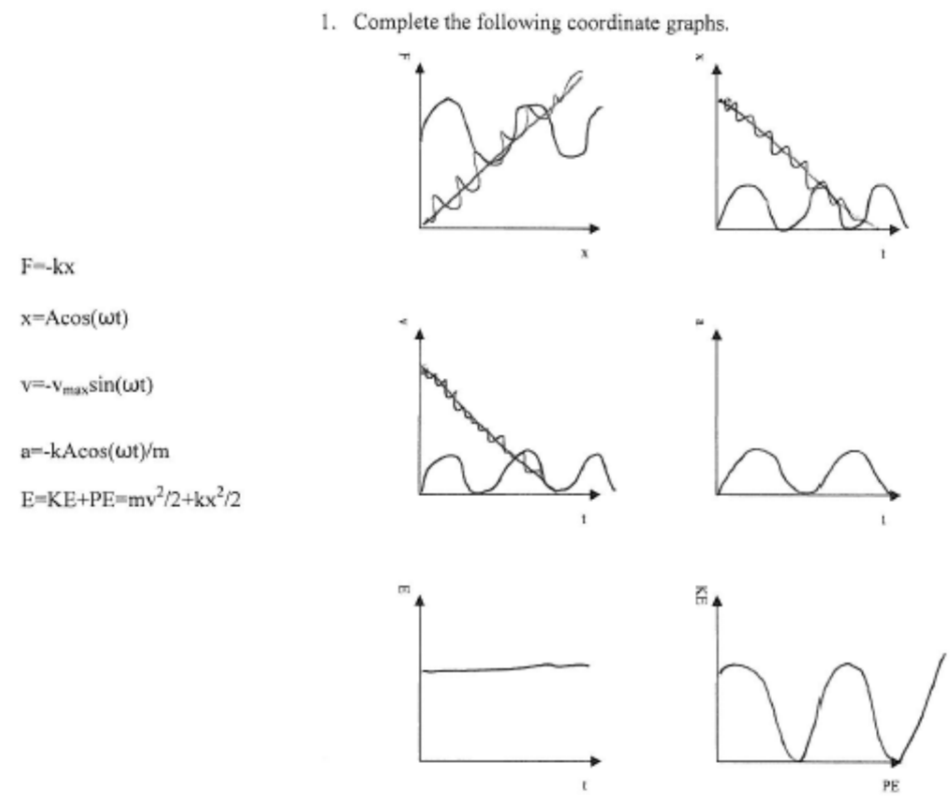


Figure 4.2: One of Unit B students' responses of drawing coordinate graphs when the formula corresponding to the coordinate graph is given in questionnaire no. 2 of the SHM questionnaire

4.2.3 Meeting with Experts

Four meetings held during the semester identified the following issues: discussion of unit teaching experience, discussion of the data from observations and questionnaires, and suggestions for the coming research in the next research phase in the next semester. The main points in every meeting are listed in Table 4.3. The goals of the study in Phase One were to develop the multiple representations questionnaire and verify if the unit students could help us to test the developing questionnaire in the next research phase. The discussions in the meetings helped us to achieve the goals. Through the meetings, we shaped the first version of the multiple representations questionnaire and verified that the students in the Unit A and Unit B were still suitable for our development of the questionnaire in the next research phase. Finally the meetings also made some useful suggestions for the next version of the multiple representations questionnaire (e.g. apply everyday life experience to the questions).

Table 4.3: Main points from meetings with experts

First Meeting (15/Aug/2008)
• Some students' basic concepts are weak. For example, they don't know density=mass/volume • Design questionnaires with multiple representations to assess students. Those multiple representations could include definition, sentences, diagrams, charts, equations, etc. • The questionnaires designed could be distributed to students in tutorials next semester.
Second Meeting (5/Sep/2008)
• Some students' physics backgrounds are too weak. It is possible to change target participants to others who have stronger physics background. • Numerical and qualitative questions can be designed in the questionnaires of students' multiple representation for assessing students' understanding. • Calculation sheets could be collected from the tests or exams as a tool for assessing students' understanding.
Third Meeting (9/Oct/2008)
• To understand students' prior knowledge, demography about students' physics background in senior high school could be needed. • Because there has already been lots of research on the module of fundamental principles and electricity, the two modules will be excluded from the coming research next semester. • The modules of atomic & nuclear radiation and optics can be added into the research scope of next

semester. Plus the modules of thermal physics and waves & sound being investigated this semester, there can be four modules in the scope of next semester research.

- Some suggestions are given to design the multiple representational questionnaires. For example, some books and website are suggested to refer to.
- Some pilot tests of the multiple representational questionnaires are expected this semester.

Fourth Meeting (30/Oct/2008)

- Discuss the results of the pilot test processed in the tutorial of Unit B.
- From the pilot test, it is found that the level of students' conceptual understanding and calculation ability is weak.
- Despite of the low quality of students' representations in the SHM questionnaire, the unit students were still suitable for testing our developing multiple representations questionnaires in the next research phase because they could present their knowledge using the multiple representations we asked.
- The pictures which students drew in the questionnaires are similar with the ones in the textbook or in the lecture notes (which can be downloaded from the Internet). These students' representations probably show their ability to memorise but not their conceptual understanding. To avoid this problem, the questions in the questionnaires could be designed according to everyday experience.
- Some questions are too general. More clear, specific questions will be needed for next semester's data collection.

4.3 Discussion and Recommendations from Research Phase One

4.3.1 Multiple Representations Used in the Lectures and Tutorials

According to my observations, the demonstration of three-dimension entity rarely appeared in lectures and tutorials. Such demonstrations did not appear in the lectures and tutorials of thermal physics module and waves and sound module. Probably it is difficult and inconvenient to find suitable materials or objects to help explain concepts in those two modules, especially those materials or objects that should be big enough for every student to watch. To avoid this situation, videos containing real life experiments or experiences could be used in the lectures.

Besides, too little time was spent to explain some parts of the lecture powerpoint presentations. The reason why this happened could be that too much content was needed to be taught in a short time, but the lecture time regulated by university was not enough. Since it is nearly impossible to increase the lecture time or reduce the content intended to be taught in a short time, a feasible way to solve the problem is supplementary teaching in the tutorials.

4.3.2 SHM Multiple Representational Questionnaire

From the analysis of the SHM questionnaire completed by students, it can be discovered that in questionnaire number one there are many answers which are from the powerpoint presentation lecture notes or the textbook. Because it was distributed to students after they were taught SHM, it is hard to distinguish whether their answers were from their memory or from their real conceptual understanding. To avoid this problem, the questionnaires for the next semester research were to be designed based on everyday experience and more clear questions were to be preferred. Students should know what the question really wants. Furthermore, the representation of calculation would not be discussed in the following research because we would be interested in students' conceptual understanding. The ability to calculate may or may not have to do with conceptual understanding.

In the SHM questionnaire number one, another problem existed. Some students drew coordinate graphs when the question asked them to draw pictures; some drew diagrams when the question asked them draw coordinate graphs. This problem could be caused by the unclear definition of these representations. Therefore in the following revised multiple representational questionnaires, all representations were to be well defined or given an example in the beginning of the questionnaire, and let students select the representations they want to use to answer each question. In this way, students would be better informed to present their conceptual understanding with as many representations as possible.

4.3.3 Recommendations for Teaching

There are some recommendations for teaching in Units A and B:

- Since it was difficult to demonstrate experiments, three-dimensional entities and real life experience, playing video including these contents would be a good option to be used in the lectures. On the one hand, lecturers would not need to bring a lot of demonstration material with him or her to the lectures. On the other hand, playing videos would not take so much time that the lecturer could not teach all the expected content to students. In addition, it may raise students' motivation for learning.

- According to the outcome of Phase one of the study, the lecturer and tutor would have to notice if the prior knowledge of Unit B students is sufficient and correct.

4.3.4 Recommendations for Research

- Obtain more detailed information on the lecturer's and tutors' multiple representations, which includes the time and frequency of every representation used in lectures and tutorials. The relation between those information and students' multiple representations needs to be examined.

- Explore teacher's and students' views on the lecturer's and tutors' multiple representations. This could be done by interviewing the teacher and students in order to gain a deeper understanding of their perceptions.

- Develop students' multiple representational questionnaires. Because the lecturer and tutors do not have enough time in class to explore every student's concepts by one-to-one talking, a well-designed questionnaire could be a good alternative. The questions in the questionnaires would be suitable for answering with multiple representations. Besides, in order to avoid that students answer the questions by memorizing the content, the questions would come from the everyday life experiences and in this way, the ability to apply classroom knowledge to life can be examined.

  As mentioned above, the questionnaires should be clear on asking students what to do, also would give an example for each representation. Students would have more clear ideas about what every representation looks like and would be asked to express their conceptual understanding with as many representations as possible.

According to the conclusion of the third meeting with experts (Table 4.3, 9/Oct/2008), there are four modules worth developing the multiple representational questionnaire for further research due to not being studies and being less relating literature before, which would be thermal physics, waves & sound, optics and atomic & nuclear radiation.

- Survey students' motivation about learning physics and students' expectations about their physics unit.

  There were about 60-70 students in each lecture class (Unit A and Unit B went to the same lectures) and about 20 students in each Unit A tutorial class, 5-10 students in each Unit B tutorial class. Compared to the number of enrolled students, the rate of class attendance was low. In addition, students were expected to try practice questions before tutorial class. However, there were still many students who did not do this and some students even did not bring the practice questions sheets to tutorial. Furthermore, only a few students proposed their questions spontaneously in tutorials, and if any, most of the questions were from the practice question sheets. From above observation, we were curious to know students' motivation of learning physics and what they expect to learn in those units.

- Investigate students' physics learning background in senior high school, which can help to understand students' prior knowledge.

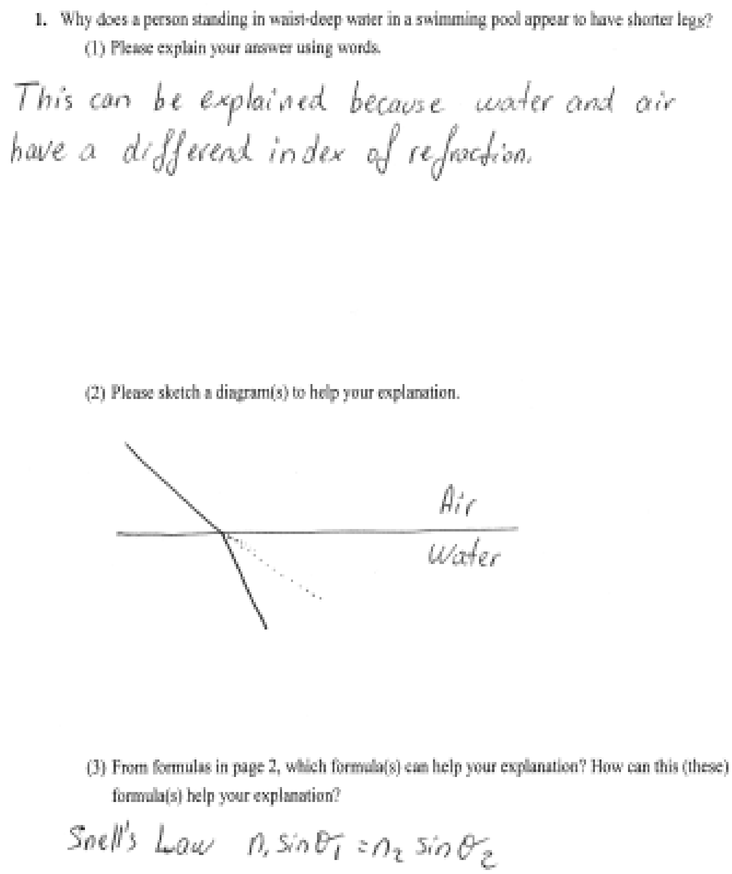
These points were put into practice in Research Phase Two.

4.4 Results of Research Phase Two: Trialing of Multiple Representation Questionnaires and Attitude Surveys

4.4.1 Results from the Thermal and Optics Multiple Representational Questionnaires

The Thermal Questionnaire (posttest) contained 12 questions in total (See Appendix 3.2). Of six students, only one student provided three representations on 10 of the 12 questions, one student provided three representations on one of the 12 questions. Of six students, only one student provided two representations on six of the 12 questions, two students provided two representations on five of the 12 questions, one student provided two representations on two of the 12 questions, two students provided two representations on two of the 12 questions.

In the Optics Questionnaire A (posttest) (See Appendix 3.4), there are six questions in total. Of six students, only one student provided one representation on one of the six questions. In Optics Questionnaire B (posttest) (See Appendix 3.5), there are also six questions in total. Of six students, only one student provided one representation on one of the six questions, one student provided no representations on one of the six questions. Besides the evidence above, we also checked the remaining students' questionnaires. It was concluded that most students just used one representation as a response in the Thermal Questionnaire (pre and posttest, see Appendix 3.2), and Optics Questionnaire (pretest, see Appendix 3.3), whilst most students used more than one representation as response in the Optics Questionnaire (posttest) in which the question format had been changed (see Chapter Three, Section 3.4.2).



1. Why does a person standing in waist-deep water in a swimming pool appear to have shorter legs?

(1) Please explain your answer using words.

This can be explained because water and air have a differend index of refraction.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

Snell's Law $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Figure 4.3: A student typical response to multiple representations on the Optics Questionnaire

No matter whether the question format had been changed or not, the majority of students were not able to solve the questions effectively. For example, Figure 4.3 shows a typical response of most students. In the part of word description, the answer does not address the main point and more details need to be described. In the diagram part, the diagram cannot present the complete situation of the question and more labels are needed to clarify the lines. In the part of the formula, the variables need to be explained and to be applied to the situation of the question.

Taking another example, students' grand mean of marks in each representation in pretests and posttests on the Thermal Physics Module are shown in Table 4.4. Each grand mean of mark is less than 2 (Mostly right) except the mark in the representation of graph in the posttest for Unit A (Grand mean=2.00, but just only one response). Typically, even after seven weeks of teaching that was designed to provide these non-major physics students with a wide range of representations, the tendency of students was to only respond to a question using one representation and with a maximum score possible of 3, the grand mean score was a little more than 1, mostly wrong. To sum up, students' understanding of tested concepts was not at a high level.

Table 4.4: Comparison of pre-test and post-test in the number of students' representations and the marks in different students' representations on Thermal Physics Module

	Unit A			Unit B		
	Pre Test Grand Mean(N=39)	Post Test Grand Mean(N=31)	Gain	Pre Test Grand Mean(N=28)	Post Test Grand Mean(N=8)	Gain
#R	1.06	1.19	0.13	1.15	1.23	0.08
A	1.07	1.27	0.20	1.20	1.20	0.00
B	0.83	0.94	0.11	0.78	0.87	0.09
C	1.69	1.67	-0.02	1.40	1.60	0.20
D	0.00	2.00	2.00	-	-	-

N: Number of Students who returned questionnaires; #R: Mean Number of Representations per questions; A: Mean score in Words per question (Written Description); B: Mean score in Diagrams per question; C: Mean score in Formula per question; D: Mean score in Coordinate Graph per question; Student who returned the pre-test did not necessarily return the post-test

4.4.2 Results from the Physics Motivation Survey

The mean scores of the five factors of Physics Motivation Survey (See Appendix 3.6) are shown in Table 4.5. The means for the factors of self-efficacy and assessment anxiety are near 3 (sometimes). The means of the other factors are located between 3 (sometimes) and 4 (usually). Therefore, the overall Physics motivation of students from Unit A and Unit B together was in upper-intermediate level (around 3 to 4) of the 1 to 5 Likert's scale when the survey was distributed (in the sixth week).

As for the reliability analysis, with the exception of grade motivation (GM), the Cronbach's alpha reliability measures for each factor are larger than 0.70, which are acceptable(DeVellis, 2003):0.86 for IMPR (N=75), 0.77 for SEAA (N=76), 0.73 for SD (N=76), 0.80 for CM (N=76), 0.47 for GM (N=76). The finding is similar with

Glynn's (2009)reliability analysis on the five factors (See Appendix 7.2), which indicates some items (e.g. item 12 and item 20, which were categorized to other factors before the factor analysis) in GM factor may need to be revised or removed.

Table 4.5: Mean and standard deviation for the five factors of the Physics Motivation Survey (N=76)

	IMPR	SEAA	SD	CM	GM
Mean	3.54	2.99	3.69	3.45	3.91
Std. Deviation	0.59	0.58	0.65	0.88	0.51
Minimum	2.20	1.67	1.75	1.00	2.60
Maximum	4.90	4.22	5.00	5.00	5.00

(Five factors: IMPR: intrinsic motivation and personal relevance, SEAA: self-efficacy and assessment anxiety, SD: self-determination, CM: career motivation, GM: grade motivation)

4.4.3 Results from Expectation and Experience Survey

From the analysis of Expectation Survey (See Appendix 3.7) and Experience Survey (See Appendix 3.8), Table 4.6 revealed that there were no statistically significant differences between students' mean expectations (3.72) and actual mean experiences (3.69) when Units A and B are considered as a whole (N=45). The Cronbach's alpha reliability values for the Expectation Survey is 0.73 (N=91), and for Experience Survey is 0.57 (N=59). However, the low value of 0.57 may be due to the small sample size. Besides the finding that students' experience had no statistical difference compared to their expectation, the mean of Expectation Survey (3.72) was in between 3 (neutral) and 4 (agree), which means their expectation were in upper-intermediate level of the 1 to 5 Likert's scale. Based on the results, the unit experience could meet students' expectation in the beginning of the unit. It was speculated that students' expectation of learning physics remained in an upper-intermediate level during the semester, namely, one aspect of students' attitude to learning physics kept positive during the semester.

Table 4.6: Paired samples t-test for the difference between mean of Expectation Survey and mean of Experience Survey (N = 45)

Survey	Cronbach'sAlpha	Mean	Standard dev	t-value
Expectation	.73	3.72	.48	.49
Experience	.57	3.69	.33	

4.5 Discussion and Recommendations of Phase Two

The study reported in this chapter is part of an investigation to encourage non-physics major students to present what they understand about physics topics of optics and thermal concepts using different representations and to determine how best to solicit and measure these representations. Much had been learned in Phase Two of this study. To improve students' low performance in the multiple representational questionnaires and encourage students' self-learning, in Phase Three, students would not be prohibited from referring to any other materials and discussing with other students while responding to the questions. Also richer data in different representations could be obtained by doing this and would help us uncover the relationships among the representations and questions.

Also, since the question format of the Optics Questionnaire posttest is likely to induce different kinds of students' representations, this format would be used in Phase Three for the third assessment of the multiple representational questionnaires. In addition, in the diagram part of the questionnaire, diagrams showing the context of the questions would be provided on the questionnaire before distribution in order to induce more diagram representations.

With regards to the motivation investigation gained from the Physics Motivation Survey, the Expectation Survey and the Experience Survey, the results contradicted the classroom observations in Phase One. In Phase Two, the Expectation Survey and the Experience Survey were distributed before the beginning and near the end of the semester course, and the Physics Motivation Survey was distributed in the middle of the semester course. It can be seen students' attitude towards learning Physics was positive, in upper-intermediate level in the beginning and in the mid of the semester course. Besides, from the result of Experience Survey, students' actual experience met their expectations. It can be speculated that the students' attitude towards learning Physics throughout the semester course was positive. However, this findings was quite different from the classroom observations in Phase One when it was noted that students did not do homework, did not propose questions actively in tutorials, the rate of class attendance was around or less than half, and so on. The reason making the conflict between the two phases would need to be further investigated in Phase Three.

There is another point worth mentioning. Although students' attitude towards learning Physics was positive while they responded to the multiple representational questionnaires, their conceptual understanding shown in their responses was superficial. It would be interesting to investigate what caused the gap and the investigation would be one of the emphases in Phase Three study and would involve student interviews.

Overall in Phase Three, the multiple representational questionnaires would be revised and distributed to students for the third trial. Besides that, the Expectation Survey, the Experience Survey and the Physics Motivation Survey would be administered again, and we would involve more non-Physics majors to complete those surveys and questionnaires to provide more reliable results. Finally, some students would be interviewed to help gain a deeper understanding of the relations within and between the multiple representations, students' conceptual understanding and students' attitude towards learning Physics.

4.6 Conclusion of this Chapter

To conclude this chapter, the main achievement in Phase One of the study was to develop the multiple representational questionnaire on SHM by classroom observation, meeting with experts, and the first trial of the questionnaire was administered. The process of developing and administering the questionnaire also inspired some discussion and suggestions for unit teaching and for further research. Besides, because of having observed some students' inattentive learning behaviours, students' learning attitude was to be investigated in the next research phase.

The Phase Two of the study focused on investigating the situation that students answered the revised multiple representations questionnaire on Thermal Physics and Optics as the second trial, and investigating students' learning attitude and the reliability of the selected attitude surveys. The results showed that students' level of tested concepts in multiple representations questionnaires was not high and students' score in each representation (except graph with only one sample) improved limitedly in thermal physics questionnaire after instruction. However, students made more attempts on different representations to answer the same question when the format of the question had been changed in optics questionnaire. The results also showed that students' learning attitudes were positive throughout whole semester, but more students' samples would be needed in order to examine the validity and reliability of the selected attitude surveys more effectively. Finally, interviewing students would be conducted in the next research phase to gather more data about multiple representations and students' learning and attitudes to their studies.

CHAPTER 5

Results and Discussion in Research Phase Three: Evaluation of the Questionnaires and Measuring Students' Conceptual Understanding with Multiple Representations

5.1 Introduction

In this chapter, responses are provided to Research Questions 1 and 2. Research Question 1 is about students' evaluations of the multiple representational questionnaires. Based on the interview data, students' positive and negative evaluations of the multiple representational questionnaires are presented and discussed. Next, to respond to Research Question 2, students' conceptual understanding assessed by different written representations (written words, diagrams, formulas and coordinate graphs) are reported and the possible causes to the results are discussed. Besides, the roles that students' oral explanations to their written responses played in assessing their conceptual understanding are identified.

5.2 Response to Research Question 1: What are students' evaluations of multiple representational questionnaires?

To answer this question, the interview data were used. From the 10 selected interviewees (identified as John, May, Amy, Alice, Ella, Grace, Hebe, Ken, Lisa, Tom), most provided an overall positive evaluation of the questionnaires. The reasons why they evaluated the questionnaires positively were that the pages presented good instruction, it was a good summary and preview for the class, could be used for revision, showed real life physics examples and enabled an awareness of multiple representations.

5.2.1 Positive Evaluations of the Multiple Representational Questionnaires

- Good instruction page providing a useful summary

Firstly, the instruction page was considered to provide good instructions as illustrated by an excerpt from the interview with Ken, which shows how the instruction page provided him with a good example of how to answer the questions in the questionnaire.

> I: Did you know what was meant to be done for each question on this questionnaire?
> Ken: I think so, yes. The good thing about it was the fact that you did have the example right at the front of how you could actually fill it out.

Several students thought that the questionnaire provided a good summary of what the students should learn in class. The comment from May typifies this view.

> I: Overall did this questionnaire help you with your thinking about Physics topic?
> May: Yes I think it did.
> I: How can that help you?
> May: I think it helped because it sort of summarised what we learnt, so in the lectures and in the tutorials in the labs and then it's sort of all in one, so it summarised it really well, so you've sort of known which areas to look at. So that was good yeah.

- For preview and revision

Several students explained that the questionnaire can be used for preview before the module starts or was suitable for revision and test preparation. A typical comment presented by Hebe follows:

> I: So it made you think deeper about the concept?
> Hebe: (omission) like for example this one. These sort of questions, and I just thought like yeah, I know them, but I didn't know that I didn't know them before.
> I: Sure.
> Hebe: But it, they had stocked in my mind… before that (lecture). I had question in mind to listen during lecture, or go and find it.

Similarly, according to several students (John, Ken), the questionnaire was deemed to be suitable for revision and test preparation.

> I: So was it a fair use of your time?

John: Was it a use of my time? It was good for revision you know like I mean I've got to go over it anyway but it wouldn't be a waste of time. I mean it helps me enforce the principles that are taking place so if that helps it mustn't be a waste of time.

I: So did this questionnaire help you with your thinking about physics topics?

Ken: Definitely. Particularly with the timing of it because we would take the post-teaching questionnaire just after we had finished the teaching, that was also the time at which we would be preparing for a class assessment test as well. So I guess I used it as part of my revision process as well.

Other students (Lisa and Ella) commented that the pre-test highlighted what they did not know

I: Did you finish quicker in the pre-test?

Lisa: Well it was quicker because I didn't know what I was doing and I just got frustrated that I didn't know anything, but this one here, I think it was just making sure I knew it you know. Making sure and if there was something that I didn't know, I'd have to, like I know that I don't know magnification yet. And I know that I don't know much about the human eye, so I just have to, at least I know what I don't know and that's what I'm going to have to study on in the next couple of weeks.

I: So do you think it was a fair use of your time?

Ella: (omission). And so it showed me what I needed to work on and what I am not understanding as well and in fact I did really well in the thermal conductivity test and I think it was partially because of doing that questionnaire.

- Close to real life

Several students, such as Ken commented that they liked the questions in the questionnaire because they are close to real life.

I: Okay. How have you found these kinds of questions? Were they helpful to you, or it's not helpful?

Ken: Oh, definitely. What I liked about them was the fact that they were closer to real world situations.

- Benefit from multiple representations

The advantage of the multiple representations to learn physics was recognized by some students. Two students' comments (Ken and Lisa) that typify this point are described below

I: So did this questionnaire help you with your thinking about physics topics?

Ken: (omission). And it's also a case of it's good sometimes to have questions asked by someone else. What I mean by that is if you have a lecturer you get used to the questions and sometimes it might be that you might be able to glean something from how the question's asked or the answer should be. But then someone else's style, being slightly different, it just does make you think about it in a different way or perhaps think about how you can present the answer in a different way.

I: So overall did this questionnaire help you with your thinking about

Lisa: Yes it did, very much so.

I: How?

Lisa: Well it got me, well it got to show me how much I don't know for one and the things that I do know, it reinforced. And it also allowed me to know that I can draw a diagram, like I said before and have a formula for things. So if I'm stuck anywhere in Physics, I can just always draw a picture and there'll always be a picture somewhere, like whether Giancoli or in the lecturer's lecture notes or something, there's always a diagram to draw. Yeah it was actually really good for that, sometimes it's easier to draw a picture than sort of do it in words.

5.2.2 Negative Evaluations

In spite of the most positive evaluations, some problems related to the questionnaire were also proposed by interviewees. Following are the summary and excerpts of the problems.

- Too many questions and time consuming

Several students thought that the questionnaires contain too many questions and were time consuming to complete. The comment from Amy, Tom and Ella typified this point of view:

I: Too many tasks for you? Too many questionnaires for you?

Amy: Yeah I think maybe. Not too many questionnaires but too many questions.

I: Too many questions?

Amy: Yeah…You just only… three part for one question. For example Thermal, total is 12 questions. That means I need to answer 36 questions. Yeah it's too much.

I: So do you think completing the questionnaire was a fair use of your time?

Tom: Honestly I thought they were a bit long. I thought 15 pages was a bit big.

I: So do you think it was a fair use of your time?

Ella: Yes actually I found it was a bit tedious because they were long but actually showed me what I need to focus on and not, so it was actually useful. And it's also a different way of thinking when it comes to explaining things and especially with physics it's a lot harder, it's hard sometimes to grasp the concepts but you really do have to.

The cause of the students' comments could be some tested concepts in the questionnaire are repetitive. Although it can be helpful to strengthen students' understanding, it is also possible, on the contrary, students feel tedious. Therefore, in the future use of the questionnaire, some of similar questions can be taken away if necessary.

- Dilemma between real life and theory

Some students mentioned it was difficult to apply the theory to the everyday life situation in the questionnaires. The comments from Ken and Alice which typified this point are shown below:

I: So, did you encounter any difficulty when you tried to use each representation?

Ken: (omission), and sometimes again some components, particularly in the optics section, you might learn the theory and you can tell that the theory should relate, just based on the information, but sometimes how it would actually present itself in the real world was a bit difficult.

I: Were those questions clear for you?

Alice: Oh okay so yep so I understood what it was asking me? Yeah they were fairly clear except for I found that the graphs were slightly unclear. Yeah I'll show you perhaps.

I: Thermal One…

Alice: Say for example this one, I wouldn't have necessary represented it say in a linear diagram. I might have represented it more in a parabola or a curve as such. Not exactly a linear graph that I'd be inclined to show but yeah because usually it's only a very perfect situation where you get very linear graphs. Sometimes you may get that curve. But yeah…'cause that was the example. I thought maybe I should make a linear as well.

Alice described an example which needed her to complete a coordinate graph showing the relation between the diameter of a metal lid (or a glass jar) and increased temperature. She stated that unless in a very perfect situation, the relation would not be linear. Indeed, unless the lid or the jar is uniformly heated and uniformly made, in a real situation, it would not present the linear relationship. However, the reason why we used the everyday life situation in the questionnaire was to help students' conceptual development and to avoid students memorizing the content of their textbooks. On the other hand, the theoretical situation is always not same as the real life situation. The real life is usually complicated and many factors can influence theory application. Not all students can be aware of the dilemma like Alice, and in the future we may need to remind them the difference between the real world and the theory, and what we emphasize is the major theory or principle behind the complicated life situation.

- The problem of existing diagrams

Students may have their own diagram to draw instead of the existing diagram. The problem happened both in thermal and optics module and they thought the existing diagrams were pointless. They did not know how to show their understanding in the existing diagrams and might have their own diagrams to present their understanding. The comments from Alice, Grace and Ken illustrated the problem:

I: Yep so do you have any difficulty when you tried to use each representation?
…(omission)
Alice: Oh question number two part two from the thermal physics questionnaire. So for example please sketch a diagram to have an explanation of the person sitting on the chair and they've just drawn arrows to show you that the heat was transferring from the person to the metal chair.
I: Yep so what's the problem?
Alice: Oh well I would have drawn a more molecular sense instead of a person in a chair. If you understood what I mean? Like I would have drawn... If I was to represent heat from the body transferring to the heat of the metal chair, I would have drawn more atoms or molecules instead of a person.
I: So did those representations make you confused of any concept?
Alice: The diagram. Because that's what you would normally expect a thermometer to show anyhow so I found it very difficult to

show you expansion because you normally expect it to expand upwards anyway. It seems logical for me that it would expand upwards so drawing on the diagram I just thought was quite pointless cause that's what it would do necessarily anyhow.

I: So what can you know, can you understand from this diagram?

Grace: It was hard to differentiate how to say the heat was conducted faster from the metal chair than it was from the wooden, because it's harder to represent that in a picture.

I: Okay. How have you found these kinds of questions? Were they helpful to you, or it's not helpful?

Ken: …(omission). I think there were a couple unfortunately where I didn't really know how to draw a diagram. One that springs to mind is the polariser …(omission)

Initially we tried to attract more students' diagram representations in this phase so we drew the background of some questions for students in advance. Since those existing diagrams were pointless for some students, in the future we may claim that students can draw their own diagrams if they do not know how to make use of the existing diagrams.

- Repetition in pre and post test

Alice commented that it was boring the questions used in pre and posttests were the same:

I: Okay. So how do you feel about answering those questions 2 times? Do you feel bored?

Alice: Of course. Of course it's very repetitive. If you ask me perhaps a similar question like similar theory but rephrased differently, it might have been a bit more interesting. It might have seemed very different to me and less pointless.

The purpose of the repetition in pre and post-test was to measure if there was any change in students' performance on the questionnaire. In the future if the use of the questionnaire is mainly for students' learning rather than assessment, it should be all right to just distribute the questionnaire once to students.

- Problems when doing pre test

Some interviewees (Hebe, Lisa) were not comfortable about doing the pretest, because they felt annoyed or stupid when they found they could not answer many questions.

> I: …(omission). How have you found that type of question? Has it been a nuisance or has it been helpful to you, in terms of your understanding of the physics?
> …(omission)
>
> Hebe: At the beginning I didn't know how to sketch a diagram and then, and because you have to consider so many things like is it like parabola… is it linear… how should it work, and then at the beginning, especially the one before teaching, is so annoying. I didn't know what to write. And I didn't know if it's okay if I say I don't know. I was just struggling what's right.
>
> I: So what was it like completing the questionnaire after the lectures, tutorials and labs?
>
> Lisa: These ones?
>
> I: Yep this questionnaire.
>
> Lisa: Well the first one I did was absolutely shocking. It was shocking because I didn't know anything and I felt a bit stupid.
>
> I: Oh…I should have said it's okay and if you say you don't know anything.
>
> Lisa: Yeah I felt like I should have known something, but then I didn't know it was a pre-questionnaire.

Regardless of the discomfort, one of the purposes we asked students to do the pretest was that we were interested in students' conceptual improvement after the unit course, and the pretest would provide a baseline for us to understand the improvement. The other purpose was that we expected students to preview what they would be taught in class and the preview would be helpful for their learning.

However, for future research, the announcement that "Please do not worry if you cannot find the answer, we just want to know your knowledge before the module starts" should be made in the questionnaire in order to reduce any discomfort about responding to items about what they know very little.

A summary of the above positive and negative evaluations of the multiple representational questionnaire is provided in Table 5.1.

Table 5.1: A summary of interviewees' positive and negative evaluations of the multiple representational questionnaire.

	Interviewees									
Positive evaluations	John	May	Amy	Alice	Ella	Grace	Hebe	Ken	Lisa	Tom
Good instruction page providing a useful summary		v						v		
For preview and revision	v				v		v	v	v	
Close to real life								v		
Benefit from multiple representations								v	v	
Negative evaluations										
Too many questions and time consuming			v		v					v
Dilemma between real life and theory				v				v		
The problem of existing diagrams				v		v		v		
Repetition in pre and post-test				v						
Problems when doing pre-test							v		v	

5.3 Response to Research Question 2: What was the level of students' conceptual understanding based on the analysis of the multiple representational questionnaires and interview explanations?

The following are the results of analyses of students' responses to the multiple representational questionnaires, including students' attempts in each representation, the number of representation per question, marks for different representation and average mark of all type representations. In Table 5.2, students' attempts in each representation in optics pre and post questionnaire (See Appendix 3.10) are shown. With the exception of coordinate graph representation (only one coordinate graph question in the questionnaire), after the instruction containing multiple representations, students' attempts in the other three representations had statistically significant increases. Compared to the pre-test, in the post-test the students' attempts in written words representation increased from 9.52 to 11.27, the diagram representation increased from 8.12 to 10.31, and the formula representation increased from 4.39 to 7.32.Besides that, the effect size for the three type representations was 0.76 (medium effect), 0.82 and 0.98 (large effect), respectively. When considering the responding rate in each representation, in the posttest, students responded 11.27 of 12 written words questions, 10.31 of 12 diagram questions, and 7.32 of 10 formula questions. The high responding rate made the marks presented in Table 5.3 more valid.

