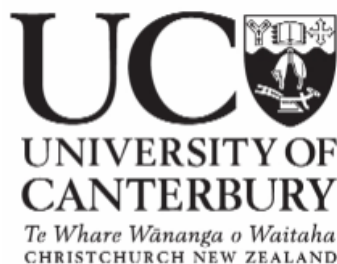


# **Improving Teaching and Learning in Introductory Physics**

A thesis  
submitted in partial fulfilment  
of the requirements of the degree  
of  
Doctor of Philosophy  
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by  
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## **Abstract**

This thesis describes three studies designed to help students learn physics better and instructors teach physics more effectively in local circumstances.

The first study investigated the effects of teaching approaches consisting of interactive engagement activities in two institutions. The teaching elements in the experimental classes were reading quizzes, interactive lecture demonstrations and student discussions. The control classes were taught in traditional style dominated by an instructor lecturing on concepts and problem solving examples. The cognitive improvement was measured by a standardized test and exam grades. The students in the experimental classes showed significant improvement in conceptual understanding and problem solving skills compared to the students in the control classes. While the experimental groups welcomed the modified instruction, they still held the view that the lecturer should play the dominant role of presenting the material.

In the second study interviews with lecturers, teaching assistants and students revealed their perceptions of the utility of real-life materials in instruction. The students asserted that activities using real-life materials were interesting and useful. However, they still considered that elements of traditional instruction were very important in good teaching. The lack of knowledge of innovative teaching approaches may explain why the instructors were sceptical about the effectiveness of real-life materials in improving their students' understanding.

To raise the instructors' awareness of issues in learning physics and to improve their knowledge of effective instruction, the third study discussed a department-based professional development course. The course incorporated interactive engagement activities and made connections to teaching and learning experiences. The course evaluation suggested that the participants became more open to new ideas and intended to implement what they had learned in the present and future academic career.

The studies in this thesis have impacted on first year courses and raised the instructors' awareness of physics education issues. The emphasis of educational enterprises should be shifted from classroom changes to educating the instructors. Instead of simply modifying teaching practice, instructors should also undergo a transformation in beliefs and knowledge in pedagogy. It is only when all instructors are willing to undergo such a transformation that a significant achievement in teaching and learning will be realized.

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# Chapter 1

## Introduction

This thesis describes a journey towards developing a scheme to help students learn and instructors teach physics better. The journey started with a project as a partial fulfilment of MScEd degree under the guidance of Phil Butler at the University of Canterbury. This was followed by an action research conducted in an Indonesian university to probe the effects of interactive engagement teaching approaches. In the subsequent year, the author was provided with an opportunity to implement a modified teaching approach in the Department of Physics and Astronomy at the University of Canterbury. At the same time, the author and Phil Butler as the head of department, instigated a professional development course for instructors. The outcome of this course was reflected in the readiness of teaching assistants to modify their instruction when all first year physics tutorials were organized to have a uniform format. The author's co-supervisor, Mike Reid, was the 100-level coordinator who initiated the change. All of these studies are reported in this thesis.

### 1.1. Underlying problems

In the 1960s, there was a change in the student population taking introductory physics. After World War II, it was realized that the advancement of science would lead to a better society (Bush, 1945). The launch of Sputnik by the Soviet Union in 1957 triggered the motivation to produce a greater number of qualified scientists and engineers in the United States. This resulted in various projects and programmes to attract more students to doing sciences at schools and universities. As a result, students taking introductory physics are not only prospective physicists but also those who want to major in engineering, other natural sciences and even humanity studies. The more diverse student population means that there is a greater number of under-motivated students in introductory physics classes than there was five decades ago. The non-physics students take the introductory physics courses as a prerequisite for their majors instead of taking it because of their interest in the courses.

Research reports have identified various learning problems that students experience in introductory physics. Students bring incorrect prior knowledge to physics classes as a result of many years of experiencing the real world (Gilbert, Watts, & Osborne, 1982; Gunstone, 1987; Halloun & Hestenes, 1985; Hills, 1989; Van Hise, 1988). Some examples of this prior knowledge are: heavier objects fall faster than lighter objects, bigger objects exert a larger

force than smaller objects, and an object moves because a force is acting on it. The so-called traditional teaching approach usually fails to rectify the incorrect prior knowledge (Mazur, 1997; Hestenes, 1998; McDermott, 2001). Students also often have difficulties in explaining real-life phenomena with the physics they learn (Moore, 2004). Moreover, physics is often considered as having little to do with the real world and more to do with plugging numbers into formulas to solve textbook problems.

Although the problems have been the subject of various studies in the past three decades, many lecturers are not aware of these problems. They adopt a teaching strategy which centres on the lecturers while the students are only a passive audience thus the incorrect prior knowledge is not properly addressed. Traditionally, a lecturer presents the material from the textbook, models the problem solving examples and occasionally performs demonstrations. The students listen to the presentation, take notes, but rarely ask questions or give comments. In tutorial sessions, the students just copy the solutions presented by teaching assistants into their notebooks. The students may have to do some practical activities in the laboratory; but they just follow the prescribed procedures without thinking for themselves very much.

Educational theories of learning provide some contributions to solving the learning problems mentioned above. According to the cognitive view of learning, learners actively modify their mental structure to make sense of the world they experience (Anderson, Reder, & Simon, 1996; Greeno, Collins, & Resnick, 1996; Mayer, 1996). The process of knowledge construction is facilitated by social interactions (Vygotsky, 1978), authentic learning experiences (Ormrod, 2003), motivation (Pintrich, Marx, & Boyle, 1993; Weinstein, 1998) and disrupting the cognitive equilibrium (Piaget, 1954).

Utilizing educational principles, physics education researchers have put forward various strategies to assist instructors to teach more effectively. Some of these strategies aim to create a learning environment where the students are actively engaged with their instructors, peers and learning materials. The so-called interactive engagement strategies have been subject to a great number of investigations (Hake, 1998a). Published reports (Hake, 1998a) indicate that these strategies improve students' conceptual understanding as well as their skills in problem solving. Other approaches incorporate examples, materials and activities taken from real-life contexts with the purpose of establishing the connections between physics and its applications in the real world.

## 1.2. Research questions

There are some issues that physics education research has not satisfactorily addressed. Most of the innovations in instruction were invented and applied in the United States and the United Kingdom. As the learning process is influenced by many factors, including previous learning experiences and current learning circumstances, the benefit of those innovations in other learning environments is questionable. The effects of research-based instruction on the students was the starting point of this investigation. The results of this study were then utilized to explore further efforts to improve teaching and learning in a local environment. Specifically, the research questions that this thesis focused on are:

1. What are the effects of research based instructional approaches, particularly interactive engagement strategies, on students' comprehension of the learning material?

The context of learning is an important factor in knowledge construction; therefore certain teaching approaches that succeed in helping students to learn in one environment may not work with students learning in a different environment (Ramsden, 1992). To investigate the effects of interactive engagement approaches in classrooms other than those in the countries where the approaches originated, two case studies were conducted in the author's institutions: the University of Surabaya, Indonesia and the University of Canterbury, New Zealand. The results were analyzed in terms of the students' cognitive improvement and their attitudes towards the modified approaches.

2. What are the attitudes of students and instructors towards research based instructional approaches or resources?

Despite the abundant availability of innovative teaching ideas and resources, many lecturers still adopt the traditional approaches. In order to reveal the reasons for this persistence, a study was carried out by interviewing students, teaching assistants and lecturers in the Physics and Astronomy Department, University of Canterbury. The participants were involved in introductory physics courses at the time of the study. The study examined the participants' perceptions of the connection between physics and real-life phenomena, teaching and learning resources, and the use of these resources in their classrooms.

3. What other efforts are needed to promote an environment more conducive to teaching and learning?

The answers to the two research questions above were used to determine further actions for helping instructors and students adopt research based instructional strategies. As the focus of this investigation is instructors and students, the next stage was establishing a means to motivate the students to improve their learning approaches and/or to motivate instructors to improve their teaching methods.

### **1.3. Thesis outline**

This thesis begins with various theories on education in Chapter 2. These theories demonstrate why traditional instructional methods fail to promote effective learning. According to these theories, learners, instead of recording information, construct their knowledge by assessing new information against existing structures, resulting in larger and more complex cognitive structures. The process of knowledge construction is facilitated by social interactions, authentic learning experiences and motivation.

Incorporating the principles drawn from educational theories elaborated in Chapter 2, physics education researchers proposed some innovative solutions to the problems caused by traditional instructions. Two prominent aspects of those innovations are instructional approaches requiring active engagement of the students and inclusion of real-life materials in instructional strategies and textbooks. Chapter 3 presents an extensive list of strategies utilizing interactive engagement and real-life materials. These strategies are discussed in terms of the role played by the real-life materials and the expected or reported outcomes. Numerous studies show that these strategies improve students' conceptual understanding and problem solving skills.

The innovative instructional strategies discussed in Chapter 3 were originated and have been implemented mostly in the United States or the United Kingdom. As the context of learning is an influential factor in knowledge construction, two case studies in two tertiary institutions were conducted to investigate the effects of teaching approaches consisting of interactive engagement activities. Chapter 4 describes these two case studies. The particular aim of these studies was to measure the students' cognitive improvement and determine their attitudes towards the modified approaches.