Table 5.2: Descriptive and inferential statistics on pre and post-tests for students' attempts in each of four representations on the Optics test (Unit A, Unit C combined)

Representation	N	Student Attempts		t-test	Cohen's *d*
		Pre	Post		
		Mean(Sd)	Mean(Sd)		
Written words	71	9.52(2.89)	11.27(1.47)	5.39**	0.76
Diagram	68	8.12(3.24)	10.31(1.96)	5.96**	0.82
Formula	31	4.39(3.42)	7.32(2.46)	5.62**	0.98
Coordinate Graph	45	1.00(-)	1.00(-)		

**p<0.01

N: the number of the students who responded using that representation at least once in pre and post test respectively

From Table 5.3, the mark for written words, diagram, coordinate graph, all type representations, and the number of representations per question had not only shown statistically significant improvement, but also had medium to large effect sizes ranging from 0.57 to 1.17. The mark for formula showed no improvement based on the t test and effect size. Regardless of the improvement of marks, all mean marks in the post test were from 1.14 to 1.71 of the maximum 3 marking scale, meaning students' understanding of the tested concepts was not at a high level. In addition, a large proportion of respondents preferred to use written words and diagrams to answer the questions (71 respondents preferred to use written words and 68 preferred to use diagrams of total 73 respondents).

Table 5.3: Descriptive and inferential statistics on pre and post tests for mark of each representation, average mark of all type representations, No. of representations on the Optics test (Unit A, Unit C combined)

Per Question	N	Pre	Post	t-test	Cohen's *d*
		Mean (Sd)	Mean (Sd)		
Written Words	71	1.09(0.43)	1.49(0.40)	8.86**	0.96
Diagram	68	0.87(0.37)	1.14(0.43)	5.62**	0.67
Formula	31	1.67(0.54)	1.62(0.32)	0.60	0.11
Coordinate Graph	45	0.91(1.31)	1.71(1.47)	3.47**	0.57
All types	71	1.02(0.39)	1.41(0.35)	9.40**	1.05
No of Representations	73	1.62(0.72)	2.37(0.55)	9.50**	1.17

**p<0.01

The same analysis was conducted with the data from the thermal module (pre and post test questionnaire see Appendix 3.9) and the results are shown in Table 5.4. Except for the diagram representation, the increase of the mark for written words, formula, coordinate graph and all types were statistically significant and had a small to large effect size (0.30 to 0.86). The number of representations per question also increased significantly as demonstrated by the t-test and effect size. In spite of those improvements, the mark for each representation or the average mark of all type representations ranged from 1.40 to 1.67 in the post test, which meant even after the unit teaching, the students' understanding of tested concepts was not at a high level. Besides in this module, a high proportion of the 73 respondents liked to use written words (73 respondents), diagrams (73 respondents) and coordinate graphs (66 respondents) to answer the questions. If we compare Table 5.3 together, it is interesting to find that formula was the last choice for students to solve questions in both optics and thermal modules.

Table 5.4: Descriptive and inferential statistics on pre and post tests for mark of each representation, average mark of all type representations, No. of representations on the Thermal Physics test (Unit A, Unit B combined)

Per Question	N	Pre	Post	t-test	Cohen's *d*
		Mean (Sd)	Mean (Sd)		
Written Words	73	1.29(0.33)	1.40(0.39)	2.37*	0.30
Diagram	73	1.45(0.35)	1.50(0.34)	1.26	0.14
Formula	45	1.11(0.71)	1.67(0.59)	4.42**	0.86
Coordinate Graph	66	1.32(0.59)	1.52(0.56)	2.79**	0.35
All types	73	1.33(0.30)	1.51(0.36)	4.15**	0.54
No of Representations	73	2.13(0.57)	2.63(0.59)	7.91**	0.86

*p<0.05 **p<0.01

It is hypothesized that the improvement in marks allocated to the students' representations may be due to the effect of the lectures and tutorials that were designed to make students more aware of the different ways they can represent their knowledge. Indeed, the content of the questionnaire is highly related to the content of lectures and tutorials. This can be demonstrated by the following interview excerpts.

Ken thought after the lectures and tutorials, it was much easier to answer the posttest compared to the pretest:

I: Okay. So what was it like completing the questionnaire after lectures, labs and tutorials?

Ken: It was really eye opening having done the pre-teaching questionnaire and then the same questions afterwards. Certainly doing the pre-questions it was amazing, particularly with the optics, I really didn't know any of the questions. With the thermal I knew a little, like I say, for example sitting on the chair. We've done that so you could describe it in words but then not be able to answer by the picture or by the formula. But then coming back to them, just after having done the lectures and the tutorials and the practice questions, much easier to answer…(omission)

From the above excerpt, Ken described that he learned how to present his understanding using diagrams and formulas after the module teaching. It was one of the main goals of the unit to develop students' ability to use different representations.

Besides that, some interviewees considered that the questionnaire was a summary of lectures and tutorials, and everything in the questionnaire was covered in the lectures and tutorials. Such a situation is typified by the comment from Ken, May, Hebe and Lisa.

I: Okay. So when you were doing this, did you look things up in your notes or books or discuss with other people?

Ken: I didn't discuss with anyone else and with the questions. I don't think I referred to the notes in the sections where I was explaining using words or drawing a diagram, or even the ones drawing a graph. But I certainly did refer back to my notes for the equations, particularly with some equations there might be more than one version of it or in a couple of the answers I've perhaps quoted specific data, like the specific heat of a particular metal I would certainly have to look that up. But for the basic explanation, no, it was enough to have gone through the concepts, I think, in the lectures.

I: So okay next question. Did you see any connections between those questions and lectures or tutorials?

May: Yeah I did. That was, it was good because it sort of summarised what was in the lectures and the tutorials, so I did see lots of connections yeah.

Hebe: Yeah. Well actually they were sort of addressing some of these questions. Like the same questions even, some of them, or the same concepts. Not the same question, but the same things.

Lisa: Yeah I did, and they were just simply the fact that it was everything that was covered in the lectures and tutorials.

The concepts tested in the questionnaire were almost the same as the concepts taught in lectures and tutorials. Therefore, if students paid attention in the lectures and tutorials, it should not be difficult to show some improvement in the post-test.

On the other hand, we speculate the reason why there was no significant change in the mark for diagram in the thermal module and mark for formula in the optics module. In the thermal module, it was easy for students to draw heat flow or object expansion even in the pretest. However, in the post test, most students could not use diagrams to show a deeper understanding, for example, linear relationship in linear expansion. As a result, there was no significant improvement in the mark for the diagram representation. Regarding the mark for the formula in the optics module, it is possible that the formulas are complicated for the students and that they were not able to gain a deeper understanding even after the module course.

Furthermore, formula representation had the lowest responding rate of the four tested representations in Table 5.3 (31 of 73 respondents) and in Table 5.4 (45 of 73 respondents) could be due to the reason that in pretest, most students could not understand the meaning of formulas. They did not know which formulas could explain their prior knowledge. Therefore they may give up the representation in pretest and may use formula in posttest. However the t test considered the students who ever used formula in both pre and posttest, so this may be the cause to the lowest responding rate.

We also tried to figure out if the time of each representation used in lectures related to students' conceptual improvement in each corresponding representation. We recorded the time of each representation used in some lectures in the thermal and optics module, and through the transfer of Timeline Maker Professional software, figures such as Figure 5.1 and Figure 5.2 were produced. The two figures presented the typical distribution of use of every representation in lectures of the optics and thermal modules respectively.

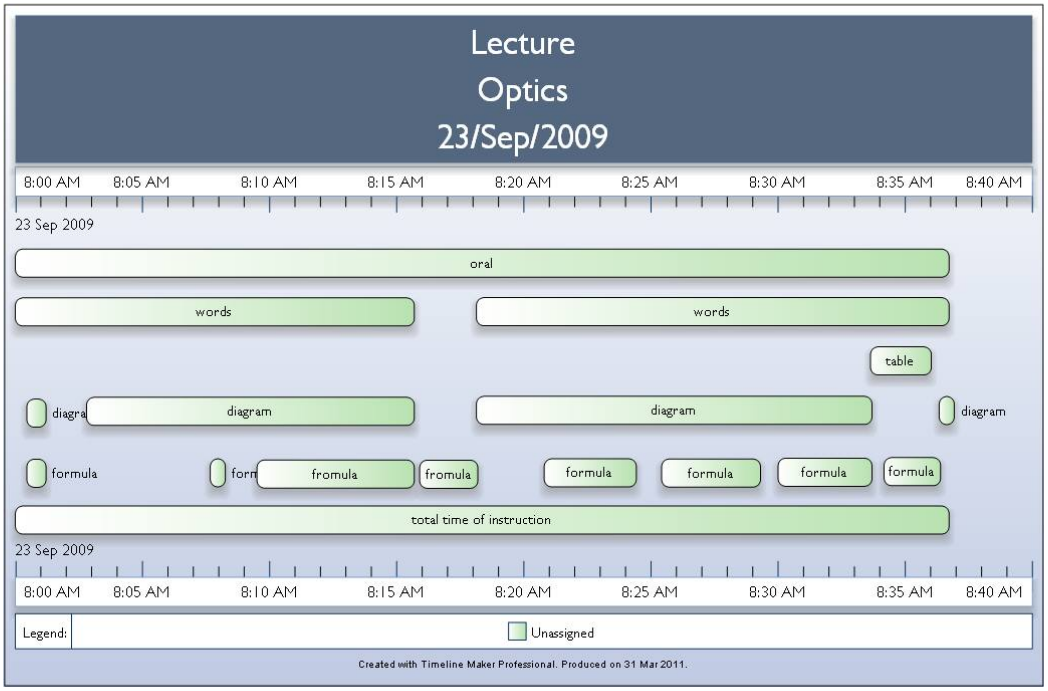


Figure 5.1: Typical distribution of use of every representation in optics lectures

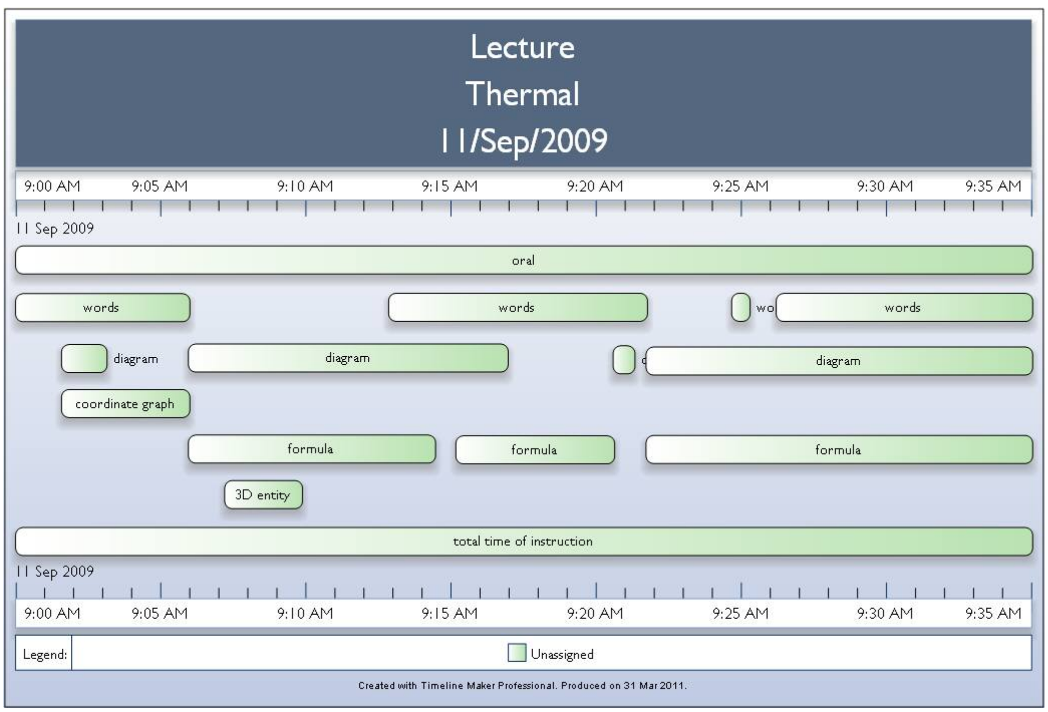


Figure 5.2: Typical distribution of use of every representation in thermal lectures

In Figure 5.1, it can be observed that generally in optics lectures, the time used in written words was longer than that in diagrams, and the time used in formula was shorter than above two representations. Besides, there was no time used in the coordinate graphs. In Table 5.3, the effect size of Cohen's d for written words (d=0.96, large effect) was larger than diagrams (d=0.67, medium effect). Further the Cohen's d in diagrams was larger than that in formula (d=0.11, trivial effect). However, in spite of no time being used in the coordinate graph, there was still medium size effect (d=0.57) in this representation. As a result, there was no significant correlation between the time of teaching and students' conceptual improvement in each representation.

As for Figure 5.2, in thermal lectures it can be seen that the teaching time of written words, diagrams and formula were similar. However, this was much larger than the teaching time of coordinate graphs. In contrast to the Cohen's d in Table 5.4, the effect size on the mark for written words (d=0.30, small effect) was larger than the mark for diagrams (d=0.14, trivial effect). The lecture's effect sizes of the former two representations were much less than that of the formula representation (d=0.86, large effect), and the effect size on the mark for coordinate graphs became much smaller (d=0.35, small effect). From the above described trend, it can be again speculated that the teaching time in one representation did not correlate with the conceptual improvement of the same representation.

It should be emphasized that the above inference was made from the situation that we only considered the teaching time in lectures. The reason why the teaching time in tutorials was not considered is because, unlike lectures, not all students went to the same tutorials. And from our observations, students who attended the tutorials were much fewer than those who attended the lectures. Therefore the teaching time in tutorials was out of our consideration.

Besides the above representations which demonstrate students' conceptual understanding in different ways, the students' interview explanations would be another type of representation. From the analysis of the interview data, the oral explanations can provide richer information about the student's conceptual understanding than the representations in the questionnaire can give. In addition the oral data can clarify the student's conceptual understanding and other representations. Sometimes, a student was able to show a better conceptual understanding than was evident from the representation(s) in the questionnaire. Such a situation is illustrated by student Grace in reference to question 7.2 in the optics questionnaire shown in Figure 5.3

I: Okay, now we start to record your questions, and you can tell me which question you feel confused, and using those different representations make you more confused.

Grace: Yep. Seven point two. You had to say whether the image changed when you move away from the convex mirror. I know the image size should change, but I didn't know which way it would change, whether it would increase in size or decrease in size. And didn't know how to draw the ray diagrams. So therefore, using a diagram, it was hard to come up with whether it would increase or decrease, and therefore. Then if you used the formula, it said if your distance of the object increases, then your height should decrease. I don't, I mean, no but …

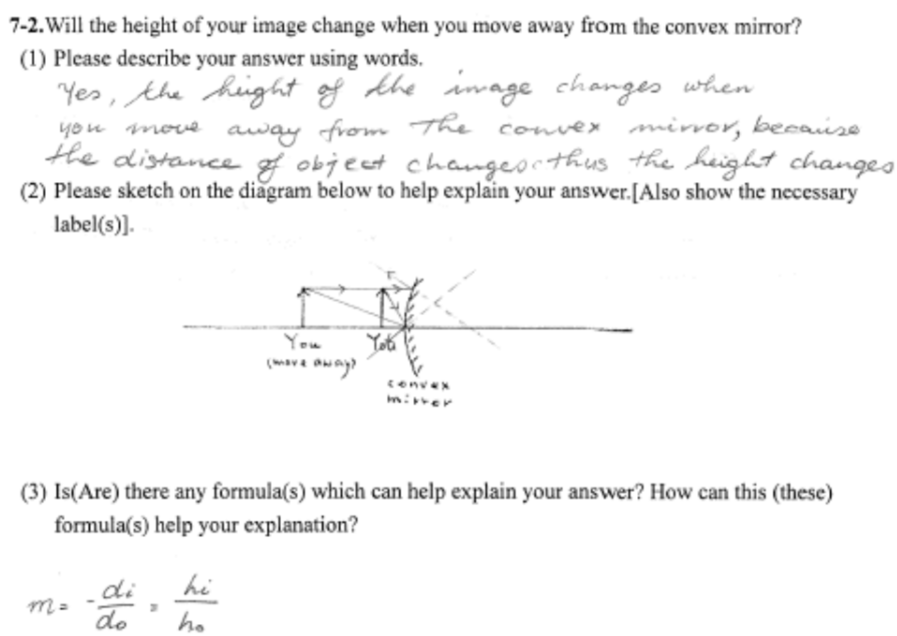


Figure 5.3: Written responses to item 7.2 on the Optics Questionnaire by student Grace

From above example, the oral explanation gave more information about and clarified her understanding in this question. If we just interpret the representations in her questionnaire, we know the student was aware of the height of the image would change but we are not sure if she knew the height of image should become smaller. Her diagram and formula are incomplete and we do not know the reason behind.

However, if we also refer to her oral explanation, we can be certain that she did not know how the height of image would change and she had trouble in drawing ray diagrams and applying formulas to such situation. We know more about her understanding with her oral explanation.

Following is another example. Lisa's oral explanation clarified her representations in question 3.2 of her optics questionnaire:

I: Let's try another question. Question 3.2. In this question, did those different representations help you develop understanding of any concepts?

Lisa: It did. I was a bit confused about what happens with a plain mirror. So, but I know, I just know that with a plain mirror it's always the same height. I just know that, so drawing it was actually a little bit difficult for me, so I had to say well if the light ray comes from wherever, it could come from wherever it might be. I could come this way, it's always going to be the same angle of incidence equals the same angle of reflection. So it's always going to come back to the same spot on the other side. Does that make sense? Which is here, the angle of incidence equals the angle of reflection.

…(omission)

I: So can you relate to those different representations?

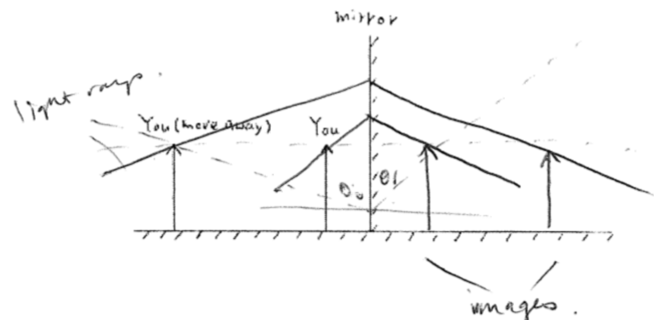
Lisa: Yeah. I can relate to this one. I know that this one, the distance of the object is there, but you know, mainly this one, for a plain mirror for me. I can't relate to this. I had to think about this because, so coordinate graph, all I know is that, okay these don't mean anything to me. I don't know. I didn't think about that.

3-2. Will the height of your image change when you move away from the mirror?

(1) Please describe your answer using words.

No ~~yes~~, As move back, the image too moves back, ∴ stays the same height.

(2) Please sketch on the diagram below to help explain your answer. [Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

$d_o = d_i$ or $\theta_i = \theta_r$.

$h_i = d_o$

(4) Please complete this coordinate graph **representing the situation when a 2.0 m-high person walks away from the point which is 1.0 m away from the plane mirror.**

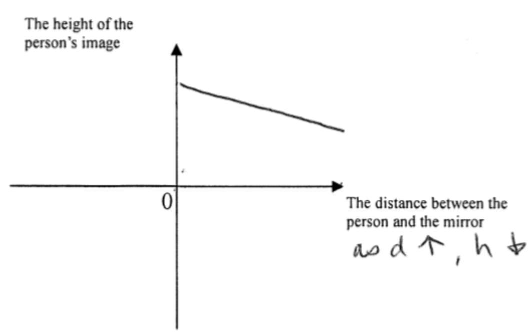


Figure 5.4: Written responses to item 3.2 on the Optics Questionnaire by student Lisa

If we just look the representations in her questionnaire, firstly we feel confused about her diagram. Her diagram shows the height of image keeps the same, which is right. But if we further check the light rays, then we are not sure if she knew how the light rays progress and how the images form in this diagram. Secondly, the coordinate graph shows totally different understanding from the written words and the diagram. In her coordinate graph, the height of the person's image becomes less and less as the distance between the person and the mirror increases. With the help of her oral explanation, we can clarify these confusions. She had the wrong understanding in the progress of the light rays and also she was not competent at using the coordinate graph.

Oral explanations sometimes showed that students had a better understanding than shown in the representations in the questionnaires. Following the Tom's oral explanation to the question number nine in the thermal questionnaire is an example:

> I: Next question. Question no 9. Can you explain this?
>
> Tom: Alright. Well since the brass strip has a higher heat coefficient, I assumed that that would expand more and this one wouldn't expand as much, causing it to sort of bend that way, so it'd curve downward. And so I just put that picture there and I put, since brass had a higher value of α, so since brass had a higher value of α, the change in level would be greater.

9. A bimetallic strip consists of a brass strip on the top and a steel strip at the bottom. If the bimetallic strip is uniformly heated keeping one end clamped in a horizontal position, how would the free end of the strip behave? The coefficient of linear thermal expansion of steel and brass are $12x10^{-6}$/C° and $19x10^{-6}$/C° respectively.

a. curve upward
b. curve downward
c. remain horizontal, but get longer
d. not change in length, due to different values of expansion coefficients
e. none of these

(1) Please explain your answer using words.

Since the brass strip has a higher heat coefficient, it will expand more than

(2) Please sketch the bimetallic strip after it is uniformly heated.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

$\Delta L = \alpha L_0 . \Delta T$

Figure 5.5: Written responses to item 9 on the thermal questionnaire by student Tom

From Tom's written responses and his oral explanation, we can find they both show similar conceptual understanding. Nevertheless, Tom's oral explanation reveals that he could use the formula to solve the question. He mentioned α, and described that the higher α, the greater the change in the length of the metal. He was familiar with the operators in the formula and the representational knowledge did not perform in his written responses.

The next example is Alice's oral explanation and written responses to question number 10 in the thermal questionnaire, which shows that Alice presented a better conceptual and representational understanding in her oral explanation than in her written responses.

I: Is there any relationship between the readings and this graph? Or this formula? Do you see any relation?

Alice: Well as, the readings would increase at I guess you could say a consistent amount. So say for example per degree so therefore for every change in length is a linear change. Same change in temperature. So as temperature changes your length would also change and that's shown in the graph as well. For the change in temperature, that's equivalent to the change in the length so the slope would be exactly the same. Yeah the gradient.

10. In constructing an expansion-type thermometer it is necessary to use a material which

a. changes phase when heated.
b. has a coefficient of thermal expansion which increases with increasing temperature.
c. has a coefficient of thermal expansion which decreases with increasing temperature.
(d.) will expand linearly with increasing temperature.

(1) Please explain your answer using words.

D, this factor is most important in order to achieve an accurate reading of temperature and also to be able to control the rate of expansion. We want a material to expand no more than a certain point in order to achieve an accurate reading.

(2) Please sketch on the thermometer shown below to help your explanation.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

$\Delta l = \alpha l_0 \Delta T$ (thermal expansion).

(4) Please complete this coordinate graph.

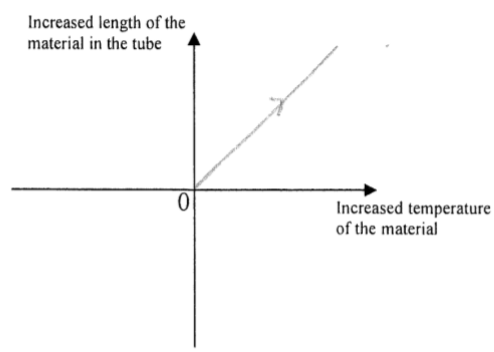


Figure 5.6: Written responses to item 10 on the thermal questionnaire by student Alice

In Alice's oral explanation, she described in detail linear thermal expansion, which demonstrated a better conceptual understanding than in her written response. Also, her oral explanation mentioned "the slope, the gradient was the same" when the variables in the coordinate graph had a linear relationship. This again showed that oral explanations sometimes can present better representational understanding than the representation itself shown in the questionnaire.

Overall, oral explanations can provide more information than is evident in the written responses in the questionnaire and further, the interviews have the function of clarifying written responses. Sometimes oral explanations can show better conceptual and (or) representational knowledge than the written responses can. Therefore if we need to assess students' understanding in the future, it is better to further check students' oral explanations if possible.

5.4 Conclusion of this Chapter

To conclude this chapter, first, the multiple representational thermal and optics questionnaire was evaluated by the 10 informative, interviewed students, and most of them gave the questionnaire an overall positive evaluation. However, some suggestions were made for revising and using the questionnaire. Second, although students' marks were not in a high level in the posttest of the questionnaire, students' average marks of all representations, the number of different mode representations presented per question improved significantly. We speculated the improvement may be due to the effect of the lectures and tutorials that were designed to make students more aware of the different ways they can represent their knowledge. We also found that there was no significant correlation between the time of teaching and students' improvement of mark in each representation. Last, students' oral explanations can provide more information through the written responses in the questionnaire and has the function of clarifying written responses. Oral explanation sometimes can present better conceptual and (or) representational understanding than the written responses can.

CHAPTER 6

Results and Discussion in Research Phase 3: Students' Use of Multiple Representational Functions

6.1 Introduction

In this chapter, responses are provided to Research Questions 3 and 4. Research Question 3 investigated how students performed when explaining their concepts using one representation on the optics and thermal physics questionnaires. Research Question 4 examined how well students performed with the multiple representation functions with and without guidance on the optics and thermal physics questionnaires. Firstly, we use the elements (representation, referent, and concept) in Pierce's Model (1931) to discuss how students performed well and confronted difficulties when they explained their concepts within one representation. Then we discussed how well students could explain their conceptions in terms of Ainsworth's framework(1999) about functions of multiple representations in the conditions with and without guidance. Finally, we discuss the difference in students' learning when guidance is present and the importance of a guide for helping students solve their difficulties and improving their understanding.

To clarify the meaning of the word "guidance" in this chapter, it needs to be explained that the guidance we provided to students during their interview means "someone reminded students the mistakes they made in the questionnaire or in their oral explanation, or reminded students to relate to different representations". Due to the limitation of the interview time, it was not intended to provide students with deep instruction. Nevertheless, the preliminary study still can provide a basis for future research.

6.2 Response to Research Question 3

How did students perform when explaining their concepts using one representation on the optics and thermal physics questionnaires?

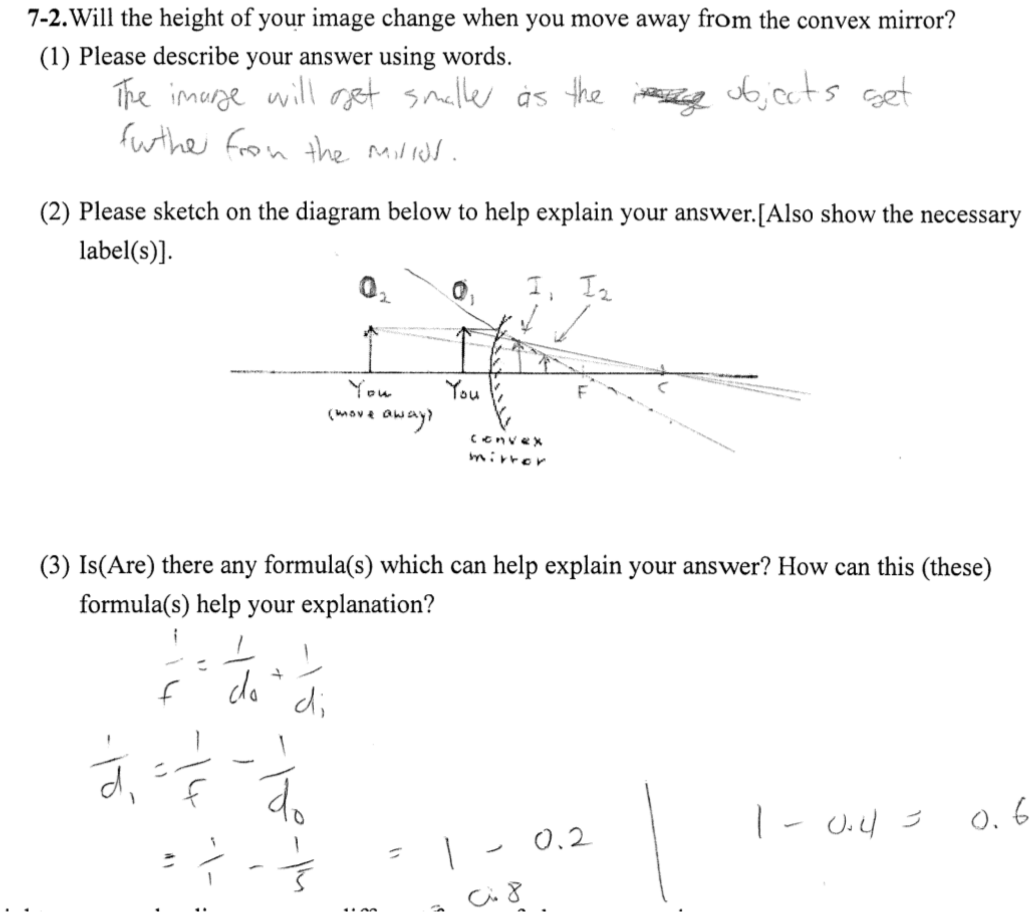
In order to answer this question, we first discuss students' positive performance followed by the difficulties they confronted when they explained their concepts within one representation in the multiple representations questionnaires. The main three elements, representation, referent and concept, in Pierce's Model were used for analysing students' explanations.

6.2.1 Positive Performance in a Specific Representation

Positive performance with regards to a specific representation was quite common in students' responses. However, it was rare to find responses that could apply the concept to another context rather than just to the context in the question. Perhaps the question context already demanded that the students needed a lot of time to respond; nevertheless we did welcome students being able to apply their concepts to more than one situation.

In the interview excerpt below that relates to Figure 6.1 (item 7-2 from the Optics test about the changing image in a convex mirror when moving away), the student John was able to provide an explanation without guidance using one referent and was also able to apply the question to a real life context(another referent) to explain the concept.

> I: So use those different representations…would that make you more confused about any concepts?
>
> John:…(omission). And you know even in practice that's correct, like you know in your mirror on your car, you know that objects that are further away are going to appear smaller and if you look at this you can see why that is the case. Because this object is further than this object so it appears smaller so that makes sense.
>
> (John 3.11.09)


7-2. Will the height of your image change when you move away from the convex mirror?

(1) Please describe your answer using words.

The image will get smaller as the objects get further from the mirror.

(2) Please sketch on the diagram below to help explain your answer. [Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

$$= \frac{1}{1} - \frac{1}{5} = 1 - 0.2 = 0.8 \qquad \Big| \qquad 1 - 0.4 = 0.6$$

Figure 6.1: John's response of Item 7-2 from the Optics test about the changing image in a convex mirror when moving away

From John's oral explanation, he applied the convex mirror to a real life situation (a convex mirror in a car). Using Pierce's Model, he presented a different referent (convex mirror in a car) and different representation (oral explanation) from the one the questionnaire uses. Nevertheless, the concept represented was the same, thus showing he had a deeper understanding of this concept.

6.2.2 Difficulty within a Specific Representation

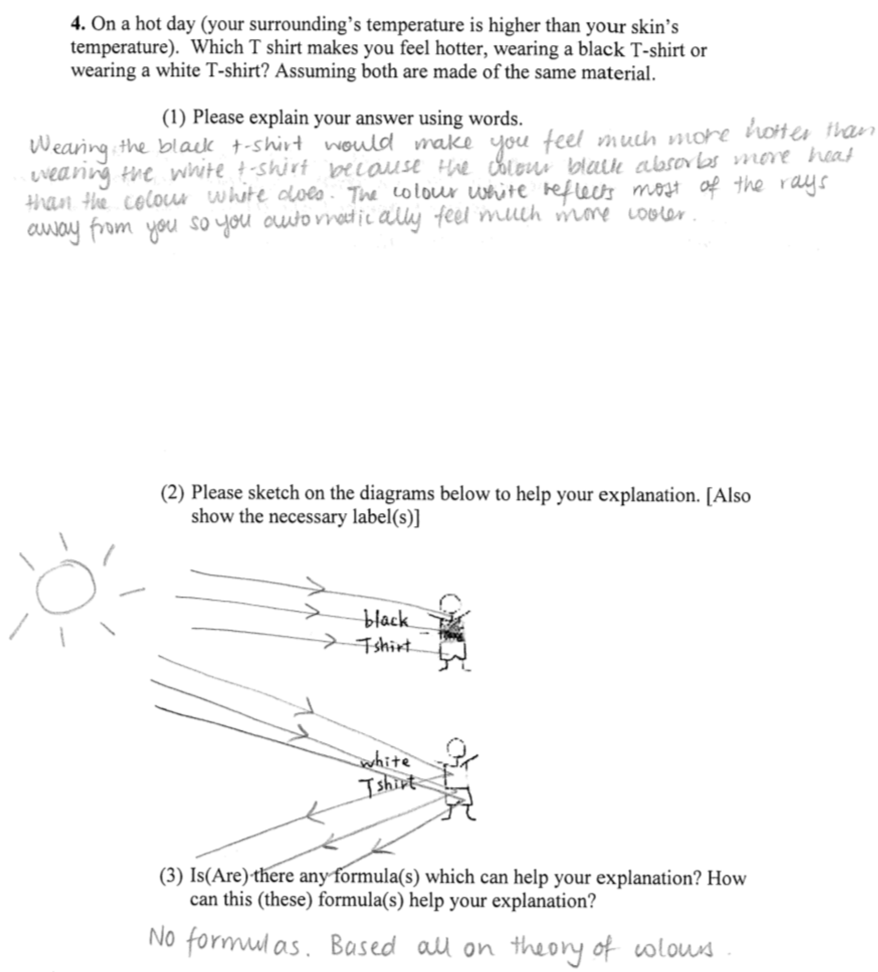
According to Pierce's Model, a concept can be explained by a representation with a referent. The concept, the representation itself and the referent are the three main components within any representation provided by students. From the questionnaire and the interview data, it was observed that if a student had any trouble to answer a question using a specific representation, he(she) must have a problem with understanding one or more than one of the above three components.

In the section that follows, we show from the interviews and the questionnaire items those problems that students experience based on each main component. In the representation itself, Student Alice had difficulty using one representation and thought heat was hard to represent in a diagram.

- Representation Itself - Existing Diagram

When interviewing student Alice on Figure 6.2 showing question 4, part 2, item 4 on the thermal questionnaire about the question about the black and the white t-shirt, the following comments were made:

> I: Yep so do you have any difficulty when you tried to use each representation?
> …(omission)
> Alice: I found that quite hard to draw as well because how do you draw heat being absorbed? Yeah. Reflection is not that hard because you can always you know rebound the ray off but how do you draw heat being absorbed by the black t-shirt? So I just draw lines pointing inwards and say that is absorbed but you can't really see that. It may just be like all the rays are shining on to the black t-shirt. Not necessarily being absorbed.
> (Alice 23.10.09)



4. On a hot day (your surrounding's temperature is higher than your skin's temperature). Which T shirt makes you feel hotter, wearing a black T-shirt or wearing a white T-shirt? Assuming both are made of the same material.

(1) Please explain your answer using words.