The results reported in Chapter 4, especially concerning the students' attitudes, needed further explanation. At this stage the long practice of traditional teaching seemed to be a possible

explanation. Many lecturers still adopt traditional approaches despite mounting evidence of the effectiveness of instructional innovations. In order to explore this persistence further, Chapter 5 reports a study which was carried out by interviewing a number of lecturers, teaching assistants and students involved in introductory physics courses in the Physics and Astronomy Department, University of Canterbury. In this study the focus was to investigate their perceptions on the utility of real-life materials in the courses. As mentioned above, the inclusion of real-life materials in instruction is one of the prominent features of innovative teaching strategies.

To identify further efforts in improving the instructors' attitudes, Chapter 6 presented a literature review on reforming education. It shows that an educational reform requires a concerted effort of all elements in the institution to make the change. Isolated cases of innovative teaching implementation will not produce significant results in improving the quality of education in particular institutions. It is the lecturers who play the pivotal role as the primary change agent in any instructional reform. Chapter 6 also specifies several initial requirements for educational reform including the change in beliefs about teaching, the feeling of dissatisfaction with the present condition, and the relevant knowledge and skills.

The theories and reports in Chapter 6 imply that the first step toward an instructional improvement is to introduce instructors to issues in educational research. The results in Chapter 5 also point towards the benefits of instructors being knowledgeable in educational research in their subject area. The analyses from these two chapters led to the establishment of a professional development course as an endeavour to bring issues in physics education research to lecturers and teaching assistants in the Physics and Astronomy Department, University of Canterbury. Chapter 7 describes the course which incorporates educational principles reported to be effective in facilitating the transformation of pedagogical knowledge. These principles are drawn from theories and reports in Chapters 2, 3 and 5.

The final chapter, Chapter 8, presents the findings and answers to the three research questions. These include the implications of the studies involved in this thesis for the current instructional practice in the Physics and Astronomy Department, University of Canterbury. Limitations of the studies and suggestions for further research are discussed. This chapter also presents the contributions of this thesis to physics education which hopefully will smooth the way towards an excellence in teaching and learning in introductory university physics.

## **Chapter 2**

### **Educational Views of Learning**

This chapter elaborates some principles from educational research on how learning takes place. Three prominent views of learning are discussed in recent literature (Eggen & Kauchak, 2004; McInerney & McInerney, 2006; Ormrod, 2003; Woolfolk, 2005): behavioural, social cognitive and cognitive views of learning. Behaviourists emphasize that learning takes place if there is a relatively permanent change in the learner's behaviour as a result of stimuli from environmental events (Skinner, 1953). The social cognitive views focus on the learning processes when learners observe other people and interact with them (Bandura, 1986). These two perspectives, however, do not discuss the learners' mental processes as they try to make sense of their experiences. According to the cognitive perspective of learning, the change in learners' behaviour could be explained by the change in mental associations arising from experiences. This school of scientific psychology became increasingly popular during the 1970s and remains as the most prominent school in psychology (Robins, Gosling, & Craik, 1999).

Cognitive views of learning suggest that learning involves a modification of mental structure where understanding takes place. The modification is influenced by learners who actively respond to the information which comes to their attention. Knowledge construction is emphasized rather than the learner being passively influenced by the environment. Section 2.1 discusses in more detail the cognitive views of learning and Section 2.2 presents three theories of cognitive development.

It is important to acknowledge the fundamental principles of learning to understand the learners' performance and to improve instruction. Many instructors, including those at tertiary level, often rely only on their past experiences to diagnose learning problems or to modify their instruction approaches. However, experience alone is not adequate if the instructors want to improve their students' performance. Instructors should also seriously consider educational principles. These principles explain, for instance, why "teaching by telling" is sometimes not very effective, why misconceptions are often resistant to change, why engaging students in discussion will help them learn better, why motivation influences achievement, and why real-life elements in instruction promote knowledge construction. Section 2.3 on constructivism and Section 2.4 on motivation provide detailed explanation of these concepts.

The philosophy discussed in the following sections is revisited in the next chapter and serves as a foundation to comprehend issues in physics education research.

## **2.1. Cognitive views of learning**

According to the cognitive view of learning, learners actively modify their mental structure to make sense of the world they experience. Knowledge is represented by this mental structure which constantly undergoes modification through interactions between the learner and the information received. Early cognitive views were concerned with how knowledge is acquired, but current perspectives emphasize how knowledge is constructed (Greeno, Collins, & Resnick, 1996; Mayer, 1996).

### **2.1.1. Basic principles of cognitive learning theories**

Because mental processes in the brain cannot be directly observed, the investigation is done by making observations on learners' responses to various treatments. This leads to inferences explaining what mental processes that may take place to produce certain responses. As a result, there is more than one explanation or idea which could be used to account for a particular response. Nevertheless, these explanations or ideas share some common basic principles which are elaborated below.

#### **1. Learners play an active role in their learning**

Cognitive learning theorists believe that learners do not simply absorb information from the environment nor simply respond to external stimuli. They actively engage in mental work to make sense of what they experience. They seek information to satisfy their curiosity, they restructure their knowledge in light of new information, and they modify their behaviour accordingly.

#### **2. Learners select the information to process**

Our senses are constantly exposed to stimuli from our surroundings. It is practically impossible to attend to all of these stimuli every time. The human brain is selective in choosing the stimuli which are regarded to be important at a particular time and place. Other stimuli may be given brief attention or ignored completely. The mechanism of selecting the information to be processed or to be discarded is discussed further in the next subsection.

### 3. Learners construct knowledge instead of recording information

Information from the learners' surroundings is not simply recorded in their brain. Pieces of information, after being selected, are analyzed to create a meaning by comparing them with the existing knowledge. Each learner, with their personal existing knowledge, may therefore produce a different interpretation from the same set of information they are exposed to. There is another reason why different learners come up with different learning results in the same learning situation: prior knowledge and beliefs.

### 4. Prior knowledge and beliefs affect knowledge construction

Learners refer to what they already know to understand new information. Prior knowledge is developed from past experiences and interpretation of meaningful information. Because prior knowledge is used as a reference in understanding new information, simply telling the learners to change what they believe does not often work.

### 5. Learning involves a change in learner's mental structure

Unlike behaviour theorists who focus on the behaviour change as a result of learning, cognitive psychologists view learning as "a change in a person's mental structures that creates the capacity to demonstrate different behaviours" (Ormrod, 2003, p. 238). The mental structures could be schemas, beliefs, goals, expectations and other components in the learner's mind. A change of these, however, does not always instantly lead to a change in behaviour.

How is the information acquired, processed, stored and retrieved to help learners make sense of the world? The next subsection elaborates the description on how people learn.

## **2.1.2. Model of information processing**

Because the mental structures and their activities cannot be directly observed, a model is needed to visualize what is happening during the learning process. The current view of information processing is based on a model proposed by Atkinson and Shiffrin (1968). This model, which is presented in Figure 2.1, has been modified and refined to reflect recent outcomes in psychology research (Leahay & Harris, 1997; Mayer, 1998a).



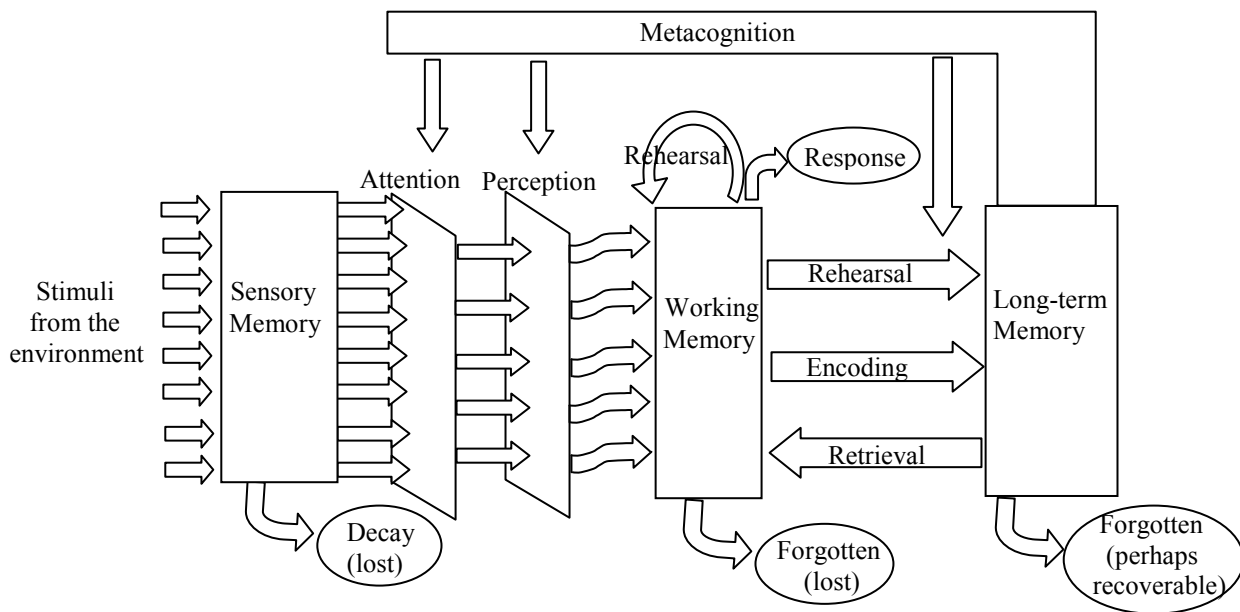


Fig. 2.1. Model of information processing  
 (From Eggen & Kauchak, 2004, p. 239)

Information from the outside world is captured as stimuli by sensory memory before it is processed further. The material in the sensory memory is supposedly a perception copy of objects and events, unencoded and unorganized (Leahay & Harris, 1997). Although the sensory memory where the information is stored has large capacity for holding the incoming information, the duration for which the information is stored has been estimated to be very limited (Leahay & Harris, 1997; Pashler & Carrier, 1996; Cowan, 1995). Nevertheless, it is important for the information to reach this point; otherwise it cannot be transferred to the next level, the working memory, through attention and perception.