Wearing the black t-shirt would make you feel much more hotter than wearing the white t-shirt because the colour black absorbs more heat than the colour white does. The colour white reflects most of the rays away from you so you automatically feel much more cooler.

(2) Please sketch on the diagrams below to help your explanation. [Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

No formulas. Based all on theory of colours.

Figure 6.2: Alice's response of Question 4 part 2 on the thermal questionnaire about the question about the black and the white t-shirt.

A similar response was given by Students Ken and Lisa in responding to question 5 from the optics questionnaire about Polaroid sunglasses shown in Figure 6.3.

> I: So, did you encounter any difficulty when you tried to use each representation?
>
> Ken: …(omission) I knew which equations we would use and even the basic understanding of how to explain it in words but just couldn't, because of my lack of understanding, I guess, as to what we would actually see in the real world. I couldn't actually answer that with a picture.
> (Ken 15.10.09)

In the above response Ken shows that he has difficulty with one representation mainly because he thought he had to draw what he actually saw in the real world.

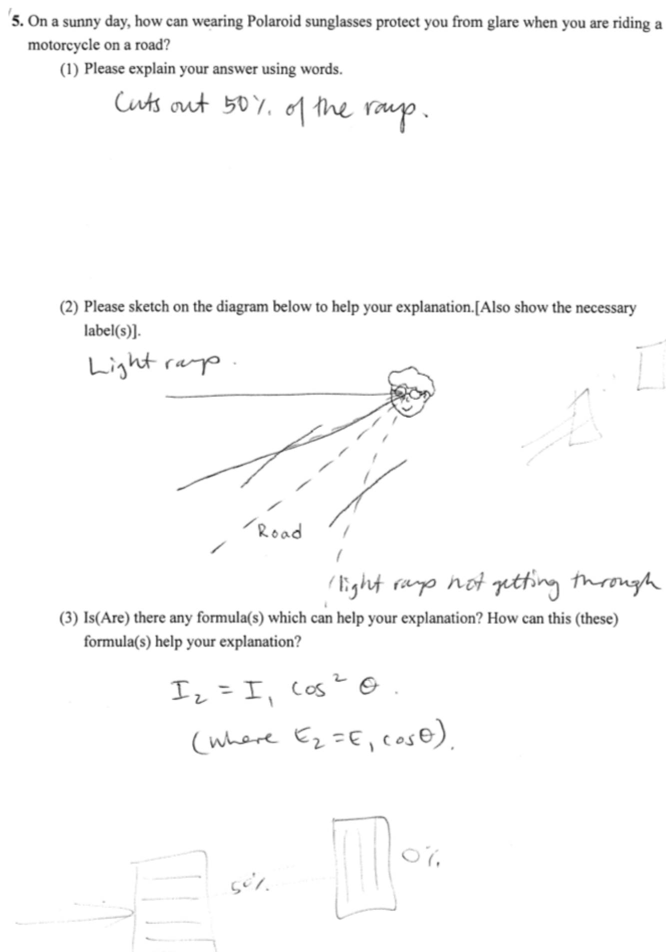


Figure 6.3: Lisa's response of Question 5 from the thermal questionnaire about Polaroid sunglasses

A similar response was echoed by Student Lisa on item 5 of the Optics Questionnaire shown in Figure 6.3.

> I: So did those different representations make you more confused about any concepts?
>
> Lisa: This one did yeah. How to do it (diagram), yeah that just didn't make sense. This one (a piece of paper with slits on it) makes sense because that's what I've been taught, but not little man on the bike.
>
> (Lisa 27.10.09)

Although the existing diagrams in the multiple representational questionnaire did encourage students to present their conceptual understanding using diagrams, they also created some problems. First, students may not understand how the existing diagrams help explain their understanding. Take Alice for example, she thought heat could not be presented in the diagram, so the existing diagram in that question for her was meaningless. Secondly, students may have their own diagrams to explain their ideas. The concept in Lisa's brain is suitable to be explained by her own diagram, which shows that her concept had not been developed to the level which can use the existing diagram in the questionnaire. To solve the problem, in the future we may need to remind students that they can draw their own diagrams beside the existing diagram if they really cannot use the existing diagrams.

- Representation Itself - Operators

Examining students' responses using Pierce's Model, Student John had difficulty understanding the formula needed to answer the question in the Optics Item 7.2 shown in Figure 6.1, John was unclear about the operator 'f' – John should have put -1,not 1 and 'di' should have got a negative value. The interview excerpt in relation to his written response was as follows.

> I: So can you relate this formula to the diagram?
> John: Okay let's see, so that's to do with, we know is the focal length is, we know what the distance of the object yeah so we can work out what the distance of the image would be. So it would be, like it would be minus the object... and when you calculate that and you take the reciprocal then that would give us the distance, so as this number (do) increases, this number (di) is going to decrease. No, that (di) would increase as well, like I can prove it when I get my calculator.
> (John 3.11.09)

John showed that he was not familiar with the positive and negative sign of the variables in the formulas, which was one of the examples with which students had difficulty using the operators of formulas. There is another example, namely, students liked to infer by putting numbers in the variables of formulas rather than infer just by the symbols of the variables. Of course we cannot say putting numbers in was a wrong thing but inferring by symbols represents that students have a high level skill in operating the formulas. From the above John's example (Figure 6.1) and below Amy's interview excerpt in relation to question 7.1 in optics questionnaire (Figure 6.4), they both describe how naturally students put numbers into the formulas to make their inference.

I: 7-1. And did this formula help you?
Amy: Yes.
I: Yeah …to your understanding.
Amy: Yeah. You can put there all the, actually you can put all the numbers in the, this questions, in these formulas and then use this formula to answer, to prove your diagrams. Maybe your diagram's wrong but you can put all the numbers in the formula so use the formula.
(Amy 19.10.09)

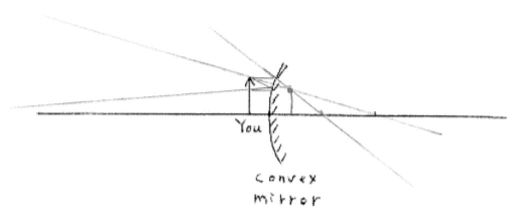
7. Assume you are 2.0 m tall person standing at a distance of 1.0 m in front of a large convex mirror.

7-1. Will your image be smaller, larger or the same size?

(1) Please describe your answer using words.

small

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

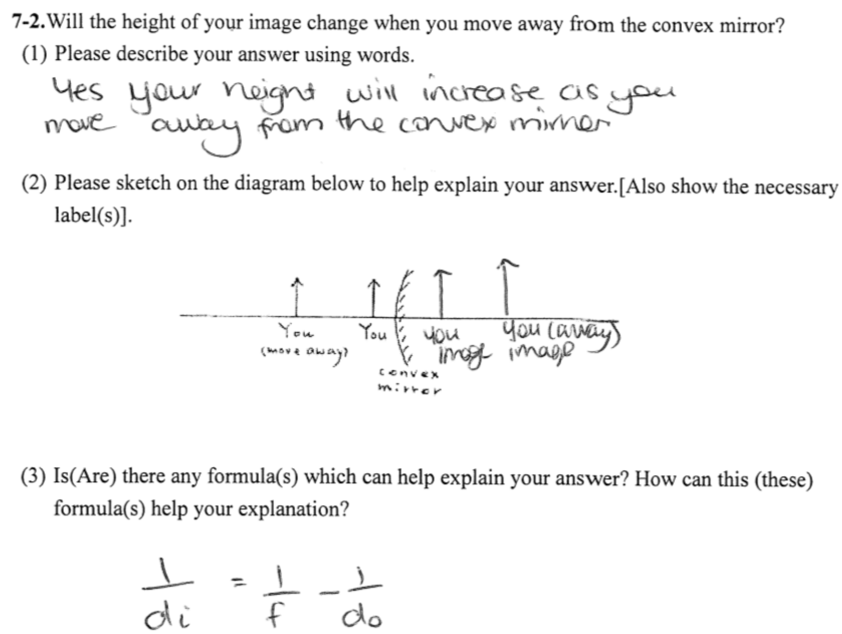
$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$, $m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$

Figure 6.4: Response of Student Amy to item 7.2 Optics

- The Referent – Mislead by Life Experiences

As is illustrated by the interview excerpt and the response to item 7.2 shown in Figure 6.5, Student May had difficulty believing that the convex mirror widens the view but believed that the image would become smaller and thinner than the object. Using Pierce's Model to explain how May gave an explanation, he showed a failure of using the referent.

> I: So did those different representations make you more confused about any concept?
>
> May: …(omission) Or whether it stayed the same 'cause I know like with a convex mirrors, they're used in like shopping centres and stuff and they widen the view.
> (May 28.10.09)



7-2. Will the height of your image change when you move away from the convex mirror?

(1) Please describe your answer using words.

Yes your height will increase as you move away from the convex mirror

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

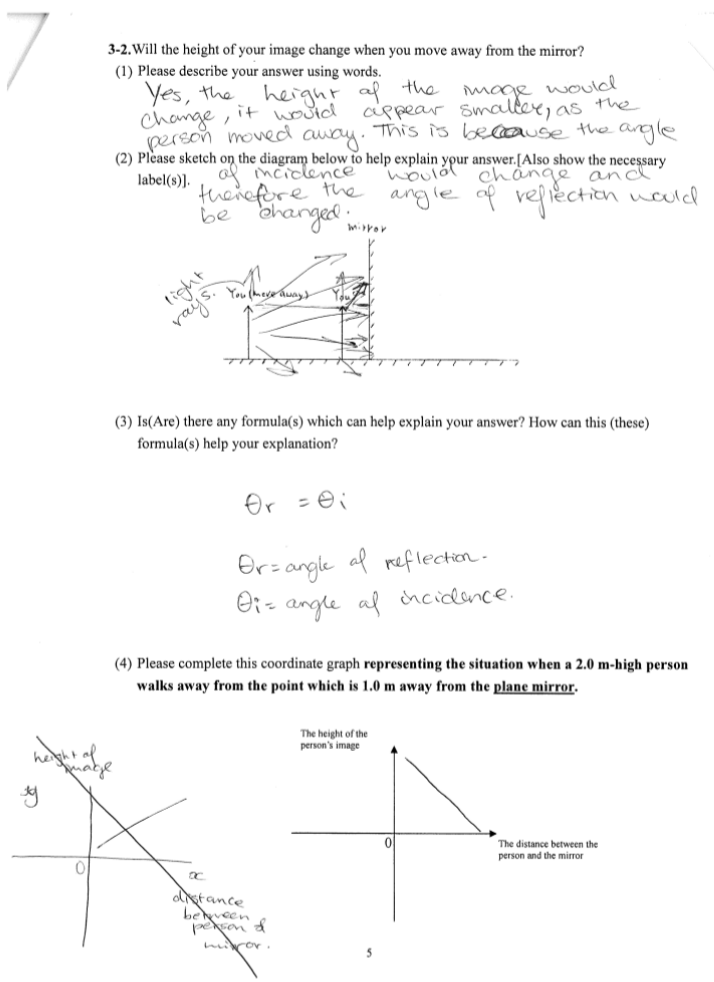
$$\frac{1}{di} = \frac{1}{f} - \frac{1}{do}$$

Figure 6.5: Student May's response to item 7.2 Optics

When May tried to apply her life experience (referent) to the question, she did not notice that her experience misled her inference in this question. Truly the convex mirror in shopping centres can widen the view but it does not mean the objects observed in the convex mirror can become wider. As a consequence, she could not develop a completely correct concept about the image formation of the convex mirror.

Ella's responses to question 3.2 of the optics questionnaire (Figure 6.6) provide another example that shows how life experience can mislead students' learning:

> I: Later. Okay. So question 3.2…can you explain your answers? You can have some time to have a look.
>
> Ella: Yeah I felt it was actually quite hard because I knew from my own experience and obviously when you move back… your image changed, it seemed smaller but I couldn't explaining it I found it really hard and I was trying to understand it and so I went on the basis of actual knowledge from standing in front of a mirror. Yeah I found this actually quite hard to just put into words or even into a diagram as well. So I don't know. (Ella 4.11.09)



3-2. Will the height of your image change when you move away from the mirror?

(1) Please describe your answer using words.

Yes, the height of the image would change, it would appear smaller, as the person moved away. This is because the angle of incidence would change and therefore the angle of reflection would be changed.

(2) Please sketch on the diagram below to help explain your answer. [Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

$\theta_r = \theta_i$

θ_r = angle of reflection.

θ_i = angle of incidence.

(4) Please complete this coordinate graph **representing the situation when a 2.0 m-high person walks away from the point which is 1.0 m away from the <u>plane mirror</u>.**

Figure 6.6: Response of Student Ella to item 3.2 Optics

In this question, it was found that Ella had such experience of moving away in front of a plane mirror and that what she observed about her image was right. The image "looked" smaller and smaller but actually the height of image did not change. Ella observed the image from her eyes and this is the reason why she was confused when trying to draw the diagram. The image shown in the diagram is "visually" different from that which she saw in front of a plane mirror. In this case, her life experience misled her conceptual understanding and this should be recognised by the instructors that sometimes our sensory organs are not reliable for us to learn or discover science.

- The Referent – Complexity of Real Life Context

There are many questions using real life situation in the questionnaire. However, it may confuse students' thinking and interfere in theirconceptual formation when using such a situation as a referent in Pierce's Model. Alice expressed this consideration in her interview excerpt:

> I: Were those questions clear for you?
> Alice: Oh okay so yep so I understood what it was asking me? Yeah they were fairly clear except for I found that the graphs were slightly unclear. Yeah I'll show you perhaps.
> I: Thermal One…
> Alice: Say for example this one, I wouldn't have necessary representatives say in linear diagram. I might have represented it more in a parabola or a curve as such. Not exactly a linear graph that I'd be inclined to show but yeah because usually it's only a very perfect situation where you get very linear graphs. Sometimes you may get that curve. But yeah, cause that was the example. I thought maybe I should make a linear as well.
> (Alice 23.10.09)

In this study, the intention was to present questions with real life contexts in order to increase students' motivation to learn Physics. However, the complicacy of real life context sometimes can be an interfering factor in the process of students' learning. Therefore to solve this problem, first, we have to select the question context carefully and avoid too complicated context. Second, some assumptions about the context have to be stated along with the question in order to simplify or clarify the question.

- The Concept – Insufficient Conceptual Understanding

In Pierce's Model, not only the two elements, representation and referent, can influence the conceptual formation, but the third element, concept, also can. Here we have to emphasize the concept to be learned by students is a more complicated concept, which needs to be constructed by other more fundamental concepts. This can be illustrated by the following Lisa's responses to question 5 of the optics questionnaire about light polarization (Refer to Figure 6.3):

> I: So did those different representations make you more confused about any concepts?
> Lisa: This one did yeah. How to do it (diagram), yeah that just didn't make sense! This one (a piece of paper with slits on it) makes sense because that's what I've been taught, but not little man on the bike.
> I: So the concept is already in your brain?
> Lisa: Right. This concept.
> I: But you just don't know how to apply the concept in this diagram?
> Lisa: Correct yeah. I agree. Yep, no idea. I don't know how to put the light rays going 50% into his eyes you know. I don't know.
> (Lisa 27.10.09)

In Lisa's understanding, she believed that the sun glasses cut 50 percent of light rays from everywhere to the young boy's eyes, which was the reason why the Polaroid sunglasses can prevent from the glare. However, this is the latter part of the whole story. She did not know that when the sunlight is reflected by the road, the reflected light rays are horizontally polarized. Without this concept, she could not develop a higher level conception which can completely explain why the sunglasses can prevent glare.

In conclusion, once students have a problem with any one of the three main elements in Pierce's Model, they will confront difficulties in their conceptual learning. On the other hand, if students can apply different referents or representations to the same concept, this means they have deeper understanding of this concept.

6.3 Response to Research Question 4: How well did students perform in their multiple representations with and without guidance on the optics and thermal physics questionnaires?

To respond to this research question, students' positive and negative performance when they explained their concepts using multiple representations in the questionnaires are shown as follows with the conditions of guidance being present or not. Again it should be emphasised that the "guide" means "someone reminded students the mistakes they made in the questionnaire or in their oral explanation, or reminded students to relate different representations". Based on Ainsworth's framework of functions of multiple representations, we demonstrate which functions students used when they are explaining concepts. The reasons behind the positive and negative performances are also inferred and consequently become important factors while learning with different representations.

6.3.1 Positive Performance in Multiple Representations (without and with Guidance)

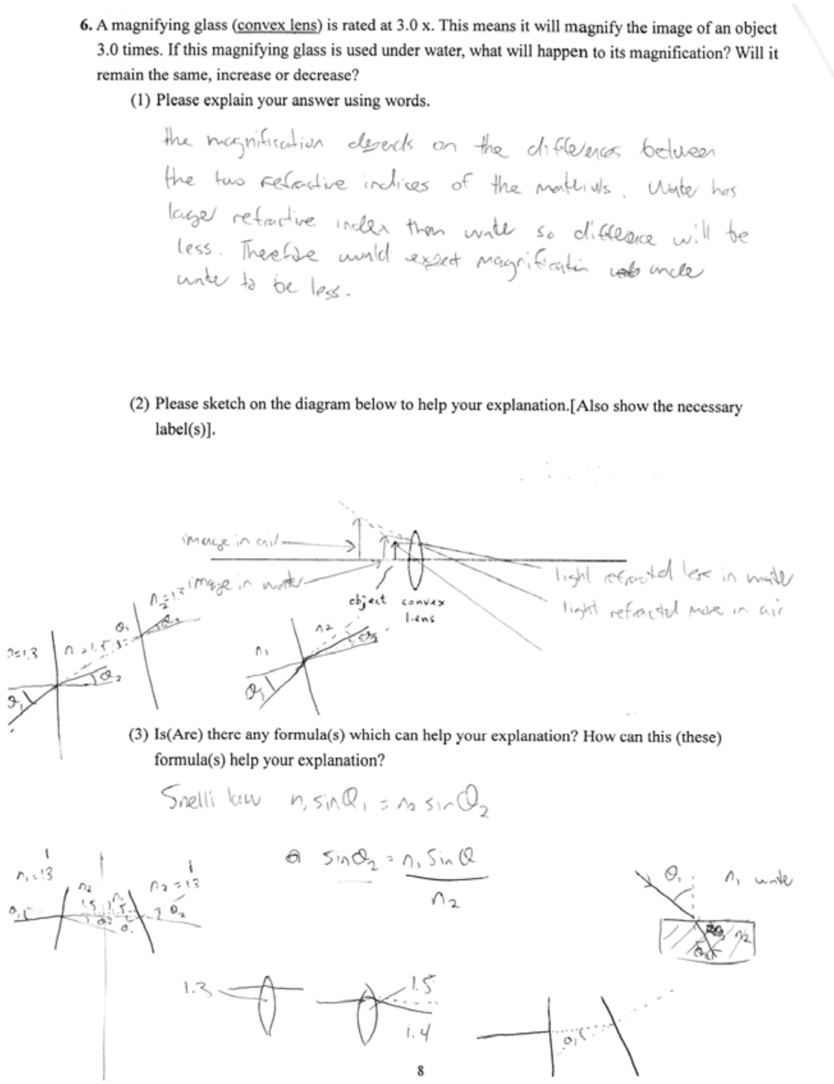
After discussing one specific representation, in this and the next section we discuss more complicated conditions, the conditions with multiple representations. In this section, students' positive performance by using multiple representations in the questionnaires is presented and discussed in the situation without and with guidance.

- Without Guidance

John's interview excerpt responding to question 6 in the optics questionnaire (Figure 6.7) illustrated that the multiple representations had the function of complementary process according to Ainsworth's framework.

> I: So the same question…did using those different representations help you develop understanding of any concepts?
>
> John: Yeah again with the others I've done, just visually seeing how the way the light rays move, you can work out what, you can work out roughly what the answer should be, again using the

formula you can, you know that the answer you get is roughly what you're expecting.(John 3.11.09)


6. A magnifying glass (convex lens) is rated at 3.0 x. This means it will magnify the image of an object 3.0 times. If this magnifying glass is used under water, what will happen to its magnification? Will it remain the same, increase or decrease?

(1) Please explain your answer using words.

the magnification depends on the difference between the two refractive indices of the materials. Water has larger refractive index than water so difference will be less. Therefore would expect magnification under water to be less.

(2) Please sketch on the diagram below to help your explanation.[Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_2 = \frac{n_1 \sin\theta}{n_2}$

8

Figure 6.7: Response of Student John to item 6 Optics

John thought the ray diagram could help him find the answer first and the formula part could help him confirm the answer obtained via the diagram. Therefore the formula representation played the role of a complementary process in this question.

The following Alice's excerpt in response to question 8 of thermal questionnaire (Figure 6.8) showed that the multiple representations could again have the function of complementary process during the time of solving the question.

I: So now I will ask you specific question. Thermal , number 8. How about this question, did those representations help you develop understanding of any concept?

Alice: …(omission) But definitely the diagram did help 'cause it showed me because if they were both exactly the same state, you could use Q=MC△T. But because they are two different states you have to use Q=MLF. Because they are two different states. So diagram does actually help to remind you that you have to use the two different equations in order to work out which one's the answer.
(Alice 23.10.09)

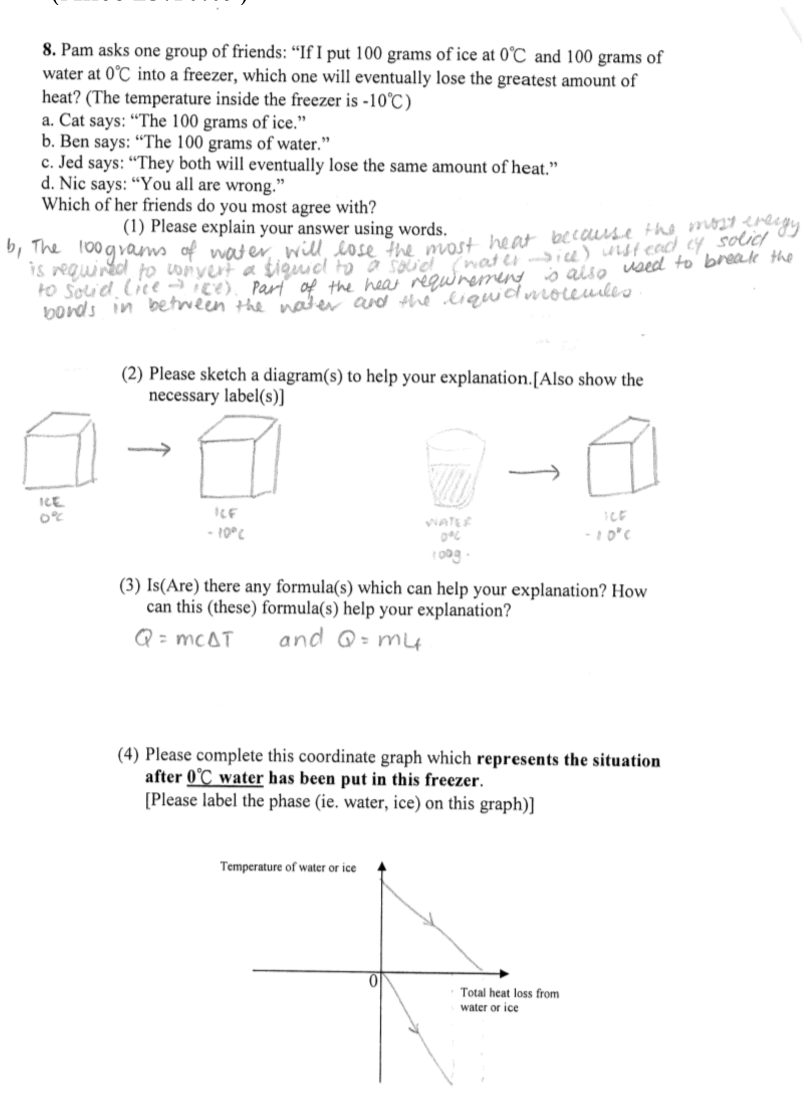

8. Pam asks one group of friends: "If I put 100 grams of ice at 0℃ and 100 grams of water at 0℃ into a freezer, which one will eventually lose the greatest amount of heat? (The temperature inside the freezer is -10℃)
a. Cat says: "The 100 grams of ice."
b. Ben says: "The 100 grams of water."
c. Jed says: "They both will eventually lose the same amount of heat."
d. Nic says: "You all are wrong."
Which of her friends do you most agree with?
(1) Please explain your answer using words.
b, The 100grams of water will lose the most heat because the most energy is required to convert a liquid to a solid (water → ice) instead of solid to solid (ice → ice). Part of the heat requirement is also used to break the bonds in between the water and the liquid molecules.
(2) Please sketch a diagram(s) to help your explanation.[Also show the necessary label(s)]
ICE 0°C → ICE -10°C
WATER 0°C 100g → ICE -10°C
(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?
Q = mcΔT and Q = mL
(4) Please complete this coordinate graph which **represents the situation after 0℃ water has been put in this freezer.**
[Please label the phase (ie. water, ice) on this graph)]
Temperature of water or ice
0
Total heat loss from water or ice

Figure 6.8: Response of Student Alice to item 8 Thermal

Alice mentioned that the diagram part reminded her that she had to use the two different equations, meaning the diagram part was a complementary process to help her succeed in another process (formula part). However, she did not relate her diagrams and equations clearly, namely explain which equation(s) belong to which diagram, although she seemed to have this knowledge.

Below is another example displaying the function of complementary process from Ken's interview:

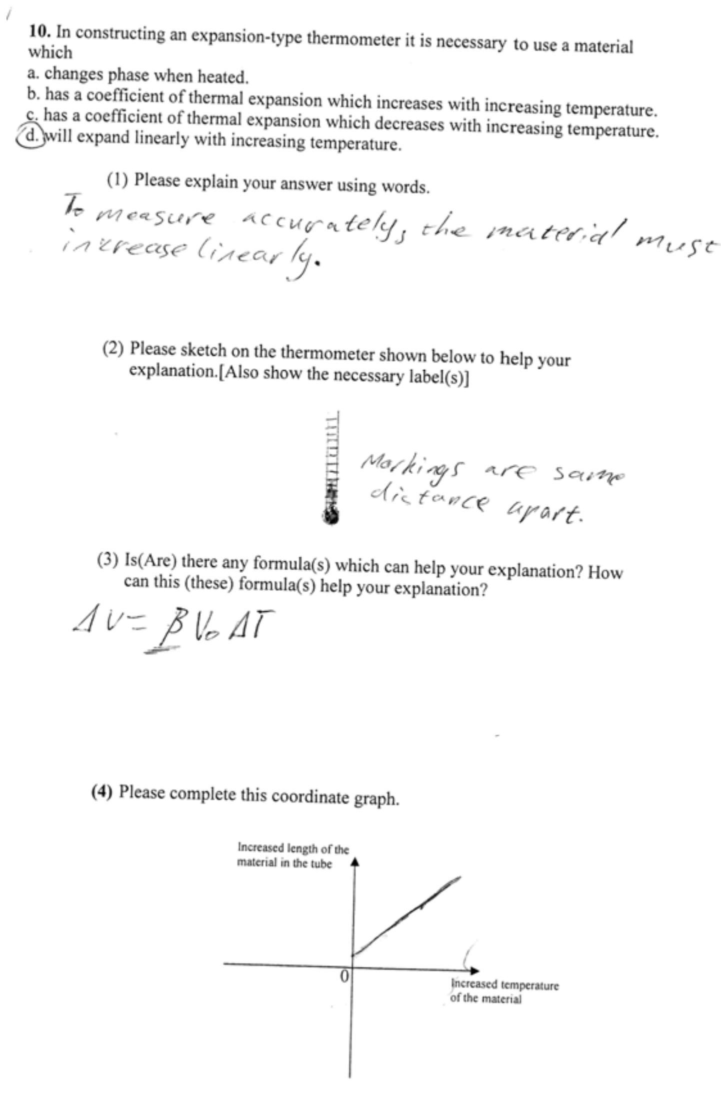
> I: Okay. How have you found these kinds of questions? Were they helpful to you, or it's not helpful?
>
> Ken: …(omission) So, I guess, the other thing was the fact that we were asked to explain in a number of different methodologies. What was helpful about that was that it forced me to think about how to explain it because sometimes you can get into the habit of, when you're asked a question, you're first thought might be, "Well, how would I calculate that?" So it might be, "Where are the numbers? How do I plug this into a formula?" And so on. Whereas here, we're asked to explain it in words as you would to someone that perhaps doesn't understand the physics concept; then the diagram, which sometimes as they say a picture can be worth a thousand words; and then asked for the formula.
> (Ken 15.10.09)

Ken commented that the different representations could help him explain the tested concepts. The complementary process and information from written words and diagrams could help him think about more besides the formula representation.

Tom's response to question 10 in the thermal questionnaire (Figure 6.9) demonstrated that the functions of complementary process, complementary information and constraints by the inherent property could be provided by multiple representations.

> I: I put those different representations together and how can they help you develop understanding?
>
> Tom: Basically well... one links to this... because (the diagram) these are equal distance in marking and this is emphasising the accuracy you know of increasing lineally, and this sort of signifies that it does increase linearly. So that was that and I suppose this part here(the formula), what is it... the thermal expansion coefficient for volume, as long as that's constant, then that helps it to stay accurate as well, and this (the thermal expansion coefficient) also makes sure it climbs in a steady straight line in the graph.
> (Tom 3.11.09)

From Tom's interview excerpt, his diagram, formula and graph provided him with different processes to explain how the material in the thermometer tube expands linearly with increasing temperature, and the diagram provided him with additional (complementary) information that the distance between markings is equal, which also constrained the meaning of linear relationship. Furthermore, Tom did not relate his diagram, formula and coordinate graph clearly.



10. In constructing an expansion-type thermometer it is necessary to use a material which

a. changes phase when heated.
b. has a coefficient of thermal expansion which increases with increasing temperature.
c. has a coefficient of thermal expansion which decreases with increasing temperature.
d. will expand linearly with increasing temperature.

(1) Please explain your answer using words.

To measure accurately, the material must increase linearly.

(2) Please sketch on the thermometer shown below to help your explanation.[Also show the necessary label(s)]

Markings are same distance apart.

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

$\Delta V = \beta V_0 \Delta T$

(4) Please complete this coordinate graph.

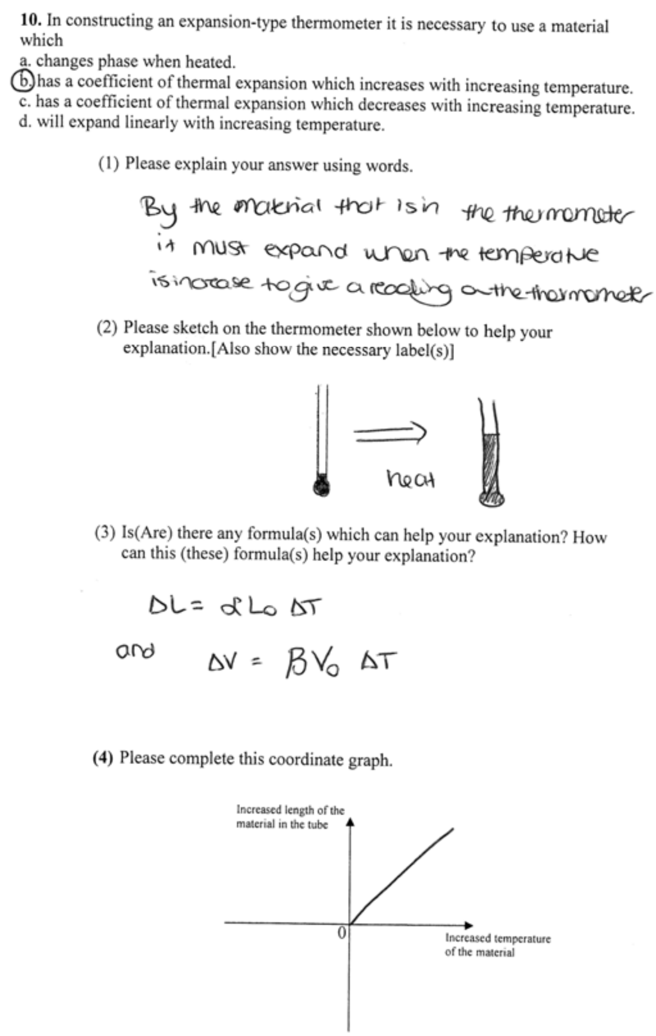
Figure 6.9: Response of Student Tom to item 10 Thermal

From above interviewees' performance, it is concluded that the functions of using multiple representations for students' learning are usually complementary process and information based on Ainsworth's categories, when students receive no guide from other people. The finding shows that students could rarely obtain deeper understanding when they used the multiple representational questionnaire just by themselves. Instead, if someone can guide them, there may be some differences in the process of their learning. This issue is to be introduced in the next section.

- With Guidance

In this section we discuss interviewees' positive performance during my guidance in their interview. First, conceptual change may happen according to May's interview excerpt in response to question 10 in thermal questionnaire (Figure 6.10):

> I: So what you wrote here, you said you choose B as the coefficient of thermal expansion which increases with increasing temperature, so can you explain what you choose with these formulas?
>
> May: So thermal expansion… maybe it's that one. I don't know now.
>
> I: So did those different representations make you more confused about any concept?
>
> May: Now when I've put it like that, I think maybe it's this one, maybe it's D, instead of B, but the general overview is that you know that as the temperature increases, the material will lineally increase as well. The length will increase, so it sort of made you understand a little bit more. 'Cause you elaborated on what you did.
>
> (May 28.10.09)



10. In constructing an expansion-type thermometer it is necessary to use a material which
a. changes phase when heated.
(b) has a coefficient of thermal expansion which increases with increasing temperature.
c. has a coefficient of thermal expansion which decreases with increasing temperature.
d. will expand linearly with increasing temperature.

(1) Please explain your answer using words.

By the material that is in the thermometer it must expand when the temperature is increase to give a reading on the thermometer

(2) Please sketch on the thermometer shown below to help your explanation.[Also show the necessary label(s)]

heat

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

$\Delta L = \alpha L_0 \Delta T$

and $\Delta V = \beta V_0 \Delta T$

(4) Please complete this coordinate graph.

Figure 6.10: Response of Student May to item 10 Thermal

In the beginning, May thought the coefficient of thermal expansion of the material in the tube should increase with increasing temperature, but after being asked to use her formulas to explain the thought, she was experiencing cognitive conflict and changed her original choice to the right one. However, from her uncertain terms (e.g. "I don't know now, maybe"), it can be inferred that her new choice or say new concept was still not solid in her cognition.