Attention “is the process of consciously focusing on a stimulus” (Eggen & Kauchak, 2004, p. 248). Learners’ existing knowledge and needs determine which information they choose to attend to. Information which does not make sense, is contrary to the learner’s beliefs, or is regarded as unimportant will disappear from the memory system. Once the information is attended to, it goes through the perception phase before reaching the working memory. Perception is “the process to attach meaning to stimuli” (Eggen & Kauchak, 2004, p. 250). Similar to the previous phase, meaning is generated by referring to the existing knowledge. The information now takes form as a representation of the physical world perceived by the learner as it moves to working memory.

Working memory is historically called short-term memory where new information is held and processed. It is where the deliberate and conscious thinking takes place by relating the new

information to the stored knowledge in long-term memory. Working memory has some limitations: short duration and limited capacity. Researchers discovered that it can only hold 5 to 9 new items of information at a time (Miller, 1956) and it holds this much information for only 20 seconds at most (Peterson & Peterson, 1959). Active cognitive processes such as selecting or organizing information further reduce the items that can be handled simultaneously to 2 or 3 items (Sweller, van Merriënboer, & Pass, 1998).

The final component of the information processing model is long-term memory. Unlike working memory, long-term memory has practically unlimited capacity and it can hold information for a relatively long time. The table below lists some differences between the two components of the human memory system.

Table 2.1. The differences between working memory and long-term memory.

Characteristics	Type of memory	
	Working memory	Long-term memory
Input	Very fast	Relatively slow
Capacity	Limited	Practically unlimited
Duration	Very brief: 5-20 seconds	Practically unlimited
Contents	Words, images, ideas, sentences	Propositional networks, schemata, productions, episodes, perhaps images
Retrieval	Immediate	Depends on representation and organization

(From Woolfolk, 2005, p. 241)

There are several ways of building knowledge in long-term memory. The first is known as rehearsal which is the process of mentally repeating information over and over again. Although this is one of the processes occurring in working memory, information may be transferred to long-term memory if it is repeated often enough (Atkinson & Shiffrin, 1968). However, this method is not effective in storing information (Anderson, 1995; Ausubel, 1968; Craik & Watkins, 1973) because there is no meaning attached to the information and very few connections made to link new information and existing knowledge. The term “rote-learning” is often used to describe this method of learning which is often adopted in early stages of learning and is useful in the absence of prior knowledge.

Another method is called meaningful encoding and is a process of representing new information in long-term memory by making connections between new information and stored knowledge in long-term memory. This method is found to yield better learning results

compared to rote-learning (Britton, Stimson, Stennett, & Gülgöz, 1998; Novak, 1998; Van Rossum & Schenk, 1984). There are conditions, however, that are required a meaningful encoding is to occur: The learner has existing knowledge to which new information can be connected and the learner recognizes that new information can be connected to existing knowledge (Ausubel, Novak & Hanesian, 1978).

Organization can also be used to build knowledge in long-term memory. It is the process of grouping related pieces of information into categories and connecting these categories to establish a meaningful structure. The relations could be made among bits of new information or between new information and existing structures. Learning is more effective if new information is presented in a well-structured organization, if new information fits an already existing organizational structure, and if relationships among items or categories are meaningful (Mandler & Pearlstone, 1966; Tulving, 1962; Bower, Clark, Lesgold, & Winzenz, 1969; Mayer, 1997; Nuthall, 1999).

Another method is elaboration which is a process of extending new information to make it meaningful by connecting it to existing knowledge. Elaboration reactivates background knowledge structure when new information is given meaning (O'Reilly, Symons, & MacLachy-Gaudet, 1998). Elaboration can also create new connections in existing structure, making it easier to understand new information (Schunk, 2000). Learners can be encouraged to elaborate by asking them to express a new idea in their own words, to give examples, to find applications of a concept, to explain to their peers, or to apply a concept to solve problems.

Visual imagery also helps in constructing knowledge. This is the process of forming mental pictures of objects or ideas (Schwartz, Ellsworth, Graham, & Knight, 1998). It is found to be effective in storing information (Dewhurst & Conway, 1994; Johnson-Glenberg, 2000; Sadoski, Goetz, & Fritz, 1993; Sadoski & Paivio, 2001). The use of visual imagery can be fostered for example by presenting abstract ideas in visual forms such as pictures, charts, maps and models, or by asking learners to create illustrations or diagrams of what they learn.