Besides conceptual change, students may recognise the importance of functions which multiple representations can provide. The next example describes how Alice recognised the importance that the diagram representation could help her constrain other representations (e.g. written words, formulas) by their inherent properties (Refer Figure 6.8):

> I: So can you relate those different representations?
> Alice: Relate them?
> I: Yeah relate.
> … (omission)
> I: Okay. So overall did you think those representations help you with your thinking in this question?
> Alice: The diagram perhaps. Cause the diagram well perhaps because all these words, the diagram actually gives you a better picture of what they're trying to ask you to do. So by the end of the day you're just trying to calculate which one lost the greatest amount of heat so was it the ice going to the ice or the water going to the ice? So therefore I'm drawing out the representation will give you a better idea of what's actually happening. What's the question trying to ask you? And then after the diagram you follow by the formula. In your head you already know which formula you should be using, but drawing the equation out just shows you step by step which one you should use first. Which one you should use next yeah. Cause sometimes they offer you a lot of parts to a question. It may be a block of ice going to steam. In that case you have more parts to the formula and drawing the representation, like drawing the diagram out would show you which step followed by which step and then that will lead to which formula followed by which formula.
> (Alice 23.10.09)

In Alice's interview excerpt, she recognised that the diagram could help her in the process of solving the question by making the stages of each phase change clear. She also could apply this advantage to another situation, a block of ice going to steam, besides the situation in this question. Although she recognised the function that the diagram representation could provide, she did not gain a deeper understanding (e.g. ability to relate or translate different representations well).

In spite of the above students' good performance during my guidance, for students to change their conception or to gain a deep-level understanding during such a short time was difficult. Nevertheless, if an expert can help students during their learning, for example, to help studentssee cognitive conflicts, it can be a start to change students' misconception or improve their understanding.

6.3.2 Why Multiple Representations were not Helpful (without and with Guidance)

In this section, those situations which caused multiple representations to lose their functions for students' learning are presented and discussed according to the conditions without and with guidance.

- Without Guidance

Attitude Problem

Firstly students' poor attitude was seen to prohibit their learning. The following excerpt is an example from John:

> I: So did you learn how to use the graph to solve those questions from other representations?
> John: No, I didn't use the graph at all. The only time I used the graph was for this one here and I just guessed, I wasn't sure if that's correct or not.
> (John 3.11.09)

John was not using the coordinate graph before answering the questionnaire. However, he still did not take the chance to be familiar with it because he appeared not have any motivation to learn. He just guessed the answer in the graph part and did not verify it by checking books or asking other people. Therefore, constructing the graph representation did not benefit his understanding.

In the next excerpt, Amy's response to question 1 in the optics questionnaire (Figure 6.11) is another example where students' attitude limitedtheir learning.

> I: Yep number 1. How about this one?
> Amy: Yeah this one is about common sense. Yeah.
> I: So this one you used two representations… why don't you use formula ?
> Amy: Oh yeah where's my formula? Forgot.
> I: Oh you forgot?
> Amy: Yeah. What formula I forgot. But I think on this one (this question), I'm not sure because this one (this question) in the

daily life you will know this one (this question) every day.
You go to the swimming pool or go to a beach yeah.

I: So you think it didn't help you to develop a deeper understanding of any concept?

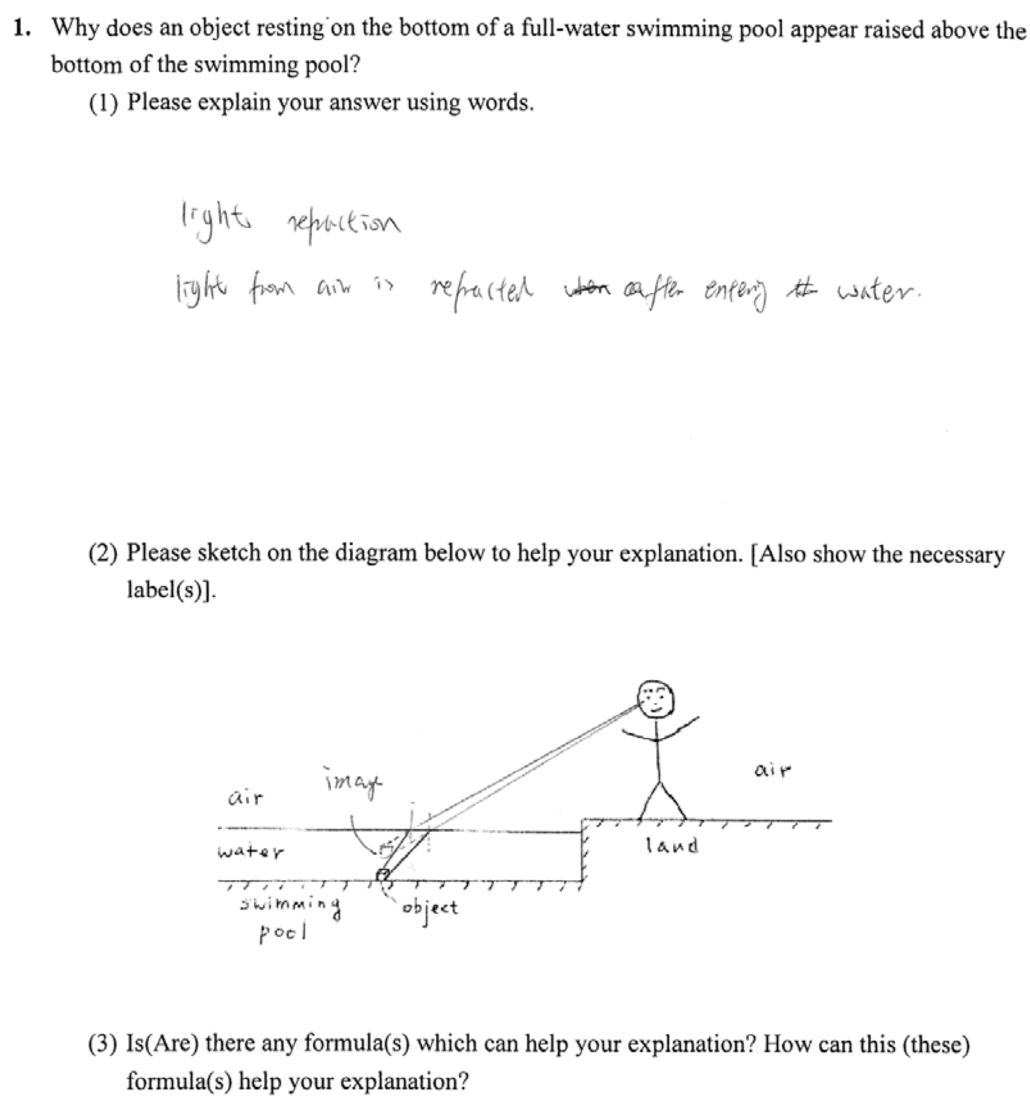
Amy: No.

I: How about confused?

Amy: No.

I: Okay.

Amy: Might be it is a little bit of common sense yeah.
(Amy 19.10.09)



1. Why does an object resting on the bottom of a full-water swimming pool appear raised above the bottom of the swimming pool?

(1) Please explain your answer using words.

lights refraction

light from air is refracted ~~when~~ after entering the water.

(2) Please sketch on the diagram below to help your explanation. [Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

Figure 6.11: Response of Student Amy to item 1Optics

Amy (her average mark of Physics Motivation Survey was 2.73 in 1~5 Likert's scale) considered this question as common sense, but if we assess her answers in the written words and diagram parts, we can find her answers were mostly wrong, especially in the progress of light rays. With the evidence that she forgot to answer the formula part, she appeared not intent to learn something from this question. As a consequence, all types of representations in this question were not helpful for improving her understanding.

In addition to the attitude problem, focusing only on one specific representation to solve the question made the remaining representations redundant, and decreased the advantages of learning from the multiple representations.

Focus Only on One Representation to Solve Questions

John focused on the diagram representation to solve question 7.2 in Figure 6.1 in the optics questionnaire with little attention to other representations:

> I: So did using those different representations help you develop understanding of any concept?
>
> John: Just the way that the light, the light rays, how, the way they travel when they hit the surface off the curved surface yeah, they're like if you know that perhaps you see there's an angle, if you take the line from the focal point it will reflect off like that.
> And then if we take it from the centre of curvature of the object, then that line is going to be perpendicular at that point so therefore the image, the light would appear to be unchanged, that's how I see it. I don't know whether that's correct or not but that's how I understand it.
> (John3.11.09)

John emphasised that the diagram was the way that he understood the tested concept. From the diagram, indeed John made good use of it, but this was also a limitation for his learning if he just could learn from only one representation. For instance, if he made some mistake in his diagram, there was no other representation which could help him find out the mistake (if both representations carry same or similar information). Many functions provided by the multiple representations would not be useful if he ignored the importance of other mode representations.

None or Very Little Understanding Gained in Each Representation

Besides just focusing on one representation to solve questions, if the learner gained no or very little understanding in each representation during their learning, multiple representations would not work their functions. This situation can be further described by the following two categories:

<u>Just Put What He(She) Knew in without Further Learning</u>

Students may present their understanding using different representations, but no further understanding had been developed. Students just answered with what knowledge they already knew, but did not learn anything from the process of answering the question. Lisa's response to question 5 in the optics questionnaire in Figure 6.3 demonstrates this view:

> I: Yeah… (those different representations) help you develop understanding of any concept?
>
> Lisa: No. In fact I think when you put the sunnies on this guy, it doesn't make sense. All I know about sunnies is that true polaroid sunglasses apparently when you turn them, they say… 'cause I've never seen one, you know you get sunshine, then you get dark patches and you get sunshine, then you get dark patches. So what I liken it to is a piece of paper that's got slits in it, like this, so say we cut out slits like that, but that's like going, sunlight through, sunlight no, sunlight through, sunlight no and that's how I understand it to be. So I guess when this guy is riding along on his little motor bike or something, he's only getting filtered light, that's all I understand of it and the filtered light takes away the glare. Now I don't exactly know what glare is, but on my understanding is, it would be too much light maybe. So therefore and I know from this intensity that if we have light coming this way, then this gonna be the whole light, but if we have those little slits in, then it's going to filter 50% of the light because only half of it can get through because of the waves. So then if 50% goes through there, then and these slits went like that, then none of it's going to get through the other side, and those that are on an angle kind of still are saying, 50% of those get through, and 50% don't. So all I know, the representations this one, yeah I'm still not really sure about how to draw that little man. But this one makes sense and cuts out 50% of the rays, that makes sense to me. (Lisa 27.10.09)

From Lisa's oral explanation and written responses, it can be found that none of her responses successfully solved the question because she did not realise that the light rays would be polarised after being reflected from the road. What she put in her questionnaire was from the textbook or from the lecturer's slides, and she could not apply what she knew to the new situation in this question. No further understanding had been developed in individual representation, and of course, no understanding from the interaction of the multiple representations.

Learner's Prior Knowledge is Insufficient and(or) Wrong

That students could not gain understanding during their learning may be due to their limited and(or) incorrect prior knowledge as illustrated in the interview with May (Also refer to Figure 6.5).

> I: Can those different representations help you develop any understanding?
> May: Probably the formula more than the image in this one because I wasn't sure if that (the diagram) was right. So like if I'm not sure it's right then it sort of confuses me a little bit more because then you think about it more. But the formula helped 'cause it was relating the distance, 'cause that was sort of this one (Question 7.1) as well wasn't it?
> I: Which one?
> May: That was part two of this question. 'Cause that was 7.1, yeah so it was sort of relating the distance of the image to the distance of the object. So you know, you understood that part, but then I wasn't sure about the diagrams as such. (May 28.10.09)

From May's oral and written responses, we can know that she could not infer the answer by using the operator of the diagram and formula representations. Besides that, her conclusion that her image would become higher as she moved away from the convex mirror was probably made by her guessing or her inaccurate memory. No past relating experience could help her make the right conclusion. In this case, limited and incorrect understanding created factual errors in every representation.

Ella's responses to question 3.2 in the optics questionnaire provide another example that limited prior knowledge could not benefit her during her learning with multiple representations (Refer Figure 6.6):

I: Okay. So what are the functions of different representations in your learning? In this question.

Ella: Well…(hesitating)

I: Or they cannot provide you any…. Just say your thinking….

Ella: No I. Yeah I really think that they do. I think that the explanation and the image, well especially the image should explain or give you like an image in your mind so you can understand it and you can see it, if that makes sense. And the formula is like can work along with it to be factual and that is yeah like the formula is x something equals something and it's whatever, and there has like constants to show it as it actually is, and then the image should probably, when you come to thinking about this, you should formulate an image like that in your mind probably. But yeah that's what I think they set as purposes.

(Ella 4.11.09)

From Ella's written responses, except that the formula part had little relation to this question, the rest of the parts hadincorrect answers. When she was asked if those different representations helped her learning, her first reaction wasto be hesitant and then gave a general answer without applying the content of this question. Again she could not use the operator of the diagram and formula representation to infer the answer, and as a result, the multiple representations were not helpful to her.

In short, based on these examples, attitude problems and students' insufficient and(or) incorrect prior knowledge are the two main factors making multiple representations not helpful for students' learning in the condition without guidance. Students' learning attitude also plays an important role, as is evidenced from the previous literature review. From the above excerpt, the importance was shown again and even may have prevented students from making effective use of multiple representations during their learning. In addition, it can be further explored why sometimes students just wrote down what they already know in the questionnaire without making effort to gain more understanding.

- With Guidance

After discussing the problems of students using multiple representations for their learning in the condition without guidance, we discuss the problems happening in the condition with guidance provided during the interviews. First, students' attitudes still can be a problem:

Attitude Problem

Ella revealed her negative attitude towards learning when responding to question 1 in the optics questionnaire (Figure 6.12) in the condition with my guidance:

> I: Okay…so using this diagram can you explain why this object appears above the actual position.
>
> Ella: I can't explain properly from my picture. I don't think like I tried to just leave it to help but I can only explain it properly in words. I don't think there's enough there to show, and probably using Snell's Law of refraction, I tried to put that along with it if it helped, because I guess the angle of the incidence is different to the angle of refraction, and then how our eye picks up the light rays and perceives where an object is.
>
> I: Very good. So do you want to say more about this formula?
>
> Ella: Um, no.
>
> I: Anything you want to explain in this formula?
>
> Ella: I find this really hard, I hate optics.
>
> (Ella 4.11.09)

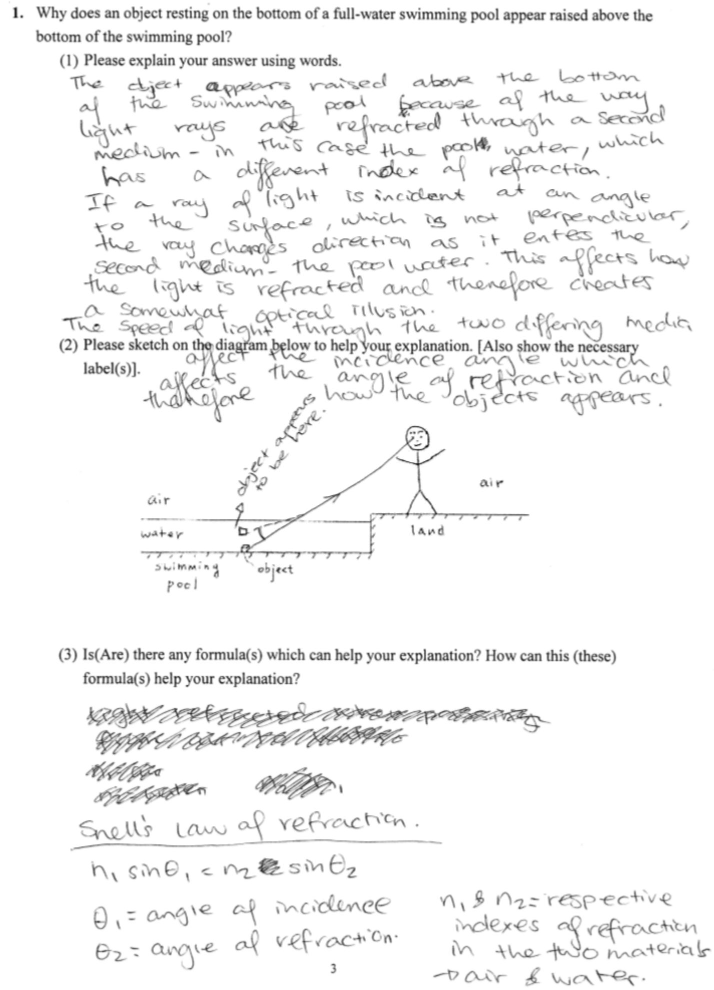


Figure 6.12: Response of Student Ella to item 1 Optics

According to Ella's written response in Figure 6.12 and her oral explanation, it can be noticed that her understanding was at a shallow level, especially in the diagram and formula part. In order to help her relate her formula to her diagram, the interviewer started to encourage her to give more explanation in her formula, but her personal dislike of optics stopped her doing so.

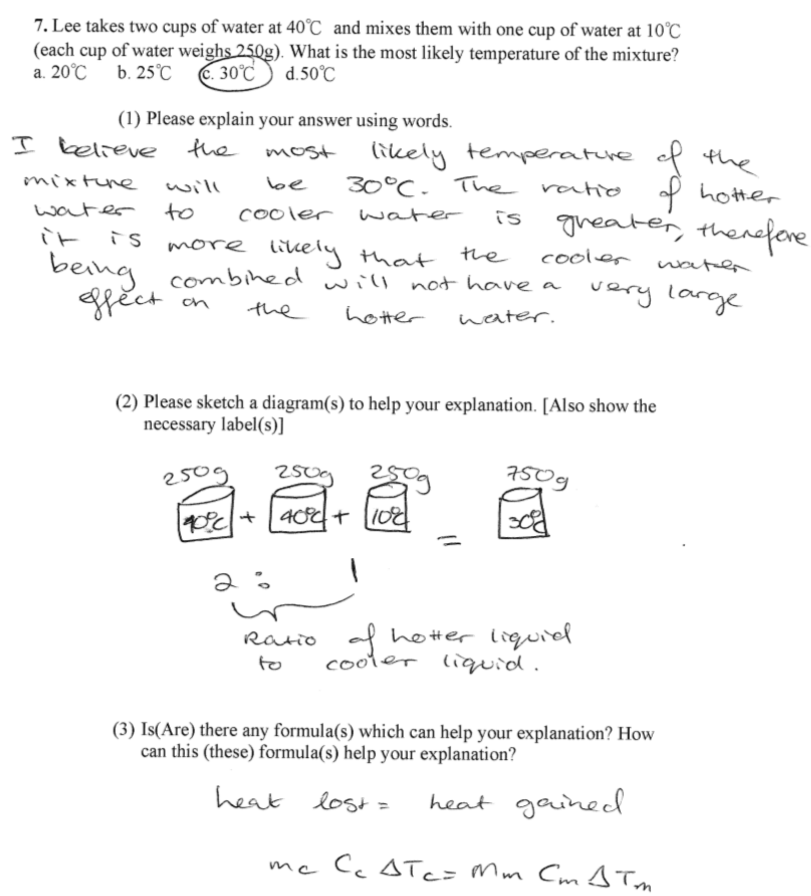
Student's Prior Knowledge is Insufficient and(or) Incorrect

As with the condition without my guidance, multiple representations were not helpful because of students' insufficient and(or) incorrect knowledge when students had my guidance. More correct existing knowledge can help students develop deeper understanding. The following three examples describe how insufficient and(or) incorrect existing understanding prohibited students from learning from the different representations.

The example of Ella responding to question 7 of thermal questionnaire in Figure 6.13 demonstrated that her insufficient knowledge of the individual diagram and the formula made her fail to relate the two representations:

I: Is there any change of the functions of those different representations in your learning? After you tried to relate...

Ella: Oh just now? Yes as you find, as I'm answering the words and diagram still a lot easier than the formula cause that's yeah, I don't think that formula is probably best to use to explain, I don't think it's very clear and it just confused me, but I couldn't find any other one (other formula).
(Ella 4.11.09)


7. Lee takes two cups of water at 40℃ and mixes them with one cup of water at 10℃ (each cup of water weighs 250g). What is the most likely temperature of the mixture?
a. 20℃ b. 25℃ c. 30℃ d.50℃

(1) Please explain your answer using words.

I believe the most likely temperature of the mixture will be 30°C. The ratio of hotter water to cooler water is greater, therefore it is more likely that the cooler water being combined will not have a very large effect on the hotter water.

(2) Please sketch a diagram(s) to help your explanation. [Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

heat lost = heat gained

$m_c C_c \Delta T_c = M_m C_m \Delta T_m$

Figure 6.13: Response of Student Ella to item 7 Thermal

Ella's written response in the diagram and formula part lacked more detailed inference process. She mentioned the ratio of hotter water to cooler water in her diagram but she could have discussed the temperature change by pouring any one cup of water into the second one, and then pouring all the water from the second one cup into the third. Similarly, in her formula response, she could have put all the numbers in and calculated the final answer. If she could be familiar with the inference process of either one of the two representations, that would have helped her become familiar with (function of extension) and relate the other representation. Her unfamiliarity with the two representations stopped her to develop a deeper understanding.

A similar problem happened to Grace when she responded to question 7.2 in the optics questionnaire as shown in Figure 6.14:

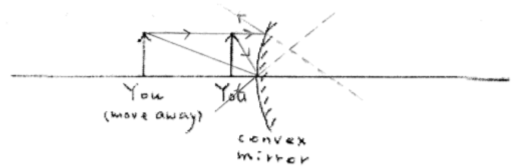
> I: Okay, now we start to record your questions, and you can tell me which question you feel confused, and using those different representations make you more confused.
>
> Grace: Yep. Seven point two. You had to say whether the image changed when you move away from the convex mirror. I know the image size should change, but I didn't know which way it would change, whether it would increase in size or decrease in size. And didn't know how to draw the ray diagrams. So therefore, using a diagram, it was hard to come up with whether it would increase or decrease, and therefore, but then if you used the formula, it said if your distance of the object increases, then your height should decrease. I don't, I mean, no but …
> (omission)
>
> I: Can you relate to those different representations?
>
> Grace: The representations, like if they're supposed to reflect each other, so …(she keeps thinking)
> (omission)
>
> I: Okay. So in this question, did any different representation help you construct any understanding?
>
> Grace: No.
> (Grace 26.10.09)

7-2. Will the height of your image change when you move away from the convex mirror?

(1) Please describe your answer using words.

Yes, the hight of the image changes when you move away from the convex mirror, because the distance of object changes thus the height changes

(2) Please sketch on the diagram below to help explain your answer. [Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

$$m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

Figure 6.14: Response of Student Grace to item 7.2 Optics

Grace's diagram in her written response in Figure 6.14 showed that she did not know how to use the ray diagrams which were presented in the lectures and laboratory classes. In addition, she just presented one of the main formulas and did not apply the question context to the formula. The insufficient knowledge in the two representations made it difficult for her to develop further understanding.

The prior incorrect understanding also became an obstacle for students' learning with multiple representations. Tom's example about his responses to question 5 in thethermal questionnaire shown in Figure 6.15 illustrated this point of view:

> I: Can you show me how to relate to these (representations)?
>
> Tom: This is the heat (the arrows in his diagrams), that's where it's leaving the toast here, which is what Q is and that's also proportional to the amount of temperature leaving. So since there's a greater amount of Q, there'd be a greater amount of temperature leaving it. This is because of its specific heat which you can't really represent on the picture, well I could have maybe shaded it or something. Because that's (the specific heat) high in water, that causes Q leaving to be lower

and because it's low (the specific heat of the toast) here, it causes the Q to be higher.

I: How about this one (his word description), can you relate it (to his formula)?

Tom: Well I guess so. Water has a high specific heat factor there, which comes down to the Q again and then, yeah toast doesn't. Or it's (toast) got a lower specific heat meaning there's more Q leaving it and emitting more energy. (Tom 3.11.09)

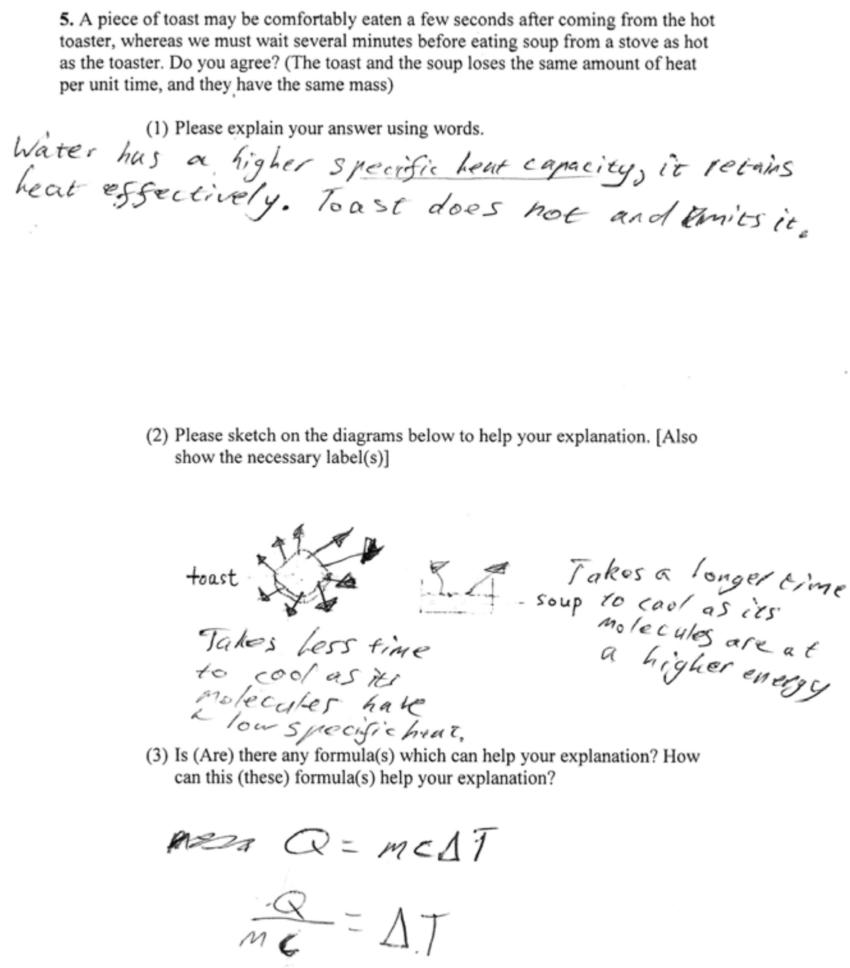


Figure 6.15: Response of Student Tom to item 5 Thermal

Tom's understanding of the question situation (referent) in Figure 6.15 was not correct. He did not notice the assumption that the heat emitted from toast and the soup was the same per unit time. Therefore his inference process in his oral explanation was incorrect. He thought if c was larger, Q would become smaller, without considering the key factor △T. The incorrect understanding in the beginning made it difficult for him to construct a correct understanding.

When Conflict Happens between Representations

Compared with the condition without my guidance, students had more opportunities of confronting cognitive conflict between representations in the condition with my guidance. However, if students could not make use of the opportunities, multiple representations could still not be helpful for their learning. The following examples describe the situation.

Ignore the Conflict

Students may ignore the cognitive conflict as May's example below when she responded to question 10 in the thermal questionnaire (Refer to Figure 6.10):

I: So what you wrote here, you said you choose B as the coefficient of thermal expansion which increases with increasing temperature, so can you explain what you choose with these formulas?
May: So thermal expansion… maybe it's that one. I don't know now.
(omission)
I: But you don't think those different representations make you more confused about any concept?
May: Not really. Maybe if I didn't know what it meant, then it would make me more confused. 'Cause if I left it blank then… that would make me confused…if I didn't do it. But 'cause I did it, I know what it means. So in this question it didn't make me more confused. (omission)
(May 28.10.09)

As shown in Figure 6.10, May originally chose the option B, coefficient of thermal expansion which increases with increasing temperature. After being asked to relate the option to her formulas, she felt confused and had cognitive conflict. As a result, she changed her options but did not give a reason to explain why she gave up her original option. Her cognitive conflict was not completely resolved.

Cannot Solve the Conflict

Students may still not solve their cognitive conflict when provided with guidance. Grace's responses to question 9 of the optics questionnaire presented this situation as discussed below and shown in Figure 6.16:

> I: But it's the same person? From this diagram…. It's the same person? the same eye? the same lens?
> Grace: Yep.
> I: So you think the focal point is different?
> Grace: Not the focal point. It just …(keep thinking)
> (omission)
> I: So, okay, let me ask you, did those different representations help you develop understanding of any concept?
> Grace: Now that you've mentioned, my whole picture kind of details the focal point, does it change, or doesn't it change, then it confused me whether it changed or not. But from the explanation using words, it implies that the focal length changes.
> (Grace 26.10.09)

9. Many old people who do not wear glasses cannot read a book on their hand. However if they put the book further away from their eyes, they can read the book. Why?

(1) Please explain your answer using words.

Similar to farsightedness (hyperopia), is presbyopia, which refers to the lessening ability of the eye to accomodate as one ages, and the near point moves out. Because the near point moves out they must move the book away from them to as a substitution to failed eye accomodation.

(2) Please sketch a diagram(s) to help your explanation. [Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

None.

Figure 6.16: Response of Student Grace to item 9 Optics

Grace was asked that if the focal points in both her eyeball diagrams were different and she was confused. She could not clarify the two situations: one is the situation that the focal point changes as someone ages, the other is the situation that the focal point does not change when the same person focuses and moves a book away. Consequently, cognitive conflict happened to her but could not be solved during my guidance.

6.4 The Difference in Students' Learning in the Condition without and with Guidance

From the above examples, it can be found that in both conditions with and without guidance, students had difficulty to gain a deep level understanding using multiple representations and they had a learning attitude problem and had insufficient and(or) incorrect prior knowledge. However, students had more opportunities to confront cognitive conflict in the condition with my guidance. If the guide beside the student can help the student to identify their mistakes and solve their problems, then the function of those multiple representations has the chance to reach a broader or better level (e.g. construct a deeper understanding).

Unfortunately, my guidance during the interview was not enough to help most students solve their problems due to the limited time of the interview. Most students who confronted cognitive conflict would ignore the conflict or just could not solve the conflict. Nevertheless, the above findings were a start to know what would happen when a student who is using the multiple representational questionnaire receives the guidance.

6.5 The Importance of a Guide Present While a Student is Learning

The function of a guide beside the student who is learning not only increases the opportunities for students to engage in cognitive conflict as described below. First, the guide may help students face and solve their cognitive conflict rather than ignore and(or) keep confused in the conflict. Second, a guide may help to solve the difficulties when students are confronted with individual or multiple representations in their learning. As mentioned above, students' insufficient and(or) incorrect prior knowledge, including representational, referent, and conceptual knowledge, are principal obstacles for students during their learning. The guide beside the student can consider different representations and the student's individual learning factors, according to the discussion of learner's cognitive tasks based on Ainsworth's DeFT framework. Then the guide can plan the goal of instruction and identify which functions the multiple representations should reach. Besides, the guide can adjust the instructional design if necessary until the learner meets the instructional goal. Finally, the guide can help to solve learners' attitude problem. From the above students' interview excerpts, students' learning attitude may have prohibited them using multiple representations in their learning. It was difficult for students to learn when they lacked motivation. The guide can explore the cause of students' inappropriate attitudes and accordingly find a way to improve their learning attitude.

6.6 The Suitability of Pierce's Model and Ainsworth's Framework for Analyzing Students' Representations

From the above process of analysis, Pierce's Model was useful for analyzing students' cognitive situation when they were presenting or learning one representation. The three main elements of this model can be used to find out how students made one representation meaningful or how they failed to construct a conception using any of the representations. Ainsworth's framework about functions of multiple representations was also suitable for the analysis. The functions she proposed appeared during students' learning based on the analysis of students' written and oral responses to the multiple representations questionnaires. However, more empirical research would be needed to verify its practicability.

6.7 Conclusion of this Chapter

To conclude this chapter, the first point is the importance of learning well within a representation. The knowledge of representation, referent and concept are all essential for students' conceptual learning within a representation. The next point is about guidance during the interview. It was found that students demonstrated more cognitive conflicts with my guidance when they explained their representations. Nevertheless, some problems appeared during their explanation with or without my guidance, including improper attitude towards learning, insufficient and(or) incorrect prior knowledge. Improper attitude towards learning may have stopped students' learning with multiple representations.

Most students who confronted cognitive conflict during my guidance either neglected the conflict or could not solve it. Therefore, a guide beside this sort of learner is important for their learning. The guide can help the learner not only improve his or her representational, referent and conceptual knowledge, but also face and solve the cognitive conflict. In addition, the guide can consider using different representations based on the learner's cognitive situation and properties, set up reasonable goal of instruction and adjust the design of instruction if necessary. Last, the guide can notice and try to improve students' attitude to learning.

CHAPTER 7

Results and Discussion in Research Phase Three: Students' Attitudes Towards Learning

7.1 Introduction to this Chapter

In this chapter, students' attitudes towards learning is the main topic for discussion and we respond to two related research questions. First, in response to Research Question 5, we examine the effectiveness of the three attitude-related surveys selected for measuring students' learning attitude by discussing the results of factor analysis, reliability test and correlation test on the surveys. We present the level of students' learning attitudes according to the results of the three selected surveys and discuss the possible threats to students' attitude towards learning. Second, to answer Research Question 6, we report our findings on the relationship between students' learning attitude and their conceptual understanding through the interview data and surveys, and provide some recommendations for future research.

7.2 Response to Research Question 5: How was the students' attitude towards learning Physics?

To measure the subjects' attitude toward learning Physics, the Physics Motivation Survey, Expectation Survey and Experience Survey were distributed. As mentioned in the methodology chapter, the Physics Motivation Survey was revised from Science Motivation Questionnaire (Chandler & Sweller, 1991), which had been tested for its construct validity with 770 non-science majors (S. Glynn, et al., 2009) and five factors were identified through an exploratory factor analysis (see Appendix 7.1). In this research, the Physics Motivation Survey was distributed to non-Physics major students and an exploratory factor analysis was conducted with a 218 student sample. As with the previous research, five factors were identified after factor analysis but the items in each factor changed to some extent (see Table 7.1). Comparing Table 7.1 to Appendix 7.1, it can be seen that items 5, 7, 21, 24 and 29 have been deleted in this research because of factor loading less than 0.4. Items 11, 16 and 19 were formerly in factor Intrinsic Motivation and Personal Relevance (IMPR), but later they were all in the factor Career Motivation (CM). If we check the three items again, it is acceptable to have such result from the meaning of each of the three items, namely, students might interpret that the three items are related to career. In the factor, Self-Efficacy and Assessment Anxiety (SEAA), items 21,24 and 29 dropped out, and item 28 moved to the factor of Grade Motivation (GM). In addition, item 15 moved in SEAA factor from the GM factor. The reason for moving items 15 and 28 may be that the meaning of the two items is quite close and both are related to grades, tests and assessment. Besides the change, SEAA factor was renamed as Assessment Anxiety (AA) in this research because the former items relating to self-efficacy were deleted due to low factor loading, and the items left were all related to assessment.

Besides, item 5 was deleted from factor SD and item 7 was deleted from factor GM. In Glynn et al.'s research, it was mentioned that factor CM had too few items, however the problem had been solved in this research because of having five items rather than two. On the other hand, items 12 and 20 again belonged to factor GM, confirming that the two items were easily interpreted by students as related to grades as in the finding in Glynn et al.'s research. Therefore, more clear wording may be necessary for the two items.