Lastly, constructing knowledge in long-term memory is fostered by activities which engage learners actively in either mental or physical states. Mental activities involve the processes previously described in this section such as meaningful encoding, organizing or elaboration. Physical activities have received increasing emphasis particularly in tertiary level science

instruction; the next chapter discusses this in more detail. The term “hands-on activities” is usually associated with innovative teaching approaches. However, it is important to make sure that learners make connections between new materials and their existing knowledge while they are engaged in working with objects or discussing with their peers (Mayer, 1999).

All processes of constructing knowledge in long-term memory mentioned above emphasize the importance of existing knowledge and making links of new information to the existing knowledge. What if the existing knowledge does not exist yet, as in young children learning new things? Do learners of different ages undertake the same processes of learning? What are the roles of other people – peers and teachers – in the learning process? These questions are addressed in the next section.

## **2.2. Theories of cognitive development**

The previous section examined some principles of learning including how knowledge is constructed. Basically, learning occurs if new ideas can be connected to the stored knowledge. The process of relating new information to existing knowledge often results in the modification of the latter. This prompts a question: How does learning take place if the existing knowledge does not exist? Another issue to consider is: What kind of knowledge or ability is established by learners of different ages? It is important to recognize how learners develop cognitively over time to understand their performance. As this thesis is about the instruction at the tertiary level, it is necessary to take a brief look at the development of cognitive ability up to the age of 18-19 years old. In this way, we can appreciate learners’ efforts to make learning possible.

Human development happens in various aspects of life: physical, personal, social and cognitive. This section discusses only the cognitive development because it is most relevant to the issue of learning and teaching pertinent to this thesis. Cognitive development is “gradual orderly changes by which mental processes become more complex and sophisticated” (Woolfolk, 2005, p. 20). Of several theories on cognitive development, the most influential ones are the work of Jean Piaget, Lev Vygotsky and Jerome Bruner, which are examined here.

### **2.2.1. Piaget’s theory of cognitive development**

Piaget developed his theory by conducting intensive observations on how children and adolescents experience and understand the world around them. He introduced a few basic assumptions to describe children's learning:

1. Children are active learners who are naturally motivated to understand their experience. They have many questions and constantly try to find the answers. This is along the lines of one of the basic principles of cognitive learning theories discussed in Section 2.1.1.

2. Children use their experience to construct and modify their knowledge.

Piaget believed that children's knowledge consists of bits of information organized in schemes. New information can add to the parts of a scheme or to provide more links among pieces of an item. The model of information processing in Section 2.1.2 illustrates a similar process occurring in long-term memory.

3. Children need to interact with their physical and social environments (Piaget, 1971, 1977). The physical environment includes objects and events that children can explore or experience. Cognitive development is promoted if children have opportunities to engage in activities, and is a process of building knowledge described in Section 2.1.2. In addition to being exposed to the physical environment, children need to have interactions with other people. This helps children toward the process of modifying their existing knowledge and understanding the world better. The role of social interaction on knowledge construction is further explored by Vygotsky's theory in the next subsection.

Piaget (1954) proposed his theory of cognitive development to explain how knowledge is constructed. Figure 2.2 (adapted from Eggen & Kauchak, 2004, p. 38) summarizes the process.

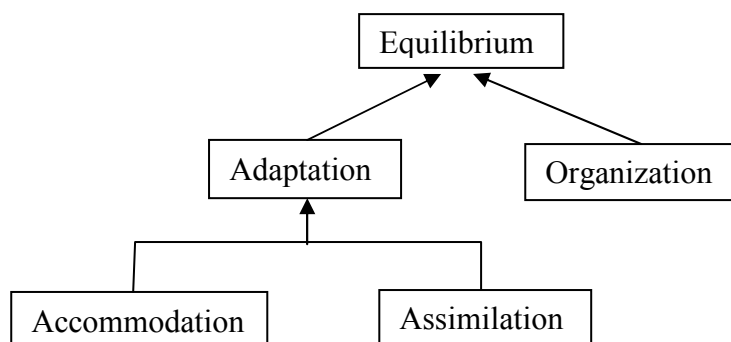


Fig. 2.2. Piaget's theory of cognitive development.