Table 7.1 Five factors sorted out through an exploratory factor analysis in this research

Factor	Items	Factor Loading	Item Description
IMPR	1	0.75	I enjoy learning physics
	2	0.49	The physics I learn relates to my personal goal
	22	0.80	I find learning physics interesting
	23	0.57	The physics I learn is relevant to my life
	25	0.54	The physics I learn has practical value for me
	27	0.55	I like physics that challenges me
	30	0.49	Understanding physics gives me a sense of accomplishment
SEAA →AA	4 (r)	0.80	I am nervous about how I will do on the physics tests
	6 (r)	0.77	I become anxious when it is time to take a physics test
	13 (r)	0.79	I worry about failing the physics test
	14 (r)	0.49	I am concerned that the other students are better in physics
	15 (r)	0.59	I think about how my physics grade will affect my grades this year
	18 (r)	0.55	I hate taking physics tests
SD	8	0.72	I put enough effort into learning physics
	9	0.60	I use strategies that ensure I learn physics well
	26	0.55	I prepare well for the physics tests and labs

CM	10	0.72	I think about how learning physics can help me get a good job
	11	0.72	I think about how the physics I learn will be helpful to me
	16	0.42	The physics I learn is more important to me than the grade I receive
	17	0.74	I think about how learning physics can help my career
	19	0.61	I think about how I will use the physics I learn
GM	3	0.58	I like to do better than the other students on the physics tests
	12	0.67	I expect to do as well as or better than other students in the physics course
	20	0.50	It is my fault, if I do not understand the physics
	28	0.61	I am confident I will do well on the physics tests

- IMPR is intrinsic motivation and personal relevance, SE(AA) is self-efficacy and (assessment anxiety), SD is self-determination, CM is career motivation, and GM is grade motivation
- Item 5, 7,21,24 and 29 had factor loading of <.4
- r: reversed item

As for the reliability analysis in each factor, generally the result in this research is similar with that of Glynn et al.'s research (See Appendix 7.2). Although the Cronbach's alpha for each factor in this research is acceptable (See Table 7.2, alpha ranges from 0.60 to 0.88), Cronbach's alpha for factor GM (grade motivation) can be improved further. The result again implied that some items in factor GM (e.g. Items 12 and 20) need revision.

Table 7.2: Cronbach's alpha reliability test for different factors of the Physics Motivation Survey (n = 218)

Factor	No. of Items	No. of Students	Reliability Cronbach's alpha	Factor Mean	Factor Std. Deviation	Item Mean
IMPR	7	220	.88	23.84	5.13	3.41
AA	6	218	.84	15.09	4.93	2.52
SD	3	219	.71	10.79	1.80	3.60
CM	5	220	.84	16.14	4.03	3.23
GM	4	220	.60	17.37	2.87	3.47

Expectation Survey and Experience Survey are newly developed instruments as mentioned in the methodology chapter, their criterion validity and reliability still need to be tested. Because in each survey, only items 1 to10 are measured in the same scale (Likert scale), the reliability analysis involved only item 1-10.Cronbach's alpha for the Expectation Survey and Experience Survey was 0.79 and 0.72, respectively, which was satisfactory (see Table 7.3). In spite of this, more research discussing their reliability and validity is needed.

Table 7.3: Descriptive Statistics and Reliability Values for the Expectation Survey and Experience Survey

Survey	No. of Items	No. of Students	Reliability Cronbach's alpha	Grand Mean (Std. Deviation)	Item Mean
Expectation Survey	10	212	.79	34.30(5.65)	3.43
Experience Survey	10	109	.72	34.55(5.11)	3.46

The correlation test between Expectation Survey, Experience Survey and five factors of Physics Motivation Survey was done to verify their criterion validity and as a basis of future research (see Table 7.4). Unlike Glynn et al.'s finding, not all factors correlated with each other significantly in this research. For instance, factor AA with factor CM, and factor AA with factor SD did not correlate significantly. The cause could be the sample size in this research (N=223) was not as large as that in Glynn et al.'s research (N=770). On the contrary, one similarity had been found between the two research investigations, namely there was a large correlation between the IMPR factor and the CM factor ($r=.675$, $p<0.01$) though each factor had changed some items.

Besides, from Table 7.4, it can be seen that there was a large correlation among the three factors: IMPR, CM and GM factor (each $r> 0.45$, $p<0.01$), indicating there was a strong relationship among personal intrinsic motivation, career motivation and grade motivation. The last finding was that all factors of the Physics Motivation Survey, had correlation with the Expectation Survey (r ranges from 0.12 to 0.64), providing good criterion validity between the Physics Motivation Survey and the Expectation Survey. However, that factor SD did not correlate with the Expectation Survey statistically significantly maybe due to the small sample size (N=216).

Table 7.4: Correlations between Motivation Survey, Expectation Survey and Experience Survey

	AssessmentAnxiety	Intrinsic Motivation and PersonalRelevance	CareerMotivation	GradeMotivation	Self-Determination	Expectation Survey	Experience Survey
AssessmentAnxiety	-	.307** N=223	-.021 N=223	.345** N=223	-.006 N=223	.490** N=216	.202* N=104
Intrinsic Motivation and PersonalRelevance		-	.675** N=223	.661** N=223	.254** N=223	.641** N=216	.422** N=104
CareerMotivation			-	.489** N=223	.339** N=223	.352** N=216	.289** N=104
GradeMotivation				-	.242** N=223	.499** N=216	.299** N=104
Self-Determination					-	.124 N=216	.149 N=104
Expectation Survey						-	.892** N=112
Experience Survey							-

p<0.05 **p<0.01

To sum up, the Physics Motivation Survey, Expectation Survey and Experience Survey are effective on measuring students' attitudes and unit learning experience. However it will be better if some items in Physics Motivation Survey can be revised and more research can be provided to demonstrate the validity and reliability of Expectation Survey and Experience Survey.

To understand students' attitude towards learning Physics, firstly students' responses to the questions measured by Likert's scale (item 1 to item 10) in Expectation Survey (pre-test) and Experience Survey (post-test) were analysed by t-test, in order to know if students' unit experience could meet their expectation. The results of the t-test analysis, including the three units together and respectively, are presented in Table 7.5. In spite of the differences between the mean of the Expectation Survey and the Experience Survey in Unit A and three units together are statistically significant, the Cohen's d effect size is small (Cohen's $d<0.2$). Therefore for practical purposes there is no difference between the mean of Expectation Survey and mean of Experience Survey. Furthermore in consideration of Unit B and Unit C, both t-test (no significant difference) and Cohen's d analysis (Cohen's $d<0.2$) indicate that there is no difference between the mean of Expectation Survey and mean of Experience Survey, no matter statistically or practically. By the above findings, a speculation is made that students' experience just met their expectation in three units altogether ($N=112$) and in each unit. Besides, if we recheck the correlation table (Table 7.4), we can find the score in Expectation Survey had large positive correlation with the score in Experience Survey ($r=0.892$, $N=112$), meaning higher expectation usually accompanied better experience.

Table 7.5: t-test and effect size test for the Expectation Survey (pre-test) and Experience Survey (post-test) in students in Unit B, Unit C and Unit A

Unit of Study	Survey	Mean	Standard dev.	t-value	Cohen's d
Unit B (n=20)	Expectation Survey	3.48	.44	.19	0.02
	Experience Survey	3.47	.41		
Unit C (n=27)	Expectation Survey	3.47	.54	1.73	0.12
	Experience Survey	3.53	.49		
Unit A (n=65)	Expectation Survey	3.36	.56	2.39*	0.13
	Experience Survey	3.43	.54		
Total Students (n=112)	Expectation Survey	3.41	.53	2.50*	0.10
	Experience Survey	3.46	.51		

*p<0.05

The descriptive statistics about the three attitude-related surveys are displayed in Table 7.6. They were all measured by Likert scale from one to five and the middle value is three. From the table it is shown that except for AA factor (Assessment Anxiety, mean=2.52), the mean in each of the remaining four factors in the Physics Motivation Survey, and the mean of the Expectation Survey and the Experience Survey are between three to four which is in the upper-intermediate level. The students' motivation towards learning Physics was good in the mid-semester when the Physics Motivation Survey was distributed except for AA factor, and the unit experience could meet students' expectation, which overall implied that students had a good attitude towards learning Physics throughout whole semester based on these questionnaires.

Table 7.6: Descriptive Statistics: Motivation Survey, Expectation Survey and Experience Survey

	N	Minimum	Maximum	Mean	Std. Deviation
IMPR	223	1.00	5.00	3.41	.73
AA	223	1.00	5.00	2.52	.82
SD	223	1.67	5.00	3.60	.61
CM	223	1.00	5.00	3.22	.81
GM	223	1.00	5.00	3.47	.60
Expectation Survey	230	1.25	5.00	3.29	.65
Experience Survey	112	1.90	4.40	3.46	.51

We also found many students' positive responses to Question 13 in Expectation Survey (Please describe briefly any particular expectations you have as you begin your study in this subject. Open ended question) and Question 13 in Experience Survey (Please describe briefly your experience of this subject, and in particular, what you think might be done to improve the subject. Open ended question). These responses can provide supportive evidence to explain why students' attitudes towards learning Physics were seen to be good. Below we list some of the students' positive responses to Question 13 in the Expectation Survey:

- I expect to learn about the relationship between our daily lives routine and physics. Also I expect to learn ways to help me with my degree of future job.
- I am just looking forward to learning more about how things in our everyday life work.
- I expect to do very well in this Unit As aiming for a high distinction and I'm very interested in Physics.
- I expect to get some skills that would eventually be useful for my professional career.
- I expect to work hard to achieve good results and learn much required information to assist the degree and profession.

Some of students' positive responses to Question 13 in Experience Survey are listed as follows:

- Physics has always been my favourite subject. It amazes me how it relates to my daily life. I always find physics enjoyable and interesting.
- I found it enjoyable and gained further understanding as to how many common things (e.g. electricity) actually work (in a greater level of detail).
- I enjoyed the experience of learning physics. It has been interesting and exciting. Improvements would be to start the lectures at a later time. 8 O'clock was too early.
- It is very interesting and a subject that makes you think more and It's very relevant to everyday thing.

- I love this subject more than the others. I know that some people suffered from difficulties in learning this subject, however it became my own challenges. I'm sure the subject is perfect, only lab session should be done after some of the relevant lecture has been elapsed.

Besides above positive responses, some responses about assessment anxiety were found to clarify why students' mean of AA factor in the Physics Motivation Survey was in the level of lower intermediate (mean=2.52). In the Expectation Survey, the feature of the students who had assessment anxiety was that they just wanted to pass the unit and the fear of failure caused them to be anxious. In the Experience Survey, some students wrote that they felt much pressure in the Computer Assisted Assessment (CAA) laboratory tests and laboratory reports, which were the two main parts for their assessment. In addition, many students mentioned the class was too intensive and rushed, which probably made the students so nervous about their assessment. Below are students' responses about assessment anxiety to Question 13 in Expectation Survey:

- My expectations are to pass.
- I have no expectations other than passing.
- I am aiming to pass this subject in addition to maths and chemistry and be able to get into Engineering next year.
- I am scared, I am going to fail!
- My expectations are true. Physics is so difficult due to my background of no maths. This topic stresses me out no end, though I am trying my best. The result will dictate if I continue with my degree.

And following are students' responses about assessment anxiety to Question 13 in Experience Survey:

- More maths to improve. Awful experience - too rushed.
- Overall I enjoyed this unit. I found the lecturer to greatly improve the unit. Possible in the future the time of tests should be after we have had all the lectures and not during the period that we are still going with lectures.
- Very time consuming. Lectures need to be less intense and less topics covered.
- A lot of information to absorb in a short time span if you want a high standard of knowledge and retention and not just looking for a tick in the box. My marks make my understanding look better than it is.
- Less content - it was hard to keep up. Allow a page of notes in the exam.
- I believe it was an intensive subject too much pressure for the lab reports and CAA labs and no time for other units.

Therefore a suggestion could be made in the beginning of Unit A in the future that if students' prior Physics level is in Year 10 or below, they are not suitable for this Unit Because Unit A contains six modules in one semester, which would be more stressful than the other two units, Unit B and Unit C, containing only three modules, which would be more achievable for those students.

Although the above students' responses may be the reasons causing their assessment anxiety, some of the responses are worth our notice. For instance, some students thought the unit they were taking was too rushed, or some students just wanted to pass the unit, which also could explain why some students had poor learning behaviours (e.g. Did not do practice questions before going to tutorials, or did not attend lectures or tutorials) which we observed in Research Phase One. Those students' thoughts appeared to influence their learning behaviour and their learning attitude. In order to cultivate students' good attitude towards learning Physics, those threats need to be resolved as soon as possible.

In conclusion, students' attitude towards learning Physics in the three units was positive except having some assessment anxiety, and they had positive unit experience during their semester. However, some threats to students' learning behaviour and learning attitude need to be noticed and removed.

7.3 Response to Research Question 6: Based on our research, what relationship can be found between students' learning attitudes and students' conceptual understanding?

7.3.1 The Correlation between the Marks of the Attitude Related Surveys, Thermal and Optics Questionnaire

To respond to this research question, first the correlations between the post-test mark and the thermal module, the optics module, and each attitude-related survey are shown and discussed (see Table 7.7). The average mark of all representations in each module was used to represent students' conceptual understanding, and students' score in the Physics Motivation Survey, the Expectation Survey and the Experience Survey represented students' learning attitude. It is revealed that all the factors in the Physics Motivation Survey had trivial or small correlation with students' conceptual understanding in thermal module (r=0.048~0.137) and that the correlation was statistically insignificant. In the optics modules, all factors in the Physics Motivation Survey correlated with students' conceptual understanding slightly (r=0.171~0.256), with some of the correlations being statistically significant ($p<0.05$). On the other hand, students' conceptual understanding had a higher correlation with Expectation Survey (r=0.368 in the thermal module, r=0.378 in the optics module) and Experience Survey (r=0.455 in the thermal module, r=0.390in the optics module), which were medium correlation and statistically significant ($p<0.01$). To explain the findings, we speculate that the items in Expectation Survey and Experience Survey are more unit-oriented and the items in Physics Motivation Survey consider more different aspects of learning attitude, or say in a more general way. However, it still can be inferred that a better attitude towards the unit would have a higher conceptual understanding in the post test of each module.

Table 7.7 Correlations: Motivation Survey, Expectation Survey, Experience Survey, Average mark of all representations in Thermal and Optics post test

	Correlation	Correlation
	Thermal Marks	Optics Marks
AA	.048 N=79	.171 N=80
IMPR	.137 N=79	.232* N=80
CM	.065 N=79	.189 N=80
GM	.073 N=79	.230* N=80
SD	.111 N=79	.256* N=80
Expectation Survey	.368** N=81	.378** N=82
Experience Survey	.455** N=65	.390** N=70

Mark All Type Thermal	-	.702** N=59

*p<0.05 **p<0.01

7.3.2 The Analysis of Interview Data and Surveys

Even though we know students' expectation about their unit had medium correlations with their conceptual understanding based on the above analysis, we examine more deeply the relation between students' attitude to learning and conceptual understanding through students' interview data and some information gained from their surveys. Three situations were identified from the 10 students interviewed.

- Situation One: A Good Attitude Correlated with Good Conceptual Development

Interviewee Ken provided detailed relation between good learning attitude and good conceptual understanding:

> I: So you think those representations really can help you develop a better understanding?
>
> Ken: …(omission). So certainly with some of your questions as well as the practice questions from the lecturer, it's shown me some areas where, even though you might be able to answer a test question, that you need to develop some further conceptual understanding. So with some of them I have actually done some external reading as well, but I guess isn't directly related to any of the assessments or to the questionnaire but more for this own piece of mind and understanding and because I'm hoping to, the course that I'm doing, I'm hoping to move into engineering. Obviously this class in physics isn't the end of the road, there's a lot more physics to come. So any additional understanding that I can get means that when we develop the concepts further, if I have an understanding of different representations of different

aspects of the problem, it means that when you come to learn more about them hopefully it makes it easier.
(Ken15.10.09)

Ken's above excerpt showed he had a strong interest in learning Physics because he did external reading. The career motivation revealed in the excerpt, saying he hoped to study engineering in the coming years and he thought studying engineering would be more challenging so any additional understanding would be helpful. His career motivation also can be proved by his average score of "career motivation" factor in his Physics Motivation Survey, which was 3.6, meaning at a good level. In short, career expectation was a main cause for Ken to have such good learning attitude and learning behaviour (he did external reading).

The following interview excerpt with Ken explained more about the relation among learning attitude, learning behaviour and conceptual understanding:

I: Some students took a lot of time to complete those questionnaires? And how long did they take you?

Ken: (omission). But probably what took the longest was to find the relevant formula, but then to actually explain or try and explain how the formula would help your understanding. So sometimes in, I guess, science education you can get into the habit of just looking at a question and thinking about how you would answer a test and what you would plug the figures into, but then stopping myself and thinking about how what I was putting in the formula actually related to the explanation that I would give to someone, was probably what took longer. So that's why certainly with the post questions it was almost double the time of the pre-teaching.
(Ken 15.10.09)

Ken's second excerpt showed his learning behaviour and his level of conceptual understanding. He could try to think about how to relate different representations by himself when answering the multiple representational questionnaire. This means that on the one hand his learning attitude or behaviour was good and on the other hand, he had had a good level of conceptual understanding and understanding in each representation. Therefore he could try to relate the different representations by himself. The excerpt also shows that learning attitude, learning behaviour and prior knowledge can support each other.

- Situation Two: A Good Attitude Accompanied by Poor Conceptual Development

However, a good learning attitude did not guarantee good conceptual understanding, which can be illustrated by Lisa's example:

> I: Yeah, how did you find, this particular unit?
> Lisa: This unit… Time consuming and I liked Optics actually, I did like Optics 'cause I got to draw diagrams and I like them, I don't know why, but they(drawing diagrams) were easier to understand the general gist of everything else. But yeah I find it time consuming and hard to understand. I just have to keep working at it. Keep reading, repetition yeah, practice. (Lisa27.10.09)

Lisa liked the optics module and liked to draw diagrams in this module, which showed that her intrinsic learning motivation was high. Besides this, she kept reading and practicing, which indicated that her learning behaviour was also good. However, she also found that learning this module was time consuming and difficult. According to her learning background information, her prior physics study finished 19 years ago, and the level was in Year 10. If we further examine her average mark of different representations in pre and post-test of multiple representational questionnaire, it can be found that her ability to represent her conceptual understanding in the beginning of optics module was not good and improved minimally in the end of this module (her mark was from 0.94 to 1.31). The prior low conceptual knowledge could be the reason why she had difficulty to improve her conceptualisation. Nevertheless, the feeling that the class was rushed class could be another reason, which was described in question 13 (open ended question) of her Experience Survey: "More maths to improve. Awful experience - too rushed". To summarise, although Lisa had a good learning attitude and learning behaviour, her prior knowledge and the rushed unit may have prevented her conceptual development.

- Situation Three: A Poor Attitude Correlated with Poor Conceptual Development

A poor learning attitude usually accompanied with poor conceptual understanding can be shown from the following two examples. The first one is the example that Amy responded to the question 1 in the optics questionnaire shown in Figure 7.1.

I: Yep number 1. How about this one?
Amy: Yeah this one is about common sense. Yeah.
I: So this one you used two representations… why don't you use formula?
Amy: Oh yeah where's my formula? Forgot.
I: Oh you forgot?
Amy: Yeah. What formula I forgot. But I think on this one (this question), I'm not sure because this one (this question) in the

daily life you will know this one (this question) every day. You go to the swimming pool or go to a beach yeah.

I: So you think it didn't help you to develop a deeper understanding of any concept?

Amy: No.

I: How about confused?

Amy: No.

I: Okay.

Amy: Might a little bit common sense yeah.

(Amy 19.10.09)

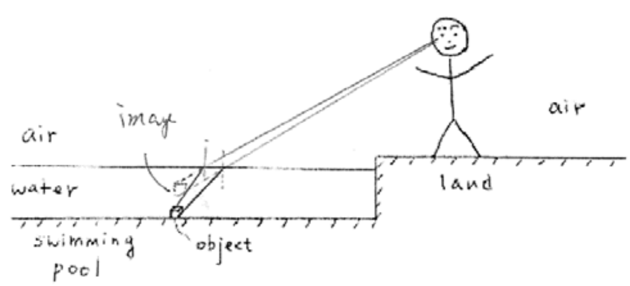
1. Why does an object resting on the bottom of a full-water swimming pool appear raised above the bottom of the swimming pool?

(1) Please explain your answer using words.

light refraction

light from air is refracted ~~when~~ after entering ~~the~~ water.

(2) Please sketch on the diagram below to help your explanation. [Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

Figure 7.1: Amy's written response to question 1 in optics questionnaire

From this example, the interviewee displayed an attitude that she did not really care what she could learn from this question. She forgot to research the formula and she thought the answer to this question was common sense, although the answer presented in her questionnaire still could be improved a lot. Her self-satisfaction influenced her learning attitude and learning behaviour (she forgot to research the formula), and stopped her from learning more and more deeply from this question.

The second example is Alice's response related to the multiple representational questionnaire:

I: Okay. So how do you feel about answering those questions two times? Do you feel bored?
Alice: Of course. Of course it's very repetitive. If you ask me perhaps a similar question like similar theory but rephrased differently, it might have been a bit more interesting. It might have seemed very different to me and less pointless.
(omission)
I: Do you think it was a fair use of your time?
Alice: Well I think that if you're doing revision and you have all your CAA lab tests that you would have done exactly the same thing so doing these questionnaires are just confirmed your understanding of the topic.
(omission)
I: So how did you find these kinds of questions in this questionnaire? Were they helpful for your learning or not helpful for your learning?
Alice: They were helpful to an extent because prior to my learning it just showed me how much I already knew about the topic. How much I need to know about the topic before I sit my CAA lab test. Other than that it was the extra load to do but yeah.
(Alice 23.10.09)

From the above excerpt, it is shown that the interviewee's dominant motivation to learn Physics was for the Computer Assisted Assessment (CAA) laboratory test, which also can be supported by the score in her Physics Motivation Survey (the factor of assessment anxiety was scored 1.33; the factor of grade motivation was scored 4.4). She believed that doing the multiple representational questionnaire was just confirming her understanding before class and tests, and other than this, it was an extra load. However, based on the average score of her pre and post-test in thermal and optics questionnaire (thermal score from pre 1.53 to post 1.67; optics score from pre 1.35 to post 1.66), her ability to represent her conceptual understanding improved to a limited extent and still had a lot of space to be further developed. Her self-satisfaction and too much attention to the tests or assessments impacted negatively on her learning attitude, and the passive attitude decided how she made use of the multiple representational questionnaires (just confirming her understanding before class and the tests), and further limited the development of her conceptual understanding.

The three situations happened during the interview with those 10 informative students (see Chapter Three). Nevertheless, the relation between students' learning attitude and their conceptual understanding could be more complicated and many factors could be involved in this relation. For example, theoretically some students who have poor learning attitudes may still have good conceptual development, as long as they have good learning behaviours.

To sum up the responses to this research question, first our finding showed that students' expectations about their unit had medium correlation with their conceptual understanding. Second, according to the analysis of students' interview excerpts and their information in their surveys, although a good attitude does not guarantee that students can improve their conceptual understanding significantly, it is one of the important factors for students' conceptual learning. Finally, for further research it is better to study the threats to and the causes of students' learning attitude and learning behaviour, and how these threats may influence their learning attitude and learning behaviour when learning physics with multiple representations.

7.4 Conclusion of this Chapter

This chapter is specifically about students' attitude towards their learning of physics in the three first year units. First of all, it was found that the Physics Motivation Survey, the Expectation Survey and the Experience Survey were effective in measuring students' attitudes and their unit learning experiences. Second, students' attitude towards learning Physics in the three units was positive despite some assessment anxiety, and they had positive unit experience during their semester. Nevertheless, some threats to students' learning attitude and learning behaviour should be eliminated or minimised. Lastly, in our study, students' expectations about their unit had medium correlation with their conceptual understanding, and good learning attitude was one of important factors in students' conceptual learning. However, more research is needed on studying the threats and causes of students' learning attitude and learning behaviour, and how these threats may affect their learning attitude and learning behaviour when learning physics using multiple representations.

CHAPTER 8

Conclusions and Recommendations

8.1 Introduction

In this chapter, the main findings of this thesis are summarised with respect to each research question. Implications for future instruction with multiple representations are then presented. Finally, some recommendations for Physics units, instruction and future research are described.

8.2 Main Findings of this Thesis

8.2.1 Research Question 1: What are students' evaluations of the use of multiple representations questionnaires in Optics and Thermal Physics?

From the 10 selected informative interviews, most students provided an overall positive evaluation of the questionnaires. The advantages and disadvantages proposed by the 10 interviewees were presented. The advantages included that the instruction pages of the questionnaires were useful, the questionnaires were a good summary and preview for students, and could be used for revision. The questionnaires also showed real life Physics examples and enabled students to think and learn from the multiple representations.

Of the disadvantages, some interviewees thought there were too many questions in the questionnaire and completing it was time consuming. Some interviewees met with dilemmas when considering the real life situations in the questions with the concepts theory they learned. Other negative comments included that they did not know how to apply their knowledge to the existing diagrams, the repetition of pre and post-test, and feeling stupid when completing the pre-test. These issues were discussed and solutions like removing some similar questions were suggested.

8.2.2 Research Question 2: What was the level of students' conceptual understanding based on the analysis of the multiple representations questionnaires in optics and Thermal Physics and interviewee's verbal explanations?

Even after instruction in Optics and Thermal Physics modules, students' marks for each representation, and average marks for all types of representations per question were not of a high level (between mostly wrong and mostly right) in the post-test of the multiple representations questionnaires. However, students' average mark for all types of representations, and the number of different mode representations presented per question improved significantly following instruction. It was suggested that the improvement might be due to the lectures and tutorials being designed to make students more aware of the different ways in which they can represent their knowledge and understanding. Evidence also showed that in the lectures, there was no significant correlation between the time that the lecturer used one representation and students' improvement of mark in that representation. Finally during the interviews, students' verbal explanations provided more information about their written responses to the questionnaires and helped considerably in clarifying their written responses. Oral explanations sometimes presented better conceptual and/or representational knowledge than did the written responses.

8.2.3 Research Question 3: How did students perform when explaining their concepts using one representation on the Optics and Thermal Physics questionnaires?

Students demonstrated a more positive performance once they mastered the three main elements in Pierce's Model, namely, representation, referent and concept. Based on our findings, students had deeper understanding of a concept if they can apply different referents or representations to the concept. However, they confronted problems in their conceptual development when they could not master anyone of the three main elements. It was found that in the aspect of representation, some students had problems on the operators and the existing diagrams in the multiple representations questionnaires. In the aspect of referent, some students were misled by their previous life experiences, and some were confused by the complexity of the real life context in the questions of the questionnaires. Lastly, some students struggled to develop more sophisticated concepts because they did not have enough understanding of those fundamental concepts.

8.2.4 Research Question 4: How well did students perform in their multiple representations with and without guidance on the Optics and Thermal Physics questionnaires?

In the condition with and without guidance, students had learning attitude problems, insufficient and/or incorrect prior knowledge (representational, referent or conceptual knowledge), and poor learning attitudes which may have inhibited their learning.

Although students saw more cognitive conflicts with guidance, most of them just ignored the conflict or could not resolve the conflict.

As a result, how a guide (e.g. a qualified teacher or instructor) helps the learner learn is important. A guide can increase the learner's knowledge based on the three main components of Pierce Model, in the aspects of representations, referents and concepts. A guide can, according to Ainsworth's DeFT framework, consider the characteristics of different representations and personal difference, design proper instruction, plan which functions of the different representations the learner should use, observe and assess how the learner undertake their cognitive tasks. Moreover, the guide can try to improve the learner's learning attitude if the learner has a problem with it.

Pierce Model and Ainsworth's framework about functions of multiple representations were useful and suitable for our analysis. Although all the three main functions that Ainsworth proposed appeared when we analysed our data, students had difficulty using the function of constructing a deep level understanding. This observation also was verified with the finding that the average marks for all types of representations per question were not of a high level (between mostly wrong and mostly right) in the post-test of the multiple representations questionnaires. The discussion in Chapter Two describes learners' deep level understanding as meaning he or she has a coherent mental model and the ability to relate and translate different representations, which is not easily achieved and is a goal for future instruction. In short, our study showed that it was easier for students in their explanations of these physical phenomena to use the functions of complementarity and constraining than the function of deep level understanding construction. However, more empirical research is needed to verify the practicability of Ainsworth's framework to analyse students' explanations using the functions of multiple representations.

8.2.5 Research Question 5: What were the students' attitudes towards learning Physics?

Exploratory factor analysis was conducted in the Physics Motivation Survey, and the result was compared with Glynn et al.'s research (2009). Consistent with the previous research, there were five factors after the factor analysis, but the items in each factor changed to some degree. Although the Cronbach's alpha for each factor in this research was acceptable (See Table 7.2, alpha ranges from 0.60 to 0.88), Cronbach's alpha for the factor Grade Motivation (alpha=0.60) could be improved further. Some items in this factor (e.g. Item 12 and Item 20) were suggested to be revised. In addition, the Cronbach's alpha for Expectation Survey and Experience Survey was 0.79 and 0.72 respectively, which was satisfactory (See Table 7.3).

According to the analysis of correlation between the Motivation Survey and the Expectation Survey, all factors of the Motivation Survey, had correlation with the Expectation Survey (r ranges from 0.12 to 0.64),showing the two surveys had good criterion validity. In short, the three attitude-related surveys were effective in measuring the students' attitudes to learning.

Paired t-tests and effect sizes were calculated with the data gained from the Expectation Survey and the Experience Survey. Students' unit experience just met their expectation of the unit. In addition, the students' degree of expectation and experience satisfactory were in the upper-intermediate level of the one to five Likert's scale (3.29 and 3.46 respectively).

The Motivation Survey showed similar results. With the exception of the factor Assessment Anxiety, the other factors in this survey presented that students' motivation were in the upper-intermediate level of the one to five Likert's scale (ranges from 3.22 to 3.60). Some students' written responses in the Expectation Survey and the Experience Survey supported that they had some assessment anxiety (e.g. they just wanted to pass the unit) and these responses should be considered with care in the future to prevent them from affecting students' attitude and behaviour towards learning.

8.2.6 Research Question 6: Is there any relationship between students' learning attitudes and the depth of students' conceptual understanding in Optics and Thermal Physics?

Firstly, it was found that all factors in the Motivation Survey had little or small correlations with students' conceptual understanding of Thermal Physics and Optics, with most of the correlation being statistically insignificant ($r=0.048 \sim 0.256$). On the other hand, students' conceptual understanding had statistically significant correlations with Expectation Survey in the medium level ($r=0.368$ in Thermal module, $r=0.378$ in Optics module).Secondly, based on students' interviews and their information in their surveys, good attitude did not necessarily result in good conceptual development because some factors (e.g. students' prior knowledge, the pace of the class) could also influence students' conceptual learning. However, there is no doubt that students' attitude to learning is one of the most important factors when students learn concepts. Finally, it is suggested that future studies focus on examining the obstacles to (e.g. too rushed class), and the causes of, students' learning attitude and learning behaviour, and how these obstacles may affect their learning attitude and learning behaviour.

8.3 Implications for Instruction

The main theme of this thesis was to explore the relation between the use of multiple representations, students' attitude to learning Physics, and students' conceptual development in first year Physics. Based on our findings, the use of multiple representations in class, could significantly help the learners develop their conceptualisations, and students' attitude to learning was an important factor during students' conceptual learning. However, students' conceptual development is not so straight forward and we need to consider other key factors (e.g. students' prior knowledge or the curriculum arrangement). These key factors not only influence the effects of multiple representations on learning, but also may affect students' attitudes. If we expect students to obtain significant conceptual growth through multiple representations, or good learning attitudes, those factors should be at an appropriate level (e.g. sufficient and correct prior knowledge). In other words, multiple representations or students' learning attitude cannot be the only factors contributing to students' success in their conceptual learning.

8.4 Recommendations

Below we make some recommendations on the three aspects of the studied units, instruction and future study.

8.4.1 For the Studied Units

The lecturer could show videos containing the content such as doing experiments, everyday life experiences which may use the different representations to help students' learning and their learning motivation and it would not take too much time in the busy class compared to allowing students to experience these activities in person. Furthermore, the lecturer and the tutors can notice if students' prior knowledge is correct and adequate, especially for Unit B and Unit C students. In the aspect of curriculum and the way of instruction, the lecturer and the tutors do not need to change a lot, but need to notice the efficacy of each representation used and the interaction of the different representations in the lectures and tutorials for students constructing deeper understanding. Finally, although it was found that students' learning attitude was acceptable, some threats (e.g. students' self-satisfaction) to their learning attitude and learning behaviour should be minimised.

8.4.2 For Instruction

There are some recommendations for the instructor and learner. First, in the aspect of assessment using multiple representations, if we want to confirm students' conceptual understanding, students' oral explanation cannot be ignored and should be taken together with their written responses. The second and third recommendations are based on our findings about the difficulties when students learning with multiple representations and based on Ainsworth's DeFT framework. Second, it is best that a professional instructor is present when the learner (especially for those who cannot adapt to the instruction in lectures) is learning with different representations, as the learner can benefit from the instructor by pointing out the learner's mistakes, provide conflicts with the learner's misconceptions, helping the learner link one representation with another. Furthermore, the instructor can assess the learner's prior knowledge before formal study and provide targeted assistance. It is efficient to help the learner develop conceptual understanding. The third recommendation is for a learner or a group of learners. To achieve the specified learning goals of instruction, the instructor may need to change the design of multiple representations (e.g. the sequence of using different representations) to help the learner(s) complete the cognitive tasks. The design of multiple representations should be flexible in curriculum. Finally, since students' learning attitude is important in students' learning, the instructor should be aware of students' learning attitudes and learning behaviours and the obstacles to them.

8.4.3 Future Research

In this thesis, we developed the multiple representations questionnaires for the Thermal Physics and Optics modules. This could also be done for other modules in the units such as Electricity. Developing the questionnaires for other modules not only can benefit the validity of the related research, but can be helpful in the instruction based on the evidence of this thesis study. Furthermore, it also can inspire the development of this sort of questionnaire in other study years. Despite mostly positive evaluations of the questionnaire in our study, some issues (e.g. too many questions) need to be revised for further use.

Although our multiple representations questionnaires had been reviewed by the thesis committee while they were developed to ensure their validity, they still need some other references to verify their criterion validity (e.g. students' final assessment marks of the semester). Additionally, as we mentioned the importance of a tutor's guidance while students learn using the questionnaire, it is worth studying not only how the tutor assists students to relate the different representations, to develop deeper understanding, but also how students use their representations to construct the deeper understanding.

Furthermore in our study, we speculated that students' improvement in the multiple representations questionnaires was because the instruction emphasised students learning multiple representations. Although our study had evidence to prove this statement, more studies are needed to more investigate research the relation between the instructor's different representations and students' conceptual improvement, especially exploring the instructor's and students' views on it.

With regard to students' learning attitudes, some suggestions for the instruments used in this thesis are provided. In our study, we modified Science Motivation Questionnaire to our Motivation Survey. Even though we have tested their construct validity and reliability in each factor, more research is needed to confirm our findings, especially with students majoring in Physics. On the other hand, the Expectation Survey and Experience Survey need more research to test their criterion validity and reliability because they were newly developed. Second, more effort should be put to examine the obstacles to, and the causes of, students' learning attitudes and learning behaviours, and how these may impact on learning.

The main aim in this thesis was to study the relationship between students' use of multiple representations, their attitudes towards learning Physics and their conceptual understanding. To conclude this thesis, students' conceptual understanding could benefit significantly from making use of the multiple representations in the instruction in class, especially when a tutor was present. It was also found that students' expectations had medium correlation to their conceptual understanding, and students' attitude was an important factor during students' learning. However, how students' attitude to learning and their conceptual understanding interact with each other and the factors in between need to be further investigated.

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Appendices

Appendix 1.1

Ethics approval for this thesis study

memorandum

Curtin University of Technology

To	Yen-Ruey Kuo, SMEC
From	Pauline Howat, Coordinator for Human Research Ethics, Science and Maths Education Centre
Subject	Protocol Approval **SMEC20080047**
Date	11 September 2008
Copy	David Treagust, SMEC Divisional Graduate Studies Officer, Division of Science and Engineering

Office of Research and Development

Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your "Form C Application for Approval of Research with Minimal Risk (Ethical Requirements)" for the project titled "*MULTIPLE REPRESENTATIONS IN TEACHING, LEARNING AND ASSESSMENT: A CASE STUDY IN FIRST YEAR UNIVERSITY PHYSICS*". On behalf of the Human Research Ethics Committee I am authorised to inform you that the project is approved.

Approval of this project is for a period of twelve months **7th September 2008** to **6th September 2009**.

If at any time during the twelve months changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately. The approval number for your project is **SMEC20080047**. *Please quote this number in any future correspondence.*

Pauline

PAULINE HOWAT
Coordinator for Human Research Ethics
Science and Maths Education Centre

Curtin University

Memorandum

To	Yen-Ruey Kuo, SMEC
From	Pauline Howat, Administrator, Human Research Ethics, Science and Mathematics Education Centre
Subject	**PROTOCOL APPROVAL – EXTENSION**
Date	15 April 2011
Copy	David Treagust, SMEC

Office of Research and Development

Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for keeping us informed of the progress of your research. The Human Research Ethics Committee acknowledges receipt of your Form B progress report for the project *"Multiple representations in teaching, learning and assessment: A case study in first year university physics."*

Approval for this project is extended for the year to 3rd April 2012.

Your approval number remains **SMEC20080047.** Please quote this number in any further correspondence regarding this project.

Please note: An application for renewal may be made with a Form B three years running, after which a new application form (Form A), providing comprehensive details, must be submitted.

Thank you.

Pauline

PAULINE HOWAT
Administrator
Human Research Ethics
Science and Mathematics Education Centre

Appendix 3.1

SHM multiple representations questionnaire (including Questionnaire no.1 and Questionnaire no.2)

Waves & Sound

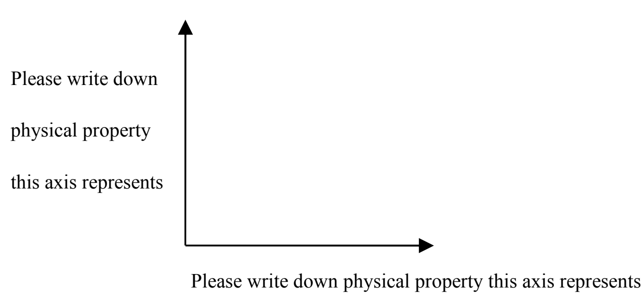
Questionnaire no.1

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.

1. Describe SHM (Simple Harmonic Motion).
2. Draw any picture(s) to express SHM.
3. Write down any formulas describing SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)
4. Draw any coordinate graph(s) to express SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)



Waves & Sound

Questionnaire no.2

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.

Here are some formulas which describe an object doing SHM (Simple Harmonic Motion).

$F=-kx$

$x=A\cos(\omega t)$

$v=-v_{max}\sin(\omega t)$

$a=-kA\cos(\omega t)/m$

$E=KE+PE=mv^2/2+kx^2/2$

F: restoring force

k: positive constant

x: displacement of the object from equilibrium position

A: Amplitude

ω: angular velocity

t: time

v: velocity of the object

a: acceleration of the object

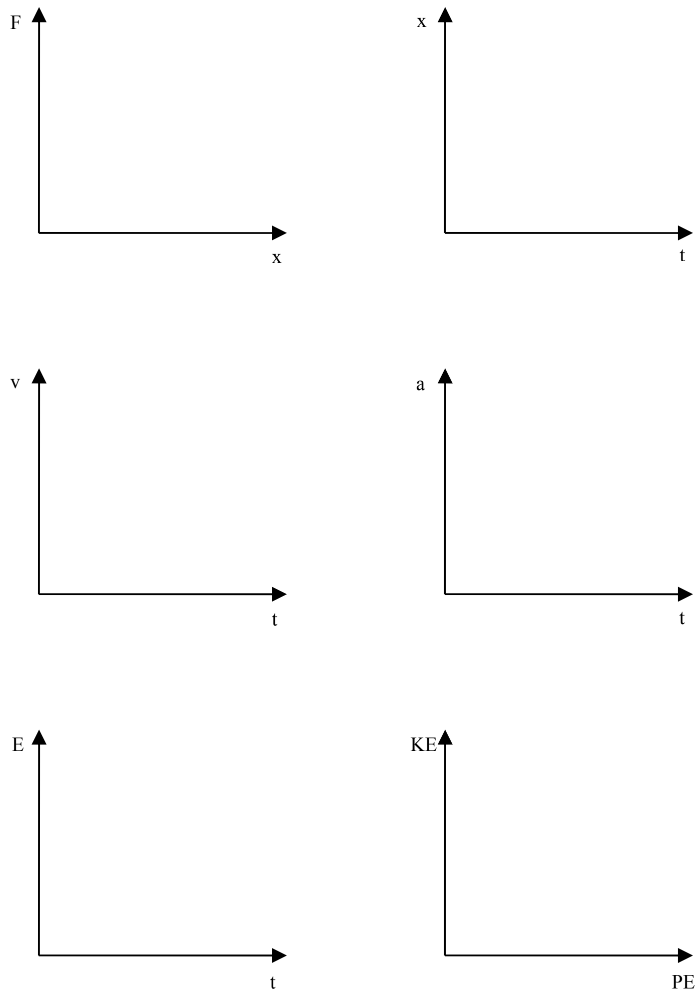
m: mass of the object

E: total energy of the object

KE: kinetic energy of the object

PE: potential energy of the object

1. Complete the following coordinate graphs.



2. Assume k=20N/m, A=10cm, $\omega = \pi /2$ sec^{-1}, v_{max}=0.3m/s, m=250g. Find F, x, v, a, E when t=1/3 sec.
3. When x=2cm, what is KE?

Appendix 3.2

Pre and post-test of multiple representations questionnaire on thermal physics in Research Phase Two

Hello,

My name is Yen-RueyKuo. I am a PhD student at SMEC (Science and Mathematics Education Centre) at Curtin University. I am currently doing research relating students' multiple representations and their conceptual understanding. The research needs your help to complete this questionnaire. All your personal information will be kept confidential.

If you have any further inquiries, please feel free to contact me viayen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Thermal Physics

Questionnaire

Note:

- Please **do not refer any other materials** (eg. books, lecture notes) and **do not discuss with other people**when you answer all Part 2 questions.
- We will mark your **serious participation** rather than right or wrong answers.

Part 1.

1.Name:

2.Student ID Number:

3. Unit studying: Physics 113/114/115

4.To which year have you previously studied Physics at school?

a. Year 10   b. Year 11   c. Year 12

Part 2.

- In the following **12** questions, please answer them and **explain your answer using the following "Tools" e.g. description, diagram, formula, graph. Use as many "Tools" as you can in responding to each question.**

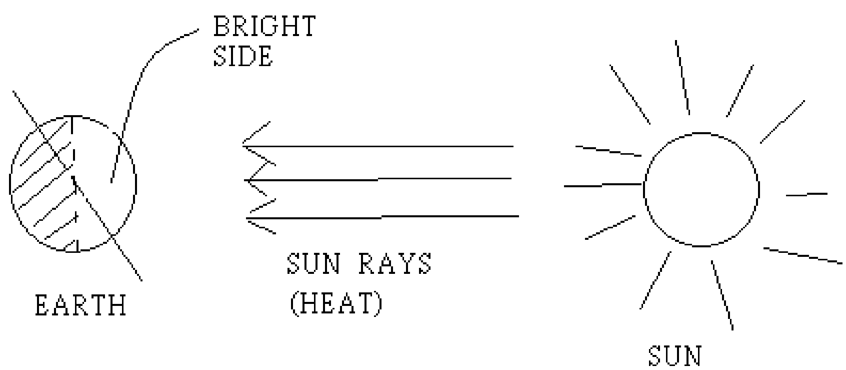
Examples of Tools

A. Description using words

e.g. The most common scale to measure temperature today is the Celsius scale, sometimes called the centigrade scale.…

B. Schematic diagram

eg.



C. Formula (Some of the following formulas can be used for your explanation)

$$KE=3kT/2$$

$$P=\varepsilon A \sigma \{(T_1)^4 - (T_2)^4\}$$

$$PV=nRT$$

$$Q = m c \Delta T$$

$$Q= m L$$

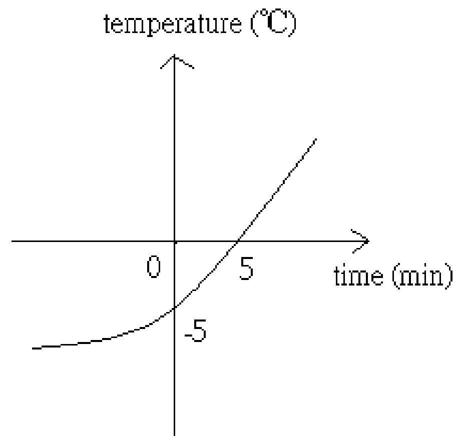
$$\Delta L= \alpha Lo \Delta T$$

$$\Delta Q/\Delta t = \{A k \Delta T\}/L$$

$$\Delta V = \beta Vo\Delta T$$

D. Coordinate graph

e.g.



Questions:

1.Can sweating cool you down? **Please explain your answer.**

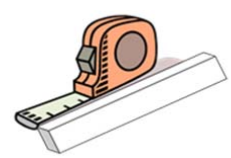
2.In winter, which makes you feel colder, sitting on a wooden chair or sitting on a metal chair? **Please explain your answer.**

3.Mary takes a glass jar and wants to open the metal lid on it. She finds the lid too tight so she decides to heat the lid under hot water tap in the sink. After doing that for a while, can she open the metal lid? **Please explain your answer.**

4.On a hot day (your surrounding's temperature is higher than your skin's temperature). Which T shirt makes you feel hotter, wearing a black T-shirt or wearing a white T-shirt? Assuming both are made of the same material. **Please explain your answer.**

5.A piece of toast may be comfortably eaten a few seconds after coming from the hot toaster, whereas we must wait several minutes before eating soup from a stove as hot as the toaster. Do you agree? **Please explain your answer.**(The mass of the toast and the mass of the soup are same)

6. A steel tape-measure is marked such that it gives accurate length measurements at room temperature. If the tape measure is used outside on a very hot day, how will its length measurements be affected? **Please explain your answer.**



Multiple Choice Questions: (Some question may have more than one choice.)

7. Lee takes two cups of water at 40℃ and mixes them with one cup of water at 10℃ (each cup of water weighs 250g). What is the most likely temperature of the mixture?a. 20℃ b. 25℃ c. 30℃ d.50℃

Please explain your answer.

8. Pam asks one group of friends: “If I put 100 grams of ice at 0℃ and 100 grams of water at 0℃ into a freezer, which one will eventually lose the greatest amount of heat? (The temperature inside the freezer is -10℃)

a. Cat says: “The 100 grams of ice.”
b. Ben says: “The 100 grams of water.”
c. Jed says: “They both will eventually lose the same amount of heat.”
d. Nic says: “You all are wrong.”
Which of her friends do you most agree with?

Please explain your answer.

9.A bimetallic strip consists of a brass strip on the top and a steel strip at the bottom. If the bimetallic strip is uniformly heated keeping one end clamped in a horizontal position, how would the free end of the strip behave? The coefficient of linear thermal expansion of steel and brass are $12x10^{-6}/C°$ and $19x10^{-6}/C°$ respectively.

a. curve upward
b. curve downward
c. remain horizontal, but get longer
d. not change in length, due to different values of expansion coefficients
e. none of these

Please explain your answer.

10. In constructing an expansion-type thermometer it is necessary to use a material which

a. changes phase when heated.

b. has a coefficient of thermal expansion which increases with increasing temperature.

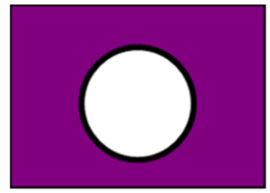
c. has a coefficient of thermal expansion which decreases with increasing temperature.

d. will expand linearly with increasing temperature.

e. will flow easily in a glass tube.

Please explain your answer.

11.A square metal plate has a 2 cm diameter hole at the centre of the plate. If the plate is uniformly heated, what will happen to the size of the hole in the plate?



a. it will increase
b. it will decrease
c. it will remain the same
d. none of the above is correct

Please explain your answer.

12. Two well insulated beakers each contain 200 g of water at 60°C. If a 40 g cube of steel is dropped into the first, and 40 g of water is added to the second which beaker will have the highest final temperature? Assume that the added cube and the added water are initially at room temperature of 25°C.

a. the first
b. the second
c. they have the same temperature
d. the temperature of the second beaker will be twice the first
e. there is insufficient data to answer the question

Please explain your answer.

Time spent to complete this questionnaire: ______________________________

Appendix 3.3

Pre-test of multiple representations questionnaire on optics in Research Phase Two

Hello,

My name is Yen-Ruey Kuo. I am a PhD student at SMEC (Science and Mathematics Education Centre) at Curtin University. I am currently doing the research relating students' multiple representations and their conceptual understanding. The research needs your help to complete this questionnaire. All your personal information will be kept confidential.

If you have any further inquiries, please feel free to contact me viayen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Optics

Questionnaire

Note: • Please **do not refer any other materials** (e.g. books, lecture notes) and **do not discuss with other people** when you answer all Part 2 questions. • We will mark your **serious participation** rather than right or wrong answers.

Part 1Your personal information:

1.Name:

2.Student ID Number:

3.Unit studying: Physics 113/114/115

4.To which year have you previously studied Physics at school?

a. Year 10 b. Year 11 c. Year 12

Part 2

- In the following **10** questions, please answer them and **explain your answer using the following "Tools"—description, diagram, formula, graph. Use as many "Tools" as you can in responding to each question.**

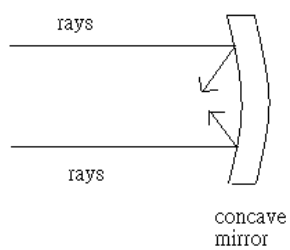
Examples of Tools

A. Description using words

e.g. Total internal reflection is the principle behind fibre optics. Glass and plastic fibres as thin as a few micrometers in diameter are common.…

B. Schematic diagram

e.g.



C. Formula(Some of the following formulas can be used for your explanation)

$$\theta i=\theta r$$

$$n=c/v$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$(1/f) = (1/do) + (1/di)$$

$$M = -(di/do) = -(hi/ho)$$

$$M_\infty=N/f$$

$$M_N=(N/f)+1$$

$$M = MoMe = (N\times L)/fofe$$

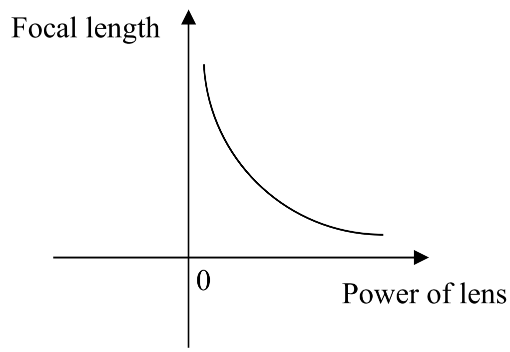
$$\theta = 1.22\lambda/D$$

$$\tan\theta p = n_2/n_1$$

$$I_2 =I_1 \cos^2\theta$$

D. Coordinate graph

e.g.



Questions

1. Why does a person standing in waist-deep water in a swimming pool appear to have shorter legs?
   Please explain your answer.

2. Light travels with a speed of $3x10^8$ m/s in vacuum.

(a) Does light travel with the same speed in water, glass and diamond?

(b) If not in which of the above materials will the light travel fastest?

Please explain your answer.

3. Assume you are a 2.0 m tall person standing at a distance of 1.0 m in front of a large <u>plane mirror.</u>

(a) Will your image be smaller, larger or the same size?

(b) Will the height of your image change when you move away from the mirror?

Please explain your answer.

4. A magnifying glass (convex lens) is rated at 3.0 x. This means it will magnify the image of an object 3.0 times. If this magnifying glass is used under water, what will happen to its magnification? Will it remain the same, increase or decrease? Please explain your answer.

5. Assume you are 2.0 m tall person standing at a distance of 1.0 m in front of a large convex mirror.

(a) Will your image be smaller, larger or the same size?

(b) Will the height of your image change when you move away from the mirror?

Please explain your answer.

6. An object is placed on the left hand side of a convex lens whose focal length is 15.0 cm. The distance of the object is 60.0 cm from the convex lens. A screen is placed on the right hand side of the convex lens. Describe how the size and location of the image would change as the object moves towards the lens.

7. On a sunny day, how can wearing Polaroid sunglasses protect you from glare when you are riding a motorcycle on a road? Please explain your answer.

8. Light waves and radio waves are different forms of electromagnetic waves.

(a) What is the same about these two waves?

(b) What is different about these two waves?

Please explain your answer and also sketch the shape of these waves.

9. Why do older people who do not wear glasses read books farther away from their eyes than do younger people? Please explain your answer.

10. If you were spearing a fish, would you aim above, below or directly at the observed fish to make a direct hit? If instead you zapped the fish with a laser beam, would you aim above, below or directly at the observed fish? Please explain your answer.

Time spent to complete this questionnaire: ______________________________

Appendix 3.4

Post-test of multiple representations questionnaire on optics in Research Phase Two (questionnaire A)

(after-teaching)A

Hello,

My name is Yen-RueyKuo. I am a PhD student at SMEC (Science and Mathematics Education Centre) at Curtin University. I am currently doing the research relating students' multiple representations and their conceptual understanding. The research needs your help to complete this questionnaire. All your personal information will be kept confidential.

If you have any further inquiries, please feel free to contact me viayen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Optics

Questionnaire

Note:

- Please **do not refer any other materials** (e.g. books, lecture notes) and **do not discuss with other people** when you answer all Part 2 questions.
- We will mark your **serious participation** rather than right or wrong answers.

Part 1Your personal information:

1.Name:

2.Student ID Number:

3.Unit studying: Physics 113/114/115

4.To which year have you previously studied Physics at school?

a. Year 10 b. Year 11 c. Year 12

Part 2

- In the following **5** questions, please **explain your answer using the following "Tools"—description, diagram, formula, graph.**

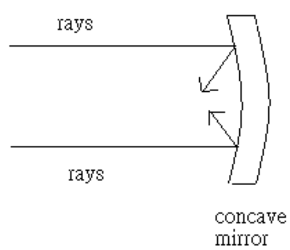
Examples of Tools

A. Description using words

e.g. Total internal reflection is the principle behind fibre optics. Glass and plastic fibres as thin as a few micrometers in diameter are common.…

B. Schematic diagram

e.g.



C. Formula (Some of the following formulas can be used for your explanation)

$$\theta i=\theta r$$

$$n=c/v$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$(1/f) = (1/do) + (1/di)$$

$$M = -(di/do) = hi/ho$$

$$M_\infty=N/f$$

$$M_N=(N/f)+1$$

$$M = MoMe = (N\times L)/fofe$$

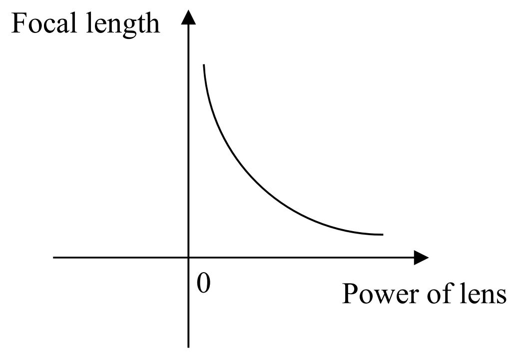
$$\theta = 1.22\lambda/D$$

$$\tan\theta p = n_2/n_1$$

$$I_2 =I_1 \cos^2\theta$$

D. Coordinate graph

e.g.



Questions

1. Why does a person standing in waist-deep water in a swimming pool appear to have shorter legs?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

2. Does light travel in water, glass and diamond with the same speed as in air? If not in which of the above materials will the light travel fastest?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) of waves in air and medium.

3. Assume you are a 2.0 m tall person standing at a distance of 1.0 m in front of a large plane mirror.

3-1. Will your image be smaller, larger or the same size?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

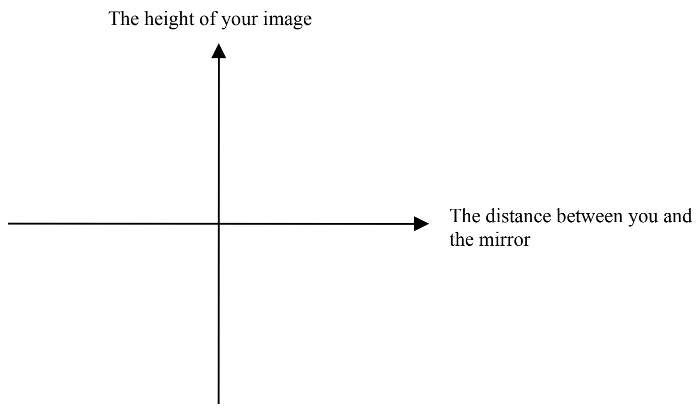
3-2. Will the height of your image change when you move away from the mirror?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

(4) Please complete the following coordinate graph.



4. An object is placed on the left hand side of a convex lens whose focal length is 15.0 cm. The distance of the object is 60.0 cm from the convex lens. A screen is placed on the right hand side of the convex lens. Describe how the size and location of the image would change as the object moves towards the lens.

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

5. On a sunny day, how can wearing Polaroid sunglasses protect you from glare when you are riding a motorcycle on a road?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation?
How can this (these) formula(s) help your explanation?

Time spent to complete this questionnaire: ____________________________

Appendix 3.5

Post-test of multiple representations questionnaire on optics in Research Phase Two (questionnaire B)

(after-teaching)B

Hello,

My name is Yen-RueyKuo. I am a PhD student at SMEC (Science and Mathematics Education Centre) at Curtin University. I am currently doing the research relating students' multiple representations and their conceptual understanding. The research needs your help to complete this questionnaire. All your personal information will be kept confidential.

If you have any further inquiries, please feel free to contact me viayen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Optics

Questionnaire

Note:

- Please **do not refer any other materials** (e.g. books, lecture notes) and **do not discuss with other people** when you answer all Part 2 questions.
- We will mark your **serious participation** rather than right or wrong answers.

Part 1Your personal information:

1.Name:

2.Student ID Number:

3.Unit studying: Physics 113/114/115

4.To which year have you previously studied Physics at school?

a. Year 10 b. Year 11 c. Year 12

Part 2

- In the following **5** questions, please **explain your answer using the following "Tools"—description, diagram, formula, graph.**

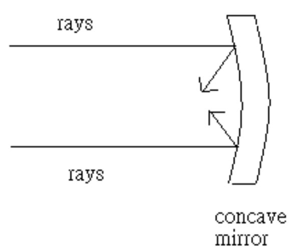
Examples of Tools

A. Description using words

eg. Total internal reflection is the principle behind fiber optics. Glass and plastic fibers as thin as a few micrometers in diameter are common.…

B. Schematic diagram

eg.



C. Formula(Some of the following formulas can be used for your explanation)

$$\theta i=\theta r$$

$$n=c/v$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$(1/f) = (1/do) + (1/di)$$

$$M = -(di/do) = hi/ho$$

$$M_\infty=N/f$$

$$M_N=(N/f)+1$$

$$M = MoMe = (N\times L)/fofe$$

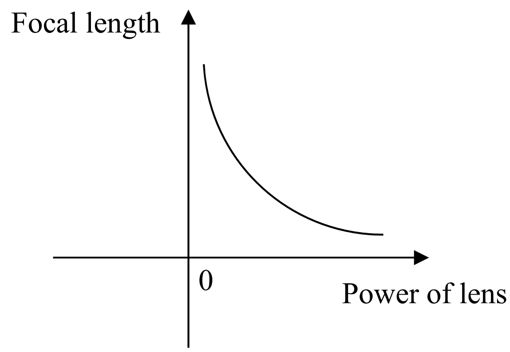
$$\theta = 1.22\lambda/D$$

$$\tan\theta p = n_2/n_1$$

$$I_2 =I_1 \cos^2\theta$$

D. Coordinate graph

e.g.



Questions

1. A magnifying glass (convex lens) is rated at 3.0 x. This means it will magnify the image of an object 3.0 times. If this magnifying glass is used under water, what will happen to its magnification? Will it remain the same, increase or decrease?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

2. Assume you are 2.0 m tall person standing at a distance of 1.0 m in front of a large convex mirror.

2-1. Will your image be smaller, larger or the same size?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

2-2. Will the height of your image change when you move away from the mirror?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

3. Light waves and radio waves are different forms of electromagnetic waves.

What is the same about these two waves? What is different about these two waves?

(1) Please explain your answer using words.

(2) Please sketch the shape of these waves to help your explanation.

4. Why do older people who do not wear glasses read books farther away from their eyes than do younger people?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

5. If you were spearing a fish, would you aim above, below or directly at the observed fish to make a direct hit? If instead you zapped the fish with a laser beam, would you aim above, below or directly at the observed fish?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.

(3) From formulas in page 2, which formula(s) can help your explanation? How can this (these) formula(s) help your explanation?

Time spent to complete this questionnaire: ______________________________

Appendix 3.6

Physics Motivation Survey in Research Phase Two

Physics Units Survey

This questionnaire is part of a study into physics subjects taken by students who are not majoring in physics. We would like you to respond to the statements below and ask you to put your student ID number, name and major on the survey. All your personal information will be kept confidential. If you have any further inquiry, please feel free to contact us via

yen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Yen-Ruey Kuo (PhD student at Science and Math Education Centre at Curtin University of Technology)

Student ID number: _______________

Name: ____________________

Major: _____________________________________

I am studying ☐**Physics 113** ☐**Physics 114** ☐**Physics 115**

In order to better understand what you think and feel about your university physics courses, please respond by filling in the circle before the most appropriate option to each of the following statements from the perspective of:

“**When I am in the university physics course…**”

01. I enjoy learning physics.

○Never ○Rarely ○Sometimes ○Usually ○Always

02. The physics I learn relates to my personal goals.

○Never ○Rarely ○Sometimes ○Usually ○Always

03. I like to do better than the other students on the physics tests.

○Never ○Rarely ○Sometimes ○Usually ○Always

04. I am nervous about how I will do on the physics tests.

○Never ○Rarely ○Sometimes ○Usually ○Always

05. If I am having trouble learning physics, I try to figure out why.

○Never ○Rarely ○Sometimes ○Usually ○Always

06. I become anxious when it is time to take a physics test.

○Never ○Rarely ○Sometimes ○Usually ○Always

07. Earning a good physics grade is important to me.

○Never ○Rarely ○Sometimes ○Usually ○Always

08. I put enough effort into learning physics.

○Never ○Rarely ○Sometimes ○Usually ○Always

09. I use strategies that ensure I learn physics well.

○Never ○Rarely ○Sometimes ○Usually ○Always

10. I think about how learning physics can help me get a good job.

○Never ○Rarely ○Sometimes ○Usually ○Always

11. I think about how the physics I learn will be helpful to me.

○Never ○Rarely○Sometimes○Usually ○Always

12. I expect to do as well as or better than other students in the physics course.

○Never ○Rarely○Sometimes○Usually ○Always

(continued)

13. I worry about failing the physics tests.

○Never ○Rarely○Sometimes○Usually ○Always

14. I am concerned that the other students are better in physics.

○Never ○Rarely○Sometimes○Usually ○Always

15. I think about how my physics grade will affect my grades this year.

○Never ○Rarely○Sometimes○Usually ○Always

16. The physics I learn is more important to me than the grade I receive.

○Never ○Rarely○Sometimes○Usually ○Always

17. I think about how learning physics can help my career.

○Never ○Rarely○Sometimes○Usually ○Always

18. I hate taking physics tests.

○Never ○Rarely○Sometimes○Usually ○Always

19. I think about how I will use the physics I learn.

○Never ○Rarely○Sometimes○Usually ○Always

20. It is my fault, if I do not understand the physics.

○Never ○Rarely○Sometimes○Usually ○Always

21. I am confident I will do well on the physics labs and projects.

○Never ○Rarely○Sometimes○Usually ○Always

22. I find learning physics interesting.

○Never ○Rarely○Sometimes○Usually ○Always

23. The physics I learn is relevant to my life.

○Never ○Rarely ○Sometimes ○Usually ○Always

24. I believe I can master the knowledge and skills in the physics course.

○Never ○Rarely ○Sometimes ○Usually ○Always

25. The physics I learn has practical value for me.

○Never ○Rarely ○Sometimes ○Usually ○Always

26. I prepare well for the physics tests and labs.

○Never ○Rarely ○Sometimes ○Usually ○Always

27. I like physics that challenges me.

○Never ○Rarely ○Sometimes ○Usually ○Always

28. I am confident I will do well on the physics tests.

○Never ○Rarely ○Sometimes ○Usually ○Always

29. I believe I can earn a Distinction grade in the physics course.

○Never ○Rarely ○Sometimes ○Usually ○Always

30. Understanding physics gives me a sense of accomplishment.

○Never ○Rarely ○Sometimes ○Usually ○Always

The End - Thank you!

Appendix 3.7

Expectation Survey in Research Phase Two

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QUESTIONNAIRE A

I am majoring in: ______________________________

This questionnaire is part of a study into physics subjects taken by students not majoring in physics. We would like you to respond to the statements below and ask you not to put your name on the survey. You can choose to not fill in this questionnaire, or to hand in a questionnaire that is blank. All responses remain anonymous. You are free to withdraw from participating in this study at any time without giving a reason. Any person with concerns or complaints about the conduct of a research study can contact the Manager, Research Ethics Office, University of Technology Sydney on (02) 9514 9615 (telephone); (02) 9514 1244 (facsimile) or hadiza.yunusa@uts.edu.au (email)

Please mark each of the statements below to indicate to what extent you agree with the statement.

Shade Circles Like This--> ●
Not Like This-->

	N/A	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. It is apparent to me that this subject is a valuable part of my degree.	○	○	○	○	○	○
2. Only people with an extraordinary ability are capable of understanding physics.	○	○	○	○	○	○
3. I am keen to see how this subject links to my major area of study.	○	○	○	○	○	○
4. I believe an understanding of physics will benefit my studies in other areas of my degree.	○	○	○	○	○	○
5. I am confident that my mathematics background is sufficient for me to be successful in this subject.	○	○	○	○	○	○
6. I expect to do well in class tests in this subject.	○	○	○	○	○	○
7. I am looking forward to doing labs in this subject.	○	○	○	○	○	○
8. If it were possible, I would have avoided taking this subject.	○	○	○	○	○	○
9. I expect the links between this subject and my major area of study to be made obvious throughout the semester.	○	○	○	○	○	○
10. I expect to have to work harder in this subject than in my other subjects this semester.	○	○	○	○	○	○

Please answer the following questions

11. What final grade are you aiming for in this subject?

☐ Pass ☐ Credit ☐ Distinction ☐ High Distinction ☐ Don't know yet

12. Did you study Physics to Year 12 at school?

☐ Yes ☐ No

13. Please describe briefly any particular expectations you have as you begin your study in this subject. If you need more space, please write on the other side of this questionnaire.

____

____

____

Thank you for completing this survey.

Appendix 3.8

Experience Survey in Research Phase Two

3973582029

QUESTIONNAIRE B

I am majoring in: ______________________________

This questionnaire is part of a study into physics subjects taken by students not majoring in physics. We would like you to respond to the statements below and ask you not to put your name on the survey. You can choose to not fill in this questionnaire, or to hand in a questionnaire that is blank. All responses remain anonymous. You are free to withdraw from participating in this study at any time without giving a reason. Any person with concerns or complaints about the conduct of a research study can contact the Manager, Research Ethics Office, University of Technology Sydney on (02) 9514 9615 (telephone); (02) 9514 1244 (facsimile) or hadiza.yunusa@uts.edu.au (email)

Please mark each of the statements below to indicate to what extent you agree with the statement.

Shade Circles Like This--> ●
Not Like This--> ⊗ ✓

	N/A	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. It is apparent to me that this subject is a valuable part of my degree.	⓪	①	②	③	④	⑤
2. Only people with an extraordinary ability are capable of understanding physics.	⓪	①	②	③	④	⑤
3. There are clear links between this subject and my major area of study.	⓪	①	②	③	④	⑤
4. I believe an understanding of physics will benefit my studies in other areas of my degree.	⓪	①	②	③	④	⑤
5. I am confident that my mathematics background is sufficient for me to be successful in this subject.	⓪	①	②	③	④	⑤
6. My achievements in class tests in this subject exceeded my expectations.	⓪	①	②	③	④	⑤
7. The labs in this subject were a positive learning experience.	⓪	①	②	③	④	⑤
8. I would advise others to avoid taking this subject if at all possible	⓪	①	②	③	④	⑤
9. The lecturers succeeded in linking this subject to my major area of study.	⓪	①	②	③	④	⑤
10. I worked harder in this subject than for my other subjects this semester.	⓪	①	②	③	④	⑤

Please answer the following questions

11. What final grade are you aiming for in this subject?

☐ Pass ☐ Credit ☐ Distinction ☐ High Distinction ☐ Don't know yet

12. Did you study Physics to Year 12 at school?

☐ Yes ☐ No

13. Please describe briefly your experience of this subject, and in particular, what you think might be done to improve the subject. If you need more space, please write on the other side of this questionnaire.

____

____

____

Thank you for completing this survey.

Appendix 3.9

Pre and post-test of multiple representations questionnaire on thermal physics in Research Phase Three

Hello,

My name is Yen-RueyKuo. I am a PhD student at SMEC (Science and Mathematics Education Centre) at Curtin University. I am currently doing research relating students' use of multiple representations and conceptual understanding. The research needs your help to complete this questionnaire. All your personal information will be kept confidential.

If you have any further inquiries, please feel free to contact me viayen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Thermal Physics

Questionnaire

Part 1.