Knowledge is organized by clustering pieces of information to form a meaningful structure. The result of this organization process is a system called a “scheme” which serves as a reference to make sense of experiences. Piaget believed that learners have a tendency to maintain the compatibility between new information or experiences and existing schemes. This “equilibrium” (Piaget, 1954) is achieved when new information can be understood by referring it to the schemes. If learners encounter experiences which cannot be adequately explained by their current understanding of the world, “disequilibrium” is created which causes a kind of mental discomfort. This motivates learners to seek ways to get back to the equilibrium state. Piaget recognized learners’ ability for an “adaptation” which is a process of adjusting existing schemes to new information or vice versa to maintain an equilibrium. Adaptation can be done in two ways: (1) accommodation, where existing schemes are modified so that new information can fit in, and (2) assimilation, where new information is modified to fit in the existing schemes.

While the model of information processing elaborated in the previous section does not say much about new information which does not fit in the current knowledge, Piaget’s theory provides an interesting insight into how humans learn. Both theories, however, emphasize the pivotal role of the knowledge already stored. Piaget’s work is valuable in understanding the growth of knowledge that instructors can promote through their instruction. Learning experiences should be designed to build on learners’ current knowledge but these experiences should disrupt the equilibrium to motivate learners to make the adaptation.

The ability of learners to achieve the equilibrium state develops over time. Piaget (Inhelder & Piaget, 1958) described this progress as stages of development which is probably the most famous piece of his work. There are four stages representing the change in children’s information processing. These stages are associated with specific ranges of age. The association is just a general guideline because each individual progresses through different rate although they all pass through each stage before moving on to the next one. The four stages of cognitive development are summarized in Table 2.2.

The first three stages of Piaget’s theory seem to be naturally passed through by all learners because of the physical realities (Neimark, 1975). The fourth stage, however, is not directly associated with concrete objects or actual realities. Certain amount of exposure to relevant experiences, for instance through practice of mathematical problem solving, is beneficial to developing formal operational abilities (Piaget, 1974). Research indicates that many students

at university level still use concrete operations in their learning (Lawson & Snitgren, 1982; Thornton & Fuller, 1981). The next chapter shows that there are similar cases where students tend to use what they see in reality to solve physics problems.

Table 2.2. Piaget’s stages of cognitive development

Stage	Approximate age	Characteristics
Sensorimotor	0-2 years	Moving from “out of sight, out of mind” to “object permanence”. Moving from reflex actions to goal-oriented activities. Beginning to develop the ability to understand cause-effect relationships and to use memory.
Preoperational	2-7 years	Rapid growth of language ability. Beginning to think symbolically by creating representations of objects in their schemes. Perception dominated thinking leading to centration and egocentrism.
Concrete Operational	7-11 years	Ability to think logically about concrete objects. Understanding the principle of conservation, the process of transformation and the possibility of reversibility. Ability to perform seriation and classification.
Formal Operational	11-adults	Ability to reason abstract and hypothetical ideas. Ability to formulate and test possible explanations to answer a question. Developing adolescent egocentrism.

(Adapted from Eggen and Kauchak, 2004, p. 41 and Woolfolk, 2005, p. 34)

Various aspects of Piaget’s theory such as: (a) learning involves constructing own understanding rather than knowledge being transferred to learner, (b) knowledge growth is promoted by providing experiences to disrupt equilibrium, (c) learning occurs by making connections between new information and existing schemes, and (d) interactions with physical and social environments are necessary to promote knowledge construction have influenced curriculum and research in instruction. Innovations in teaching approaches place the focus of attention on the students in student-centered learning strategies. Interactive-engagement methods, where students have discussions with their teacher and peers, are reported to improve understanding. Hands-on activities become increasingly important in science instruction. The same phenomena are also observed in physics education; some essential aspects of Piaget’s theory are revisited in the next chapter.

### 2.2.2. Vygotsky’s theory of cognitive development

Piaget indicated that social interactions create disequilibrium to encourage growth in knowledge. His emphasis is on the individual level where learners construct their understanding through the process of adaptation. Social interactions can reinforce this

mechanism but it is the learners themselves who play the major role in developing their knowledge. Vygotsky, on the other hand, advocated the dominant influence of social interactions, as well as language and culture, on promoting cognitive growth. His view is well-known as the sociocultural theory.

Vygotsky (1978) believed that interactions with peers or knowledgeable adults initiate the process of developing understanding. Children actively participate in dialogues with other people, discover how others think about their experiences, then incorporate the ways others interpret the world into their own ways of thinking. This process of internalization is possible through interactions with adults from whom children receive explanations, directions, and feedback as well as with their peers who often provide several ways to view a particular situation.

Vygotsky introduced the concept of “zone of proximal development” which is a range of tasks that individuals cannot yet accomplish on their own, but can be successful under the guidance of more capable persons or in collaboration with their peers. Learners do not benefit much from doing the tasks they are independently capable of. Instead, by successfully learning something beyond their current knowledge with the help of others, learners are able to develop their knowledge towards more complex and sophisticated structure.