1. Student ID number: _______________
2. Name: ____________________
3. Major: _____________________________________
4. Gender: ☐Male ☐Female
5. I am studying ☐Physics 113 ☐Physics 114 ☐Physics 115
6. To which year have you previously studied Physics at school?

   ☐Year 10 ☐Year 11 ☐Year 12
7. How long ago was your last Physics study undertaken at school?

   ____
8. How often did you go to lectures in this Module?

   ☐rarely ☐sometimes ☐(nearly)always
9. How often did you go to tutorials in this Module?

   ☐rarely ☐sometimes ☐(nearly)always

Part 2.

To help you understand how to respond to each question in this part, please refer to the following example.

Example

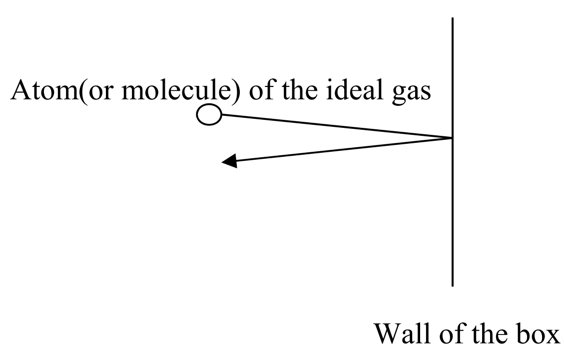
An ideal gas is put in an airtight box. If the temperature of the gas increases from 298K to 323K, and the volume of the box does not change, will the pressure of the gas increase, decrease or remain the same?

(1) **Please explain your answer using words.**

The pressure of the gas will increase. The atoms (or molecules) will move faster, which will apply more force to the inside wall of the box and cause more pressure to the box.

(2) **Please sketch a diagram(s) to help your explanation.[Also show the necessary label(s)]**

Atom(or molecule) of the ideal gas hits inside wall of the box



(3) **Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?**

$$PV=nRT$$

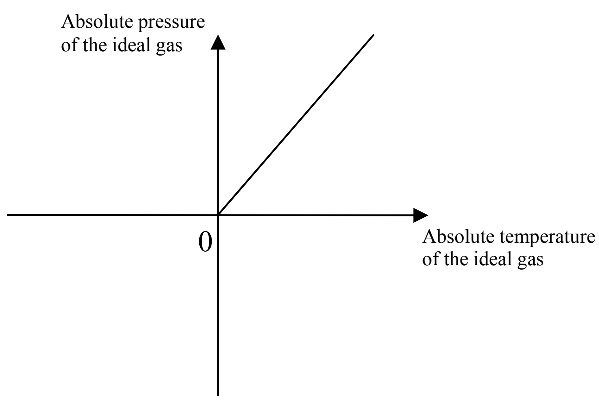
P: pressure of the ideal gas

T: temperature of the ideal gas

In this case, T(323K)>T(298K),

so P(323K)>P(298K)

(4) **Please complete this coordinate graph.**



Questions:

1. Can sweating cool you down?

(1) Please explain your answer using words.

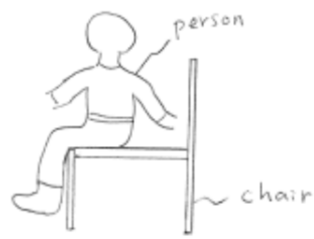
(2) Please sketch on the diagram below to help your explanation.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

2. In winter, which makes you feel colder, sitting on a wooden chair or sitting on a metal chair?

(1) Please explain your answer using words.

(2) Please sketch on the diagram below to help your explanation.[Also show the necessary label(s)]

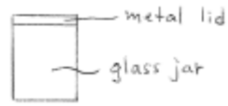


(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

3. Mary takes a **glass jar** and wants to open the **metal lid** on it. She finds it is too tight to open the lid, so she decides to put the jar in the sink and turns on the hot water tap to heat the lid with running hot water. After doing that for a while (the temperature of the lid and jar becomes different), she opens the lid successfully. Why?

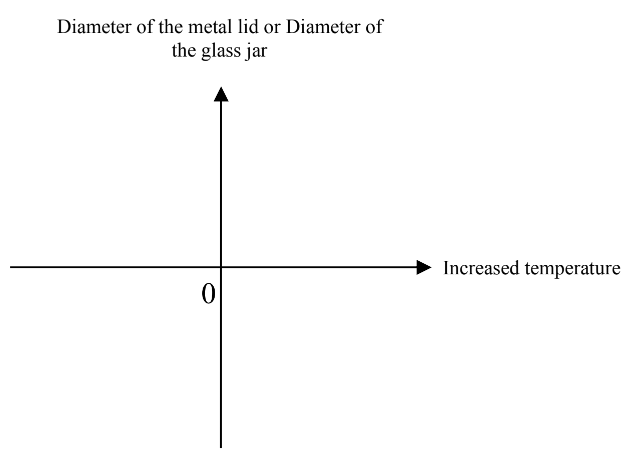
(1) Please explain your answer using words.

(2) On the diagram below, please use dotted lines to sketch the lid and jar after they are heated by running hot water.[Also show the necessary label(s)]



(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

(4) Please complete this coordinate graph.
(Please label the shape you draw with "metal lid" and "glass jar")



4. On a hot day (your surrounding's temperature is higher than your skin's temperature). Which T shirt makes you feel hotter, wearing a black T-shirt or wearing a white T-shirt? Assuming both are made of the same material.

(1) Please explain your answer using words.

(2) Please sketch on the diagrams below to help your explanation.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

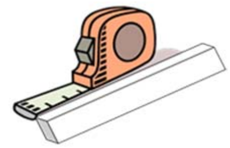
5. A piece of toast may be comfortably eaten a few seconds after coming from the hot toaster, whereas we must wait several minutes before eating soup from a stove as hot as the toaster. Do you agree?(The toast and the soup loses the same amount of heat per unit time, and they have the same mass)

(1) Please explain your answer using words.

(2) Please sketch on the diagrams below to help your explanation.[Also show the necessary label(s)]

(3) Is (Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

6. A steel tape-measure is marked such that it gives accurate length measurements at room temperature. If the tape measure is used outside on a very hot day, how will its length measurements be affected?



(1) Please explain your answer using words.

(2) Please sketch the calibration from 0 to 1 of the tape-measure when it is used outside.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

Multiple Choice Questions: (You can select more than one choice if you wish)

7. Lee takes two cups of water at 40℃ and mixes them with one cup of water at 10℃ (each cup of water weighs 250g). What is the most likely temperature of the mixture? a. 20℃ b. 25℃ c. 30℃ d.50℃

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

8. Pam asks one group of friends: “If I put 100 grams of ice at 0℃ and 100 grams of water at 0℃ into a freezer, which one will eventually lose the greatest amount of heat? (The temperature inside the freezer is -10℃)

a. Cat says: “The 100 grams of ice.”

b. Ben says: “The 100 grams of water.”

c. Jed says: “They both will eventually lose the same amount of heat.”

d. Nic says: “You all are wrong.”

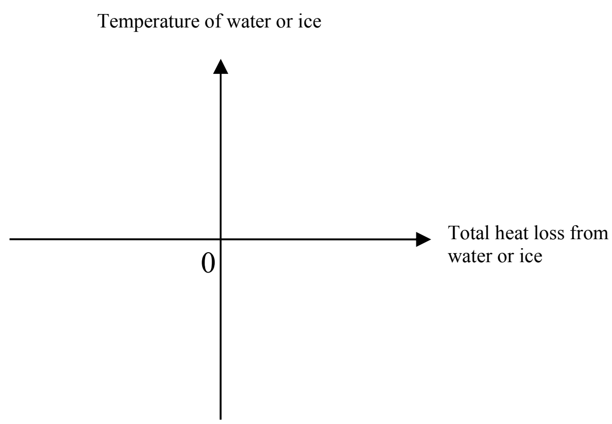
Which of her friends do you most agree with?

(1) Please explain your answer using words.

(2) Please sketch a diagram(s) to help your explanation.[Also show the necessary label(s)]

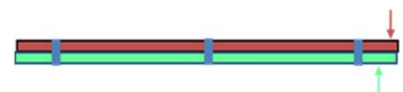
(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

(4) Please complete this coordinate graph which **represents the situation after <u>0℃ water</u> has been put in this freezer**.
[Please label the phase (i.e.: water, ice) on this graph)]



9. A bimetallic strip consists of a brass strip on the top and a steel strip at the bottom. If the bimetallic strip is uniformly heated keeping one end clamped in a horizontal position, how would the free end of the strip behave? The coefficient of linear thermal expansion of steel and brass are 12×10^{-6}/C° and 19×10^{-6}/C° respectively.

a. curve upward
b. curve downward
c. remain horizontal, but get longer
d. not change in length, due to different values of expansion coefficients
e. none of these



(1) Please explain your answer using words.

(2) Please sketch the bimetallic strip after it is uniformly heated.[Also show the necessary label(s)]

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

10. In constructing an expansion-type thermometer it is necessary to use a material which

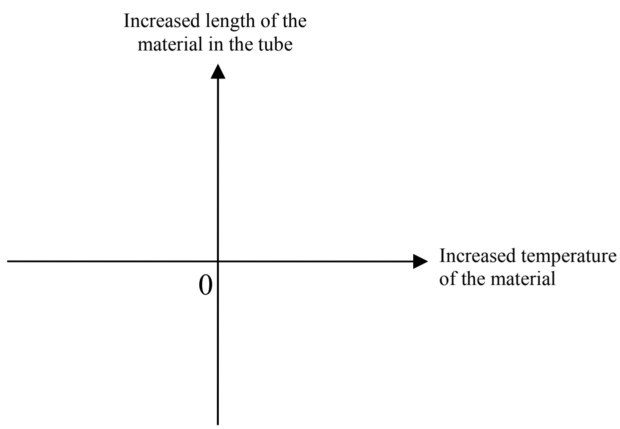
a. changes phase when heated.
b. has a coefficient of thermal expansion which increases with increasing temperature.
c. has a coefficient of thermal expansion which decreases with increasing temperature.
d. will expand linearly with increasing temperature.

(1) Please explain your answer using words.

(2) Please sketch on the thermometer shown below to help your explanation.[Also show the necessary label(s)]

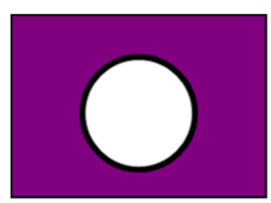
(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

(4) Please complete this coordinate graph.



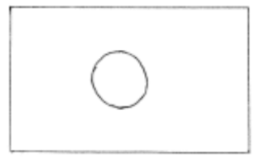
11. A square metal plate has a 2 cm diameter hole at the centre of the plate. If the plate is uniformly heated, what will happen to the size of the hole in the plate?

a. it will increase
b. it will decrease
c. it will remain the same
d. none of the above is correct



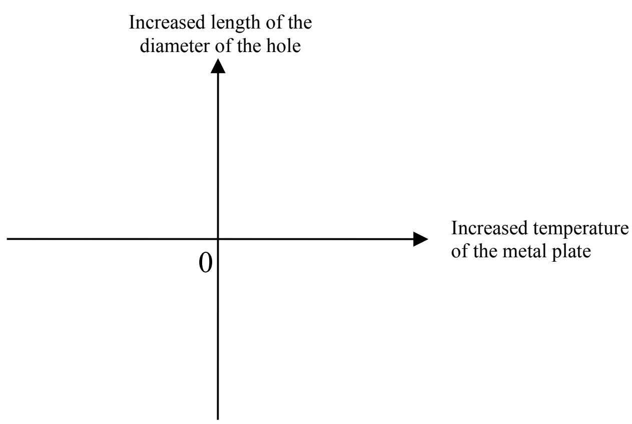
(1) Please explain your answer using words.

(2) On the diagram below, please use dotted lines to sketch the metal plate (including the hole) after it is uniformly heated.[Also show the necessary label(s)]



(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

(4) Please complete this coordinate graph.

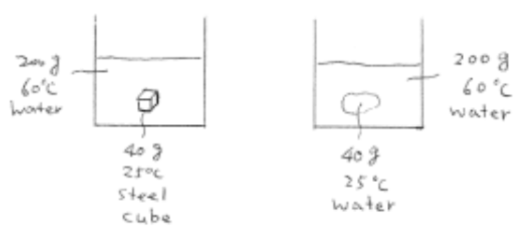


12. Two well insulated beakers each contain 200 g of water at 60°C. If a 40 g cube of steel is dropped into the first, and 40 g of water is added to the second which beaker will have the highest final temperature? Assume that the added cube and the added water are initially at room temperature of 25°C, and there is no heat loss from the beakers. (Specific Heat of Steel: 0.11 kcal/kg•°C; Specific Heat of Liquid Water: 1.00 kcal/kg•°C)

a. the first
b. the second
c. they have the same temperature

(1) Please explain your answer using words.

(2) Please sketch on the diagrams below to help your explanation.[Also show the necessary label(s)]



(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

Time spent to complete this questionnaire: ____________________________

Appendix 3.10

Pre and post-test of multiple representations questionnaire on optics in Research Phase Three

Hello,

My name is Yen-RueyKuo. I am a PhD student at SMEC (Science and Mathematics Education Centre) at Curtin University. I am currently doing research relating students' use of multiple representations and conceptual understanding. The research needs your help to complete this questionnaire. All your personal information will be kept confidential.

If you have any further inquiries, please feel free to contact me viayen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Optics
Questionnaire

Part 1.

7. Student ID number: _______________

8. Name: ____________________

9. Major: _____________________________________

10. Gender: ☐Male ☐Female

11. I am studying ☐Physics 113 ☐Physics 114 ☐Physics 115

12. To which year have you previously studied Physics at school?

☐Year 10 ☐Year 11 ☐Year 12

13. How long ago was your last Physics study undertaken at school?

____

14. How often did you go to lectures in this Module?

☐rarely ☐sometimes ☐(nearly)always

15. How often did you go to tutorials in this Module?

☐rarely ☐sometimes ☐(nearly)always

Part 2.

- **To help you understand how to respond to each question in this part, please refer to the following example.**

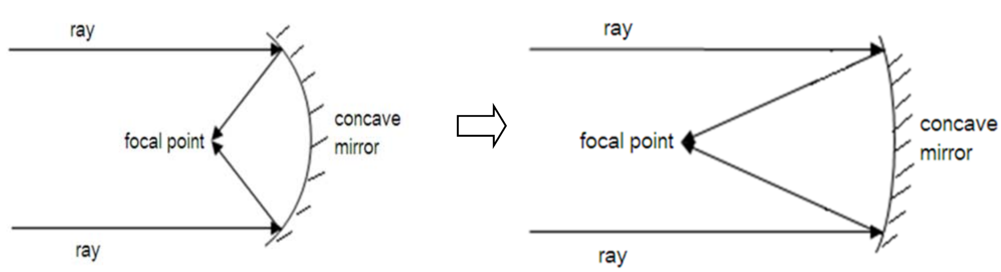
Example

If the radius of curvature of a concave mirror increases, will the focal length of the concave mirror increase, decrease of remain the same?

(1) **Please explain your answer using words.**

The focal length of the concave mirror will increase. The radius of curvature of the mirror increases, which means the surface of the mirror is not as curved as before. Therefore the parallel rays of light will be reflected to a new focal point which is further from the mirror than previous one, namely the focal length will increase.

(2) **Please sketch a diagram(s) to help your explanation. [Also show the necessary label(s)]**



(3) **Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?**

f=r/2

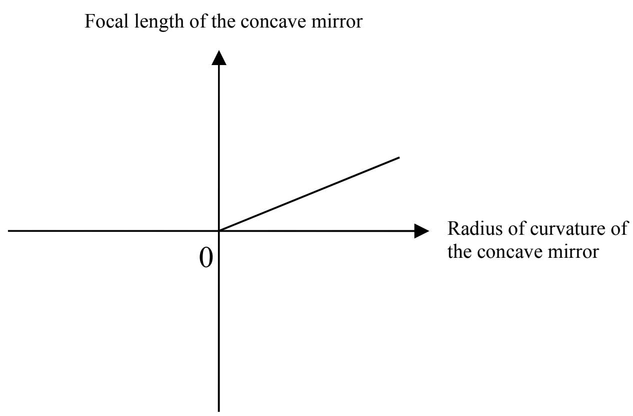
f: focal length of the concave mirror

r: radius of curvature of the concave mirror

In this case, r(after)>r(before),

so f(after)>f(before)

(4) **Please complete this coordinate graph.**

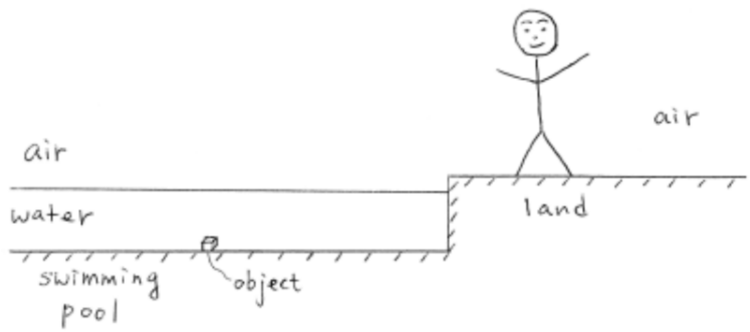


Questions

1. Why does an object resting on the bottom of a full-water swimming pool appear raised above the bottom of the swimming pool?

(1) Please explain your answer using words.

(2) Please sketch on the diagram below to help your explanation. [Also show the necessary label(s)].

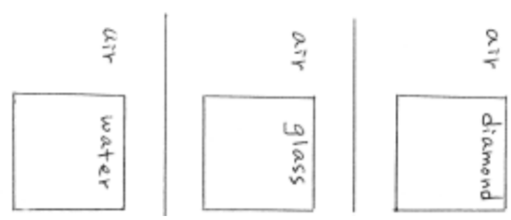


(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

2. Does light travel in water, glass and diamond with the same speed as in air? If not in which of the above four materials will the light travel fastest?

(1) Please explain your answer using words.

(2) Please sketch the light in air and medium using the form of waves. [Also show the necessary label(s)].

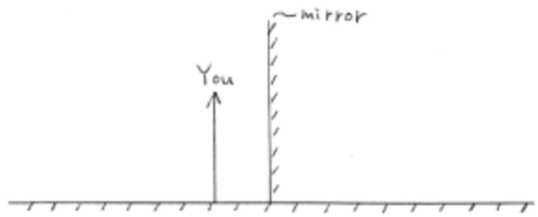


3. Assume you are a 2.0 m tall person standing at a distance of 1.0 m in front of a large plane mirror.

3-1. Will your image be smaller, larger or the same size?

(1) Please describe your answer using words.

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].

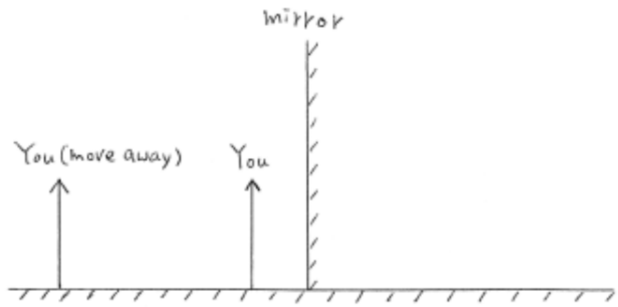


(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

3-2. Will the height of your image change when you move away from the mirror?

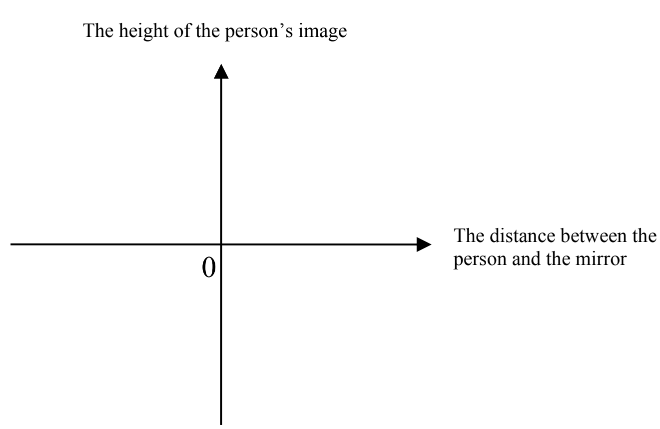
(1) Please describe your answer using words.

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

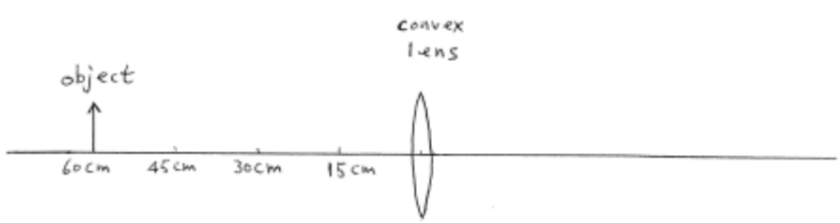
(4) Please complete this coordinate graph **representing the situation when a 2.0 m-high person walks away from the point which is 1.0 m away from the <u>plane mirror</u>.**



4. An object is placed on the left hand side of a convex lens whose focal length is 15.0 cm. The distance of the object is 60.0 cm from the convex lens. A screen is placed on the right hand side of the convex lens. Describe how the size and location of the image on the screen would change as the object moves towards the lens.

(1) Please describe your answer using words.

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

5. On a sunny day, how can wearing Polaroid sunglasses protect you from glare when you are riding a motorcycle on a road?

(1) Please explain your answer using words.

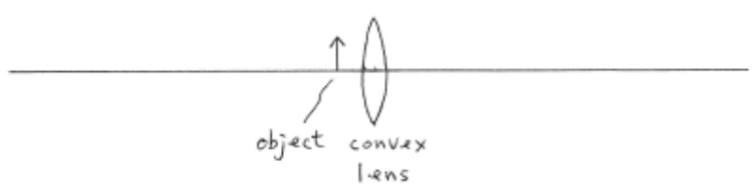
(2) Please sketch on the diagram below to help your explanation.[Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

6. A magnifying glass (<u>convex lens</u>) is rated at 3.0 x. This means it will magnify the image of an object 3.0 times. If this magnifying glass is used under water, what will happen to its magnification? Will it remain the same, increase or decrease?

(1) Please explain your answer using words.

(2) Please sketch on the diagram below to help your explanation.[Also show the necessary label(s)].



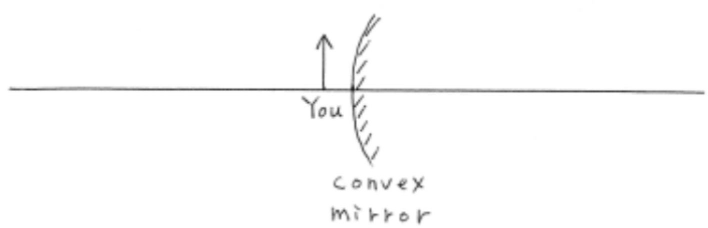
(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

7. Assume you are 2.0 m tall person standing at a distance of 1.0 m in front of a large <u>convex mirror.</u>

7-1. Will your image be smaller, larger or the same size?

(1) Please describe your answer using words.

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].

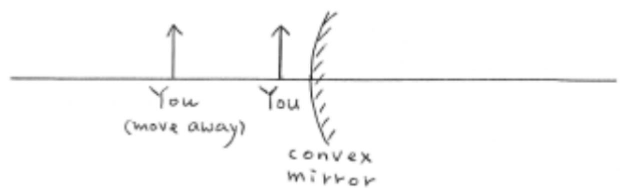


(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

7-2. Will the height of your image change when you move away from the convex mirror?

(1) Please describe your answer using words.

(2) Please sketch on the diagram below to help explain your answer.[Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help explain your answer? How can this (these) formula(s) help your explanation?

8. Light waves and radio waves are different forms of electromagnetic waves.

What is the same about these two waves? What is different about these two waves?

(1) Please describe your answer using words.

(2) Please sketch the shape of these two waves. [Also show the necessary label(s)].

9. Many old people who do not wear glasses cannot read a book on their hand. However if they put the book further away from their eyes, they can read the book. Why?

(1) Please explain your answer using words.

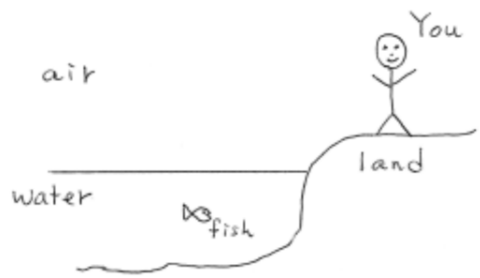
(2) Please sketch a diagram(s) to help your explanation.[Also show the necessary label(s)].

(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

10. If you were spearing a fish, would you aim above, below or directly at the observed fish to make a direct hit? If instead you zapped the fish with a laser beam, would you aim above, below or directly at the observed fish?

(1) Please explain your answer using words.

(2) Please sketch on the diagram below to help your explanation.[Also show the necessary label(s)].



(3) Is(Are) there any formula(s) which can help your explanation? How can this (these) formula(s) help your explanation?

Time spent to complete this questionnaire: ______________________________

Appendix 3.11

Revisions in the tested questions of thermal and optics multiple representations questionnaires in Research Phase Three compared to Research Phase Two

- Revisions in the Thermal Module
  - Question 3

    In this question, the statement "After doing that for a while, can she open the metal lid? Please explain your answer" in second version questionnaire was changed to "After doing that for a while (the temperature of the lid and jar becomes different), she opens the lid successfully. Why?" in third version questionnaire. The cause to do this was the former statement was ambiguous. "After doing that for a while" does result two different situations, one is the temperature of the lid will be higher than that of the jar, and the other is if the time that the lid and jar under hot water is long enough, the lid and the jar will reach the same temperature. Although it was good for students to think about those two different situations, for marking purpose we just asked students the first situation in third version questionnaire.

  - Question 5

    In version three questionnaire, we added the condition "The toast and the soup loses the same amount of heat per unit time" so that the students could specifically discuss the relationship between temperature and specific heat of the toast and soup, which was also convenient for marking.

- Question 12

  The specific heat of each substance (ie. Liquid water, steel) was given in version three questionnaire for students' reference.

- Revises in the Optics Module
  - Questionnaire A, question 1 in Phase two (corresponding to question 1 in Phase three)

    In Phase two the question was "Why does a person standing in waist-deep water in a swimming pool appear to have shorter legs?", however, it was changed to "Why does an object resting on the bottom of a full-water swimming pool appear raised above the bottom of the swimming pool?" in Phase three. The reason of the change was it was easier for students to draw the "object" than draw "legs" to show the phenomenon of light refraction in the diagram part of the question. Despite the change, they both asked students the same concept.

  - Questionnaire A, question 2 in Phase two (corresponding to question 2 in Phase three)

    The sentence "If not in which of the above materials will the light travel fastest?" was added the word "four" and became "If not in which of the above four materials will the light travel fastest?". Doing this made this question more clear (compare the four materials), and easier for marking.

- Questionnaire A, question 3 in Phase two (corresponding to question 3 in Phase three)

  The words description part was put the sentence “Please explain your answer using words”. However in this type of question, nothing really had to be explained but something needed to be described. Therefore we changed the sentence to “Please describe your answer using words”, which suited the question situation more properly. Besides, one thing needed to be mentioned here is that not only this question but all questions which have the same feature were revised in the same way.

- Questionnaire B, question 2-2 in Phase two (corresponding to question 7-2 in Phase three)

  The word “convex” was put in the sentence “Will the height of your image change when you move away from the mirror?” before the word “mirror” in order to remind students that we were asking the concept about convex mirror, not plane mirror. (usually mirror means plane mirror in everyday life)

- Questionnaire B, question 4 in Phase two (corresponding to question 9 in Phase three)

  In Phase two, the question was “Why do older people who do not wear glasses read books farther away from their eyes than do younger people?”, but we revised it to “Many old people who do not wear glasses cannot read a book on their hand. However if they put the book further away from their eyes, they can read the book. Why?”. The reason for the revise was the previous question made students confused which answer, “the difference between young people’s lens and old people’s lens” or “for old people because the distance of the object (the book) has become longer, the image can form on the retina properly”, should be responded with. In fact we were testing the concept of the latter one, so the revision could make the question clearer about what we were really going to ask.

Appendix 3.12

Physics Motivation Survey in Research Phase Three

Physics Units Survey

This questionnaire is part of a study into physics subjects taken by students who are not majoring in physics. We would like you to respond to the statements below and ask you to put your student ID number, name and major on the survey. All your personal information will be kept confidential. If you have any further inquiry, please feel free to contact us via

yen-ruey.kuo@postgrad.curtin.edu.au

Thanks for your participation.

Yen-RueyKuo(PhD student at Science and Math Education Centre at Curtin University of Technology)

---

1. **Student ID number: _______________**
2. **Name: ____________________**
3. **Major: _____________________________________**
4. **Gender: ☐Male ☐Female**
5. **I am studying ☐Physics 113 ☐Physics 114 ☐Physics 115**
6. **To which year have you previously studied Physics at school?**

   ☐Year 10 ☐Year 11 ☐Year 12

In order to better understand what you think and feel about your university physics courses, please respond by filling in the circle before the most appropriate option to each of the following statements from the perspective of:

"**When I am in the university physics course…**"

01. I enjoy learning physics.

○Never ○Rarely○Sometimes○Usually ○Always

02. The physics I learn relates to my personal goals.

○Never ○Rarely○Sometimes○Usually ○Always

03. I like to do better than the other students on the physics tests.

○Never ○Rarely○Sometimes○Usually ○Always

04. I am nervous about how I will do on the physics tests.

○Never ○Rarely○Sometimes○Usually ○Always

05. If I am having trouble learning physics, I try to figure out why.

○Never ○Rarely○Sometimes○Usually ○Always

06. I become anxious when it is time to take a physics test.

○Never ○Rarely○Sometimes○Usually ○Always

07. Earning a good physics grade is important to me.

○Never ○Rarely○Sometimes○Usually ○Always

08. I put enough effort into learning physics.

○Never ○Rarely○Sometimes○Usually ○Always

09. I use strategies that ensure I learn physics well.

○Never ○Rarely○Sometimes○Usually ○Always

10. I think about how learning physics can help me get a good job.

○Never ○Rarely○Sometimes○Usually ○Always

11. I think about how the physics I learn will be helpful to me.

○Never ○Rarely○Sometimes○Usually ○Always

12. I expect to do as well as or better than other students in the physics course.

○Never ○Rarely ○Sometimes ○Usually ○Always

13. I worry about failing the physics tests.

○Never ○Rarely ○Sometimes ○Usually ○Always

14. I am concerned that the other students are better in physics.

○Never ○Rarely ○Sometimes ○Usually ○Always

15. I think about how my physics grade will affect my grades this year.

○Never ○Rarely ○Sometimes ○Usually ○Always

16. The physics I learn is more important to me than the grade I receive.

○Never ○Rarely ○Sometimes ○Usually ○Always

17. I think about how learning physics can help my career.

○Never ○Rarely ○Sometimes ○Usually ○Always

18. I hate taking physics tests.

○Never ○Rarely ○Sometimes ○Usually ○Always

19. I think about how I will use the physics I learn.

○Never ○Rarely ○Sometimes ○Usually ○Always

20. It is my fault, if I do not understand the physics.

○Never ○Rarely ○Sometimes ○Usually ○Always

21. I am confident I will do well on the physics labs and projects.

○Never ○Rarely ○Sometimes ○Usually ○Always

22. I find learning physics interesting.

○Never ○Rarely ○Sometimes ○Usually ○Always

23. The physics I learn is relevant to my life.

○Never ○Rarely ○Sometimes ○Usually ○Always

24. I believe I can master the knowledge and skills in the physics course.

○Never ○Rarely ○Sometimes ○Usually ○Always

25. The physics I learn has practical value for me.

○Never ○Rarely○Sometimes○Usually ○Always

26. I prepare well for the physics tests and labs.

○Never ○Rarely○Sometimes○Usually ○Always

27. I like physics that challenges me.

○Never ○Rarely○Sometimes○Usually ○Always

28. I am confident I will do well on the physics tests.

○Never ○Rarely○Sometimes○Usually ○Always

29. I believe I can earn a Distinction grade in the physics course.

○Never ○Rarely○Sometimes○Usually ○Always

30. Understanding physics gives me a sense of accomplishment.

○Never ○Rarely○Sometimes○Usually ○Always

The End - Thank you!

Appendix 3.13

Expectation Survey in Research Phase Three

7782122021 Your Name: ____________
Student ID Number: ____________
Unit Studying: Physics 113/114/115

carrick INSTITUTE

QUESTIONNAIRE A

I am majoring in: ____________________

Gender: Male / Female

Please mark each of the statements below to indicate to what extent you agree with the statement.

Shade Circles Like This--> ●
Not Like This--> ⊗ ✓

	N/A	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. It is apparent to me that this subject is a valuable part of my degree.	○	○	○	○	○	○
2. Only people with an extraordinary ability are capable of understanding physics.	○	○	○	○	○	○
3. I am keen to see how this subject links to my major area of study.	○	○	○	○	○	○
4. I believe an understanding of physics will benefit my studies in other areas of my degree.	○	○	○	○	○	○
5. I am confident that my mathematics background is sufficient for me to be successful in this subject.	○	○	○	○	○	○
6. I expect to do well in class tests in this subject.	○	○	○	○	○	○
7. I am looking forward to doing labs in this subject.	○	○	○	○	○	○
8. If it were possible, I would have avoided taking this subject.	○	○	○	○	○	○
9. I expect the links between this subject and my major area of study to be made obvious throughout the semester.	○	○	○	○	○	○
10. I expect to have to work harder in this subject than in my other subjects this semester.	○	○	○	○	○	○

Please answer the following questions

11. What final grade are you aiming for in this subject?

☐ Pass ☐ Credit ☐ Distinction ☐ High Distinction ☐ Don't know yet

12. Did you study Physics to Year 12 at school?

☐ Yes ☐ No (☐ to Year 11 / ☐ to Year 10)

13. Please describe briefly any particular expectations you have as you begin your study in this subject. If you need more space, please write on the other side of this questionnaire.

____

____

____

Thank you for completing this survey.

Appendix 3.14

Experience Survey in Research Phase Three

3973582029

- Your Name: ____________
- Student ID Number: ____________
- Unit Studying: Physics 113/114/115

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QUESTIONNAIRE B

- **I am majoring in:** ______________________
- Gender: Male / Female
- How long ago was your last Physics study undertaken at school? ____________

Please mark each of the statements below to indicate to what extent you agree with the statement.

Shade Circles Like This--> ●
Not Like This--> ⊗ ✓

	N/A	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. It is apparent to me that this subject is a valuable part of my degree.	○	○	○	○	○	○
2. Only people with an extraordinary ability are capable of understanding physics.	○	○	○	○	○	○
3. There are clear links between this subject and my major area of study.	○	○	○	○	○	○
4. I believe an understanding of physics will benefit my studies in other areas of my degree.	○	○	○	○	○	○
5. I am confident that my mathematics background is sufficient for me to be successful in this subject.	○	○	○	○	○	○
6. My achievements in class tests in this subject exceeded my expectations.	○	○	○	○	○	○
7. The labs in this subject were a positive learning experience.	○	○	○	○	○	○
8. I would advise others to avoid taking this subject if at all possible	○	○	○	○	○	○
9. The lecturers succeeded in linking this subject to my major area of study.	○	○	○	○	○	○
10. I worked harder in this subject than for my other subjects this semester.	○	○	○	○	○	○

Please answer the following questions

11. What final grade are you aiming for in this subject?

☐ Pass ☐ Credit ☐ Distinction ☐ High Distinction ☐ Don't know yet

12. Did you study Physics to Year 12 at school?

☐ Yes ☐ No (☐ to Year 11 / ☐ to Year 10)

13. Please describe briefly your experience of this subject, and in particular, what you think might be done to improve the subject. If you need more space, please write on the other side of this questionnaire.

____

____

____

Thank you for completing this survey.

Appendix 3.15

Worksheet for recording teachers' representations

Date: Module: Attendance:

Representation	Oral	Words	Picture	Table	Diagram	Coordinate graph	Formula	Calculation	Animation	3D entity	Total Time of Instruction
Time											

Appendix 3.16

An example of students' interview transcripts

INTERVIEW TRANSCRIPT

Participant (Interviewee): Ken Date: 15 Oct 2009

(I: Interviewer P: Participant)

I: I have questions for you. First question is: How much physics has been studied before this class?

P: Sure. I studied physics up to Year 12 but since leaving high school haven't done any studies or involved in any work that needed physics so I haven't actually studied it for around 16 years. So this semester was the first time for quite some time.

I: Okay. And how did you find this physics course; was it either difficult or about right or too hard?

P: I thought it was about right. Because it's separated into modules I found that each of the modules has had sections that have been fairly easy, each of them has had modules, or parts, that have been quite hard. Most of it though, as long as you have done the pre-reading, attended the lectures and looked at the practice questions, by doing all of that most of them have been achievable.

I: Okay. How have you found these kinds of questions? Were they helpful to you, or it's not helpful?

P: Oh, definitely. What I liked about them was the fact that they were closer to real world situations. I know in our course, certainly the lecturer puts in some questions that we might come across in the real world but he also, I guess, has to test concepts that we don't really have any experience of actually doing or even visualizing perhaps. So just randomly I opened to this particular page, I mean, this one on thermal physics, you've got a

person sitting on a chair, we have all had this experience of sitting on a wooden chair or sitting on a metal chair. Even as a child you do that and you learn quite quickly that you don't want to sit on a metal chair in winter. So, I guess, the other thing was the fact that we were asked to explain in a number of different methodologies. What was helpful about that was that it forced me to think about how to explain it because sometimes you can get into the habit of, when you're asked a question, you're first thought might be, "Well, how would I calculate that?" So it might be, "Where are the numbers? How do I plug this into a formula?" And so on. Whereas here, we're asked to explain it in words as you would to someone that perhaps doesn't understand the physics concept; then the diagram, which sometimes as they say a picture can be worth a thousand words; and then asked for the formula. Out of all of the questions I probably did find often the pictures were the most difficult, just for me. I guess not being very artistic and not having dealt a lot with physics diagrams, but that's not to say that it wasn't helpful to try and think about what picture would be helpful. I think there were a couple unfortunately where I didn't really know how to draw a diagram. One that springs to mind is the polariser but, for me, kind of reinforced that is one part of the optics topic that I have a basic understanding of, I know, even in the practice questions that we were doing are assessed questions in the lab, I sometimes had problems with. And I studied those specifically.

I: Okay. So what was it like completing the questionnaire after lectures, labs and tutorials?

P: It was really eye opening having done the pre-teaching questionnaire and then the same questions afterwards. Certainly doing the pre-questions it was amazing, particularly with the optics, I really didn't know any of the questions. With the thermal I knew a little, like I say, for example sitting on the chair. We've done that so you could describe it in words but then not be able to answer by the picture or by the formula. But then coming back to them, just after having done the lectures and the tutorials and the practice questions, much easier to answer. There were still one or two, like I say, that for example I couldn't maybe do a picture but I knew straight away that I didn't know… if that makes sense. Sometimes that

can be the most important thing, is you learn the information but you also know the limits of the information that you have.

I: Okay. So when you were doing this, did you look things up in your notes or books or discuss with other people?

P: I didn't discuss with anyone else and with the questions. I don't think I referred to the notes in the sections where I was explaining using words or drawing a diagram, or even the ones drawing a graph. But I certainly did refer back to my notes for the equations, particularly with some equations there might be more than one version of it or in a couple of the answers I've perhaps quoted specific data, like the specific heat of a particular metal I would certainly have to look that up. But for the basic explanation, no, it was enough to have gone through the concepts, I think, in the lectures.

I: Did you know what was meant to be done for each question on this questionnaire?

P: I think so, yes. The good thing about it was the fact that you did have the example right at the front of how you could actually fill it out. The only difficultly was sometimes in fitting my explanation to the questionnaire but that's more about, particularly when you've got a new concept, if you've learnt it a particular way sometimes it takes a bit of time to actually think how to phrase it, to answer a particular question. But, no, I think definitely the examples at the front were the most important part.

I: So, did you encounter any difficulty when you tried to use each representation?

P: Yes. For myself the diagrams were difficult. As I say, part of that's I'm not a very pictorial person anyway, and sometimes again some components, particularly in the optics section, you might learn the theory and you can tell that the theory should relate, just based on the information, but sometimes how it would actually present itself in the real world was a bit difficult. So, for example, again that polariser one, I understand the concept and how the sunglasses work and I understand that there would be light coming a particular way and it would be blocked

by the polarises being a certain way, but how that actually manifests itself, I couldn't actually represent that graphically. I knew which equations we would use and even the basic understanding of how to explain it in words but just couldn't, because of my lack of understanding, I guess, as to what we would actually see in the real world. I couldn't actually answer that with a picture.

I: So did this questionnaire help you with your thinking about physics topics?

P: Definitely. Particularly with the timing of it because we would take the post-teaching questionnaire just after we had finished the teaching, that was also the time at which we would be preparing for a class assessment test as well. So I guess I used it as part of my revision process as well, because we have practice questions that the lecturer has given us that we've gone through but then taking your questions meant that we had to think, again, about this kind of real world application and certainly in the questions the lecturer would focus, obviously, on the same topics or aspects of the topic but he would also phrase some of them in a real world type situation. So it was certainly advantageous to have it done in that order. And it's also a case of it's good sometimes to have questions asked by someone else. What I mean by that is if you have a lecturer you get used to the questions and sometimes it might be that you might be able to glean something from how the question's asked or the answer should be, but then someone else's style, being slightly different, it just does make you think about it in a different way or perhaps think about how you can present the answer a different way.

I: Okay. So did those different representations help you, enable you to think deeper about a concept?

P: Yes, absolutely. Particularly for pretty much most of the questions in the thermal section, it was usually easy to look at the equations that we had actually used and find which one would, I believe, be most relevant to the situation. But then because we had to explain it using words, it forced me to look at what the equation was saying and then how you would explain that to someone that didn't… it didn't even matter if they didn't know the equation, but if they didn't know what the concept was with the equation,

so for example the one about the piece of toast can be eaten a few seconds after coming from the toaster but you have to wait before eating soup. Again, it's like the chair, something that everyone's done and usually as a child you learn that and your mum might tell you that you've got to leave your soup to cool. To be able to explain to someone why that occurs, although it's a fairly easy concept within thermal physics, to think about how to phrase it so that you're not using jargon can be difficult and it's not something that I remember doing previously in my physics studies. It was very much a case in high school of… you would maybe, even if you were given a question similar to this, you were just looking for one line that said what the concept was and perhaps what the equation was, rather than actually explaining what was going on to someone that didn't know what the answer was.

I: So how can using those different representations help you develop better understanding of a concept?

P: I guess because being able to answer the questions using the different representations does rely on understanding different aspects of what's going on. So if we look at this example where we're putting the ice and water into the freezer and looking at which one would eventually lose the greatest amount of heat, you've got initially what actually relates to. So for me, generally, the first thing I would look at is the formula because I'd be looking at what information we're given. We're given water, ice, it's been cooled down and we're being asked about energy. So that requires information about what parts of the question are going to be relevant. So that gives the suggestion of what the formula does but then just because you could perhaps plug values into the formula, you then have to think about, well, what does the result of that formula actually mean and that's where you can try and give the answer or explain your answer using words. Unfortunately with this example I didn't actually know what type of diagram would be helpful but you still think about what types of things you actually see in other diagrams and what types of things are trying to be shown. So just across the page, the biometalic strip, perfect example of where a diagram actually you can put down your understanding and make sure that both the diagram and the explanation make sense in terms of what the formula is, which is all, again, based on the information that you're given in the question. And then back on the one with water,

putting in terms of a graph, graphs are very handy for checking your understanding of what's happening when something changes, so in this case, looking at the cooling of water and ice you get an idea of what actually happens over time. So even though, looking at the question, you have an understanding of where you start and where you finish, in physics, like in many other disciplines, it's actually how things actually change. So that also reminds me of what happens with latent heat, for example, I can't remember if we had a question on that, but certainly one of the concepts with latent heat is that you can have an increase in temperature and then a stop while it's, for example, melting and then it increases again and then you have a stop while it's vaporising. You can understand that, I guess, on a basic level, but actually being able to put it in a graph representation you can actually prove what you would be seeing in the lab when you were measuring the temperature.

I: So you think those representations really can help you develop a better understanding?

P: Definitely. And can point out areas where you may not have the depth of understanding that you would like. So certainly with some of your questions as well as the practice questions from the lecturer, it's shown me some areas where, even though you might be able to answer a test question, that you need to develop some further conceptual understanding. So with some of them I have actually done some external reading as well, but I guess isn't directly related to any of the assessments or to the questionnaire but more for my own piece of mind and understanding and because I'm hoping to, the course that I'm doing, I'm hoping to move into engineering. Obviously this class in physics isn't the end of the road, there's a lot more physics to come. So any additional understanding that I can get means that when we develop the concepts further, if I have an understanding of different representations of different aspects of the problem, it means that when you come to learn more about them hopefully it makes it easier.

I: So can you see the relations between those different representations; like between graph and diagram, or between diagram and words, or between formulas and graphs?

P: **Definitely. You can see that obviously they're about the same concept when you answer a particular question. I guess the explanation using words is a summary, if you like, of what's actually occurring. The diagram is often a representation of what you would actually see. So, like this one that we're on at the moment with the tape measure expanding, this gives you an idea of, you've got your explanation as to what's happening but then you've got an idea of what you would actually see if you were in that particular situation. What the formula does is it allows you to actually quantify what's happening. So, even though in this case you probably wouldn't note that much difference with the tape measure, it does show that, given the same situation but different circumstances, how, for example it makes me suddenly think of, I don't know, railway tracks. So that you can imagine looking at the formula, based on the same situation you can see that if you had a much larger initial length that you would get a much larger increase. And with the graphs, as I mentioned briefly before, the way that they relate is they take the situation, they take the information from the formula and even, to an extent, what you would actually see but, as I say, it gives you an idea of what happens over a period for example. So if you change a particular circumstance, if you change an angle, if you change a temperature or, as I say, over a passage of time, I think the graph relates to all three. You see the concept in the graph. The graph gives you an idea of what you would actually see in the diagram at different times. And certainly based on the formula, gives you an idea or represents what type of formula it is. So if it's a linear function you expect that you would actually see a linear relationship.**

I: **Some students took a lot of time to complete those questionnaires? And how long did they take you?**

P: **Oh, I must admit, I did write them down. With the before questionnaires it looks like about an hour. And with the afters it was about an hour and a half. I guess the main difference was, with the explanation using words, if I didn't know it was quite quick because I just wrote on the paper that I didn't know. With the after questionnaire it probably didn't take much more time to actually write the explanation in words because I tended to only use a couple of sentences because it was the crux of the problem that I was trying to explain. The diagrams also were fairly quick. If you knew**

how to represent it in a diagram it was generally a small change or just showing how things would be added together or whatever it would happen to be. But probably what took the longest was to find the relevant formula, but then to actually explain or try and explain how the formula would help your understanding. So sometimes in, I guess, science education you can get into the habit of just looking at a question and thinking about how you would answer a test and what you would plug the figures into, but then stopping myself and thinking about how what I was putting in the formula actually related to the explanation that I would give to someone, was probably what took longer. So that's why certainly with the post questions it was almost double the time of the pre-teaching.

I: So do you think it's a fair use of your time?

P: Oh, definitely. Definitely. It's almost, as I say, like having another collection of practice questions with a different way of asking them and a different way of representing it. Unfortunately I don't think it's the sort of thing that you could do for each of the modules and, I guess, to the same extent that we are given the normal practice questions, if you like, because the lecturer often will give us, say, 30 or 40 test questions. I could see that if you wanted to get these sort of questions, if you had 30 or 40 of these questions for each of the six modules, it would overload everyone. But, particularly for me, nothing against the thermal, but particularly the optics was a topic that I had a much poorer understanding before the teaching. So the fact that it gave me a way of trying to explain the concepts that I didn't know beforehand was certainly very helpful.

I: So was it a fair amount of effort for the mark…10%?

P: Oh, I think so, particularly compared to laboratory reports where, as well as attending the laboratory session, preparing one of those reports can be five to 10 hours and each of the reports is worth about 4% each. So it definitely was. So all up I would have spent the same amount of time on all four questionnaires as I would on one report, so definitely.

I: So, last question: Did you get any insight into your own learning by answering the questionnaire with different representations?

P: **Absolutely. Particularly in terms of the diagrams, it reinforced for me the fact that my visual learning is not as strong perhaps as my verbal learning. So I'm much more comfortable, well, and in fact even within verbal, I'm much more comfortable with the mathematical side than that. So certainly dealing with the equations is my strongest point, then perhaps the verbal side, and then the least of that was the pictorial side. But again, with optics because it is dealing with light and dealing with vision it's one that certainly is better, or it gives you a more rounded understanding if you can actually draw the diagrams. And certainly with many of them you actually can't understand unless you draw the diagram, particularly the mirrors and the lenses. That's one section that, regardless of, even if I think from the question that I know exactly what the answer's going to be as to where an image should appear, I always do draw the diagram because it allows you very quickly to make sure, to give yourself a check. If you know the way that the light rays should actually reflect, for example, or pass through the lens, if you do something wrong in your calculation and the image is appearing somewhere that it shouldn't, it gives you a great way of checking if you have done something wrong.**

I: **Okay. Thank you very much.**

P: **You're most welcome.**

[INTERVIEW CONCLUDED]

Appendix 4.1

The five students' responses to the multiple representational questionnaire on the topic of simple harmonic motion

Student S1:

Waves & Sound

Questionnaire no.1

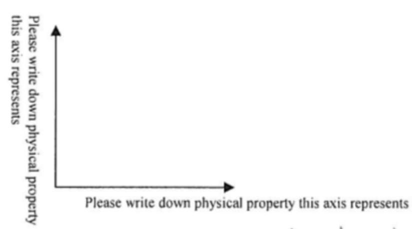
Sarah.

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

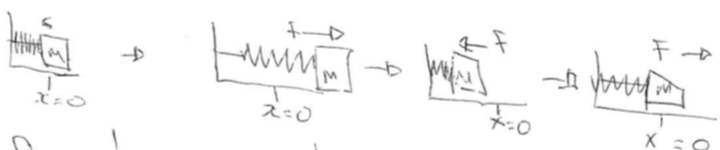
A.

1. Describe SHM (Simple Harmonic Motion).
2. Draw any picture(s) to express SHM.
3. Write down any formulas describing SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)
4. Draw any coordinate graph(s) to express SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)



① Simple Harmonic Motion is a object vibrating along a surface with no friction that oscillates

②



③ $f = \frac{1}{T}$, $v = \frac{d}{t}$, $E = PE + KE$ ⇒ when no friction

$\omega = \sqrt{\frac{k}{m}}$

④

Waves & Sound

Questionnaire no.2

Sarah

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.

Here are some formulas which describe an object doing SHM (Simple Harmonic Motion).

$F=-kx$

$x=A\cos(\omega t)$

$v=-v_{max}\sin(\omega t)$

$a=-kA\cos(\omega t)/m$

$E=KE+PE=mv^2/2+kx^2/2$

F: restoring force
k: positive constant
x: displacement of the object from equilibrium position
A: Amplitude

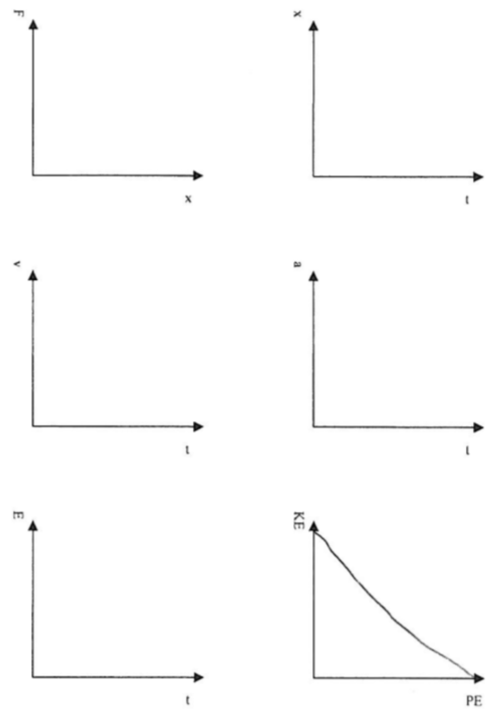
ω: angular velocity

t: time
v: velocity of the object
a: acceleration of the object
m: mass of the object
E: total energy of the object

KE: kinetic energy of the object

PE: potential energy of the object

1. Complete the following coordinate graphs.



2. Assume k=20N/m, A=10cm, $\omega=\pi/2\ sec^{-1}$, v_{max}=0.3m/s, m=250g. Find F, x, v, a, E when t=1/3 sec.
3. when x=2cm, what is KE?

Student S2:

Waves & Sound

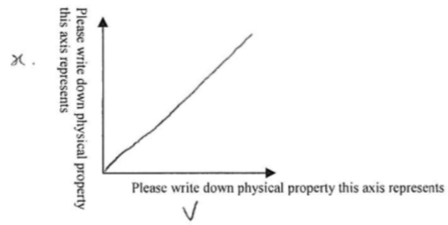
Questionnaire no.1

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

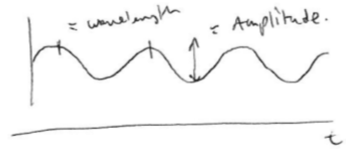
A.

1. Describe SHM (Simple Harmonic Motion).
2. Draw any picture(s) to express SHM.
3. Write down any formulas describing SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)
4. Draw any coordinate graph(s) to express SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)



1) A simple Harmonic Motion is a motion which moves in a wave formation bouncing up and down. The motion is defined by its frequency, ~~the height~~ the number of wavelength in a period and by the amplitude, the height of these wavelengths.

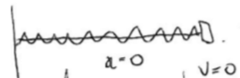
2)



3) $f = \frac{1}{T}$. ~~the term~~ $\lambda = 2L$ $T = 2\pi\sqrt{\frac{L}{g}}$

$K = Fx$. $x = A\cos(\omega t)$. $v = \lambda \times f$. $T = 2\pi\sqrt{\frac{m}{k}}$

4)



— (Spring.)

	a=0	V=0.
V=0.	V=max.	a=max
a=max.	KE=max.	PE=max.
PE=max		

Waves & Sound

Questionnaire no.2

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.

Here are some formulas which describe an object doing SHM (Simple Harmonic Motion).

$F=-kx$

$x=A\cos(\omega t)$

$v=-v_{max}\sin(\omega t)$

$a=-kA\cos(\omega t)/m$

$E=KE+PE=mv^2/2+kx^2/2$

F: restoring force
k: positive constant
x: displacement of the object from equilibrium position
A: Amplitude

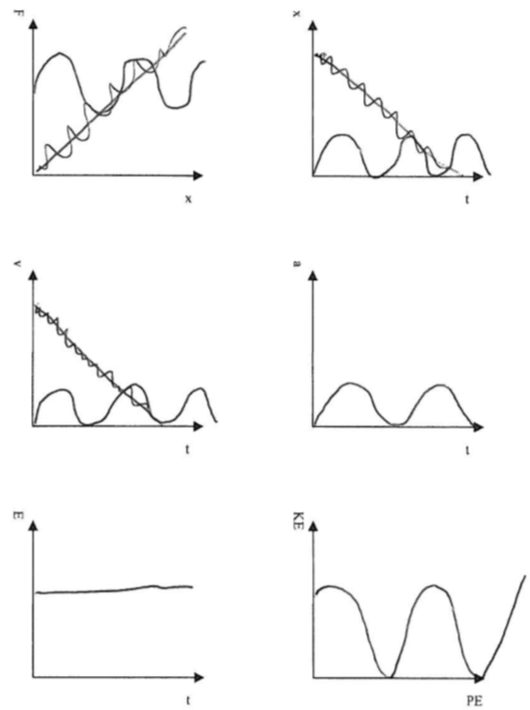
ω: angular velocity

t: time
v: velocity of the object
a: acceleration of the object
m: mass of the object
E: total energy of the object

KE: kinetic energy of the object

PE: potential energy of the object

1. Complete the following coordinate graphs.



2. Assume k=20N/m, A=10cm, $\omega=\pi/2 \text{ sec}^{-1}$, v_{max}=0.3m/s, m=250g. Find F, x, v, a, E when t=1/3 sec.
3. when x=2cm, what is KE?

$x = 10$

$a = -1.99.$

2) $F = -kx.$ $\quad x = A\cos(\omega t)$

$x = 10 \times \cos(\pi/2 \times \frac{1}{3})$

$= 9.99 \sim 10.$

$F = -(20)(10) = -200 \text{ J}$

$v = (-0.3)\sin(\pi/2 \times \frac{1}{3}) = -0.0027$

$a = \frac{-(20)(10)\cos(\pi/2 \times \frac{1}{3})}{0.250}$

$=$

3) $KE = mv^2$

$= 0.25 \times (0.0027)$

$= 0.000675 \text{ J}.$

Student S3:

Schmitty

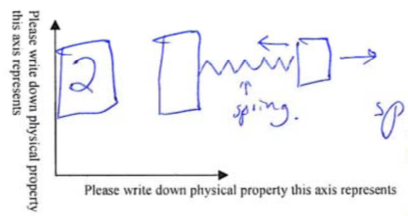
Waves & Sound

Questionnaire no.1

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.
1. Describe SHM (Simple Harmonic Motion).
2. Draw any picture(s) to express SHM.
3. Write down any formulas describing SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)
4. Draw any coordinate graph(s) to express SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)



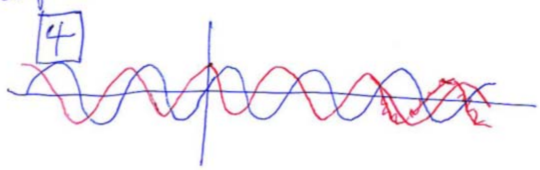
springs back & forth.

1. SHM is an object that goes either back & forth, left and right, or up and down for a certain distance, constantly. On a graph It's just a sin or a cos wave.

3. $s = a\sin(bt)$
s=displacement
velocity $= ba.\cos(bt)$
acceleration $= -b^2.a.\sin(bt)$

/ = velocity.
/ = displacement.

4.



Schmitty

Waves & Sound

Questionnaire no.2

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.

Here are some formulas which describe an object doing SHM (Simple Harmonic Motion).

$F=-kx$

$x=A\cos(\omega t)$

$v=-v_{max}\sin(\omega t)$

$a=-kA\cos(\omega t)/m$

$E=KE+PE=mv^2/2+kx^2/2$

F: restoring force
k: positive constant
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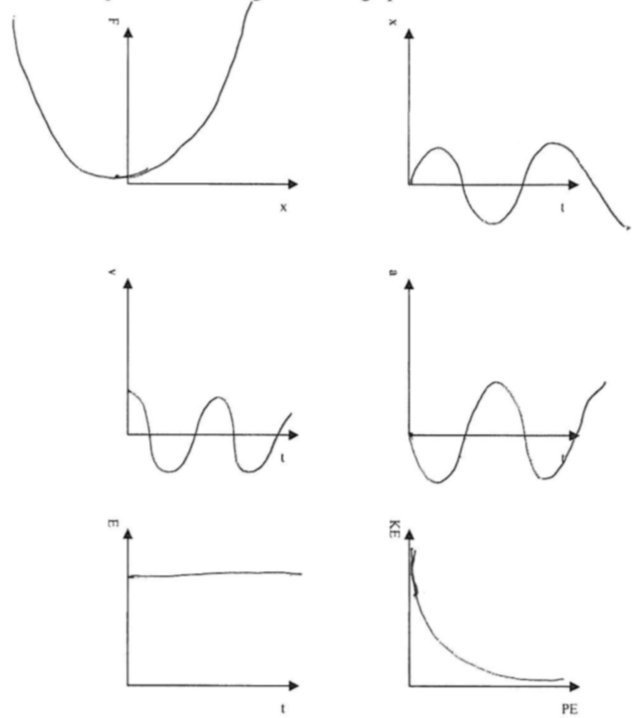
ω: angular velocity

t: time
v: velocity of the object
a: acceleration of the object
m: mass of the object
E: total energy of the object

KE: kinetic energy of the object
PE: potential energy of the object

1. Complete the following coordinate graphs.



2. Assume k=20N/m, A=10cm, $\omega=\pi/2\ sec^{-1}$, v_{max}=0.3m/s, m=250g. Find F, x, v, a, E when t=1/3 sec.
3. when x=2cm, what is KE?

$x = 10\cos\frac{\pi}{2\times 3}$

$= 10\cos\frac{\pi}{6}$

2. $F = -20\times 10\cos\frac{\pi}{6}$

$F = -200\cos\frac{\pi}{6}$

$v = -0.3\sin\frac{\pi}{6}$

$a = -20\times 10\cos\frac{\pi}{6}\times 250$ | $a = -200\cos\frac{\pi}{1500}$

3. $\frac{250\times(-0.3\sin\frac{\pi}{6})^2}{2} + \frac{20\times(10\cos\frac{\pi}{6})^2}{2} = KE+PE$

Student S4:

Waves & Sound

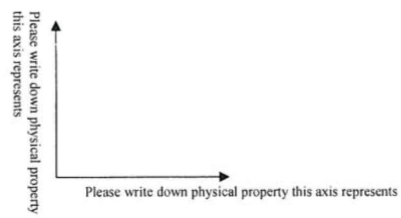
Questionnaire no.1

Instructions:

1. **Please <u>complete questionnaire no. 1 before questionnaire no. 2.</u> When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **<u>Please don't use any calculators.</u>**
3. **Please express your understanding as much as you can.**

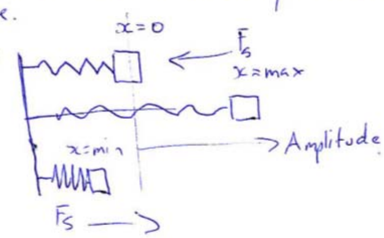
A.

1. Describe SHM (Simple Harmonic Motion).
2. Draw any picture(s) to express SHM.
3. Write down any formulas describing SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)
4. Draw any coordinate graph(s) to express SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)

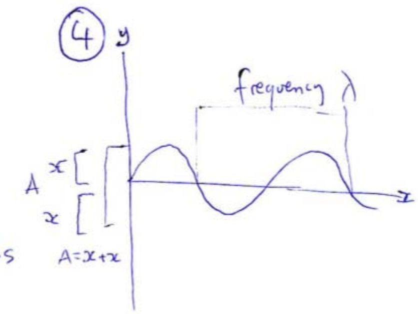


(1) the oscilation of a mass, in relation to time assuming no friction. Can be the swing of a pendulum, a spring or a table with a rotating mechanism on top viewed from the side.

(2)



(4)



(3) $F = -kx$ Total $E = KE + PE$

$PE = 0.5kx^2$ Period $= (2\pi)(L/g)^{0.5}$

Waves & Sound

Questionnaire no.2

Instructions:

1. **Please complete questionnaire no. 1 before questionnaire no. 2. When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **Please don't use any calculators.**
3. **Please express your understanding as much as you can.**

A.

Here are some formulas which describe an object doing SHM (Simple Harmonic Motion).

$F=-kx$

$x=A\cos(\omega t)$

$v=-v_{max}\sin(\omega t)$

$a=-kA\cos(\omega t)/m$

$E=KE+PE=mv^2/2+kx^2/2$

F: restoring force
k: positive constant
x: displacement of the object from equilibrium position
A: Amplitude

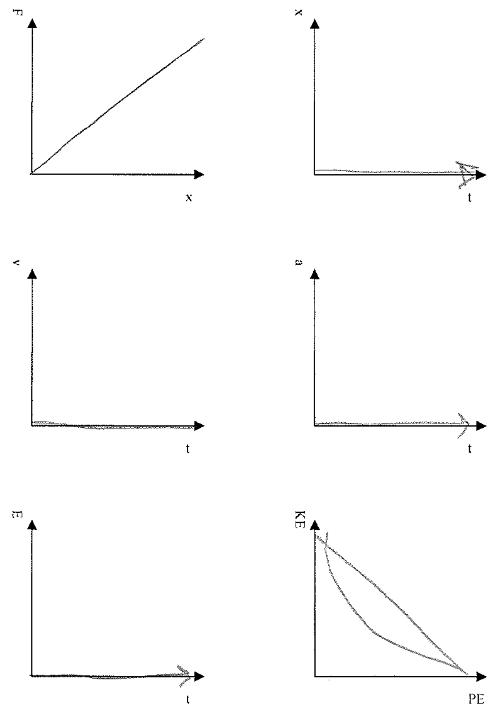
ω: angular velocity

t: time
v: velocity of the object
a: acceleration of the object
m: mass of the object
E: total energy of the object

KE: kinetic energy of the object

PE: potential energy of the object

1. Complete the following coordinate graphs.



2. Assume k=20N/m, A=10cm, $\omega=\pi/2\ sec^{-1}$, $v_{max}=0.3m/s$, m=250g. Find F, x, v, a, E when t=1/3 sec.

3. when x=2cm, what is KE?

K = 20 N/m
A = 10cm
$\omega = \pi/2\ sec^{-1}$
$v_{max} = 0.3\ m/s$
m = 0.250 kg

F ? -2.5 N/m
x ? 0.125
v ?
a ?

$k = \frac{F}{a}$ F = -Kx

$x = \frac{F}{K}$ $\frac{0.250 \times 9.8}{20}$

x = 0.125

F = -20(0.125)
F = -2.5 N/m

a = mv

x = A cos(ωt)
x = 0.51

Student S5:

Waves & Sound

Questionnaire no.1

Instructions:

1. **Please <u>complete questionnaire no. 1 before questionnaire no. 2.</u> When you start completing questionnaire no. 2, do not add or revise your response on questionnaire no. 1.**
2. **<u>Please don't use any calculators.</u>**
3. **Please express your understanding as much as you can.**

A.

1. Describe SHM (Simple Harmonic Motion).
2. Draw any picture(s) to express SHM.
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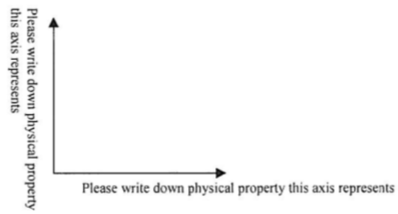
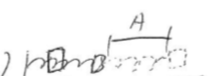
4. Draw any coordinate graph(s) to express SHM. (The physical properties could be displacement, velocity, acceleration, time, energy, etc.)



1) The movement of an object ~~which~~ which is attached to a spring moving forward and backward or upward and down

2) 

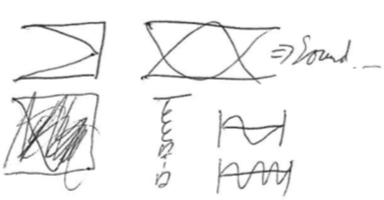
3) $T=2\pi\sqrt{\frac{m}{k}}$ $V=\sqrt{\frac{F}{m/L}}$ $f_1=\frac{V}{2L}$ $v=2\pi f$ $x=A\cos(wt)$

$f=\frac{1}{T}$ "$v=\frac{d}{t}$" $f=n\left(\frac{V}{2L}\right)$ $=\sqrt{\frac{m}{k}}$

$v=f\lambda$ $a=w^2A$ $v=331+0.6t$ ⇒ Speed of sound

$F=-kx$ $v=w^2A$

"$F=ma$"

4) 

Appendix 7.1

Five factors identified through an exploratory factor analysis in Glynn et al.'s(2009)

Factor loadings on the Science Motivation Questionnaire

Item #	Factor Loading	Item
Factor 1: intrinsic motivation and personal relevance		
22	0.81	I find learning the science interesting
1	0.76	I enjoy learning the science
25	0.75	The science I learn has practical value for me
23	0.70	The science I learn is relevant to my life
16	0.63	The science I learn is more important to me than the grade I receive
2	0.63	The science I learn relates to my personal goals
27	0.62	I like science that challenges me
30	0.61	Understanding the science gives me a sense of accomplishment
19	0.60	I think about how I will use the science I learn
11	0.60	I think about how the science I learn will be helpful to me
Factor 2: self-efficacy and assessment anxiety		
4	0.81	I am nervous about how I will do on the science tests (r)
13	0.78	I worry about failing the science tests (r)
6	0.76	I become anxious when it is time to take a science test (r)
28	0.73	I am confident I will do well on the science tests
14	0.69	I am concerned that the other students are better in science (r)
29	0.65	I believe I can earn a grade of "A" in the science course
18	0.63	I hate taking the science tests (r)
24	0.54	I believe I can master the knowledge and skills in the science course
21	0.49	I am confident I will do well on the science labs and projects
		Note. The "r" items were reverse scored.
Factor 3: self-determination		
8	0.82	I put enough effort into learning the science
26	0.76	I prepare well for the science tests and labs
9	0.73	I use strategies that ensure I learn the science well
5	0.39	If I am having trouble learning the science, I try to figure out why
Factor 4: career motivation		
17	0.79	I think about how learning the science can help my career
10	0.77	I think about how learning the science can help me get a good job
Factor 5: grade motivation		
3	0.65	I like to do better than the other students on the science tests
7	0.58	Earning a good science grade is important to me
12	0.53	I expect to do as well as or better than other students in the science course
15	0.50	I think about how my science grade will affect my overall grade point average
20	0.46	It is my fault, if I do not understand the science

Appendix7.2

Reliability test for different factors of Science Motivation Questionnaire(S. Glynn, et al., 2009)

Eigenvalue, percent of variance explained, and Cronbach's coefficient alpha for each factor

Factor	Eigenvalue	% of variance	Cumulative %	Cronbach's alpha
Factor 1	9.03	30.09	30.09	0.91
Factor 2	4.02	13.41	43.50	0.88
Factor 3	2.58	8.59	52.09	0.74
Factor 4	1.40	4.65	56.74	0.88
Factor 5	1.05	3.49	60.23	0.55

Factor 1 is intrinsic motivation and personal relevance, Factor 2 is self-efficacy and assessment anxiety, Factor 3 is self-determination, Factor 4 is career motivation, and Factor 5 is grade motivation.