Some principles embedded in Vygotsky’s theory have been utilized in various teaching strategies, for example scaffolding, guided participation and peer interaction. Support and guidance are provided to help learners to perform a task in their zone of proximal development. This support is then gradually withdrawn so that learners become more independent. Scaffolding can be done by modelling, thinking aloud, questioning, adjusting instructional materials, providing prompts and cues, doing part of the problem, giving detailed feedback and allowing revisions (Eggen & Kauchak, 2004; Rosenshine and Meister, 1992). In guided participation, assistance is provided for learners to perform adult-like tasks (Radziszewska & Rogoff, 1991; Rogoff, 1990, 1991). Learners are encouraged to use terminologies and to carry out procedures typically involved in activities conducted by more knowledgeable or skilful people. Some examples of these activities are planning a field trip, facilitating a discussion and doing a scientific experiment. Peer interaction involves learners taking part in collaborative work where they provide scaffolding to one another. Tasks, which are too difficult for an individual learner, can be successfully accomplished by a group of learners. The term “interactive-engagement” has become increasingly popular in physics



instruction and has been reported to improve conceptual understanding. More discussions on this issue are presented in the next chapter.

### **2.2.3. Bruner's theory of cognitive development**

Piaget and Vygotsky recognized the construction of knowledge as learners try to understand the world around them. As learners progress with their learning, the mechanism of knowledge construction becomes more sophisticated. The similar principle is also apparent in Bruner's theory of cognitive development (Bruner, 1961, 1966).

There are three main stages of intellectual development that learners go through from simple to complex thinking. The basic stage is called enactive stage where learners manipulate objects to learn about the world around them. Objects exist in the real sense where they can be seen, touched, smelled and played with. The next stage is iconic stage where learners represent experiences and objects as concrete images. Instead of handling concrete objects, learners are able to use models, demonstrations and pictures to learn something new. In the most advance stage, the symbolic stage, learners are able to think abstractly with symbols. At this stage, learners can mentally process hypothetical objects or situations they have not previously experienced with.

Bruner suggested that instruction follows a sequence of the three stages. To achieve an optimum result, learners should first have a concrete experience which they can physically do something about. Then, learners should be encouraged to create representations of what they learn in some forms (diagrams, pictures, own wording, etc). Finally, learners can be motivated to extend what they learn and apply it in a hypothetical situation. Normally, learners follow the order of these developmental stages. Bruner believed, however, that learners who are already at the symbolic stage often get some benefit when they are provided with opportunities of experiencing the previous stages.

The principle of progressing towards a higher level of thinking process is reflected in several applications that Bruner (1966) suggested to improve instruction. One of these applications is the spiral curriculum, where concepts are developed from simple forms involving concrete objects and experiences to a high level of abstraction. Learners' prior knowledge and current developmental stages serve as foundation blocks on which knowledge is built. A "big picture" is introduced at the beginning, then it is explored and expanded in an increasingly complex

fashion over time. Discovery learning is another application suggested by Bruner. In this approach, learners work from examples to find general principles on their own. They discover the principles, structures or relationships involved in materials they manipulate. The knowledge generated is significantly meaningful in terms of its utility to be applied in other situations. This transfer of learning is revisited later in this chapter.

Bruner's ideas are in line with cognitive learning theories in the sense that learners construct their understanding on their own, rather than that understanding being transmitted by other people. Growth of knowledge occurs when learners are provided with learning experiences in which they are actively involved. These are the essence of constructivism which is explored in the next section.

## **2.3. Constructivism**

The term constructivism is used in various, sometimes conflicting ways by philosophers, psychologists, educators and others. Educational psychologists view constructivism as a perspective of learning where learners construct their understanding by themselves, rather than having that understanding transmitted to them by external agents (Bruning, Schraw, & Ronning, 1999; Bransford, Brown, & Cocking, 2000). Researchers and educators in physics education are increasingly aware of the fact that constructivism may shed light to various issues in the area. In order to fully understand the contribution of constructivism in physics education, it is necessary to first examine several aspects of constructivism such as its characteristics and suggested implementations. This section also looks at misconceptions which is a problem that needs to be dealt with before a conceptual change can occur. The result of a conceptual change is scientifically accepted skill and knowledge which, hopefully, can be transferred to various contexts including out-of-school applications and future occupations.

### **2.3.1. Characteristics and implementations**

Despite the different meanings which could be attributed to different constructivist views, there are some common characteristics amongst them (Bruning, Schraw, & Ronning, 1999; Mayer, 1996):

1. Learners construct their own understanding

Theorists no longer view learning as a process of recording information or absorbing knowledge from learners' surroundings. Learners are viewed to interpret information based on their current knowledge and to construct understanding that is meaningful to them. The role of constructing knowledge should be made aware to learners (Cunningham, 1992) so that they can be more actively involved in the learning process.

## 2. Current knowledge influences learning process

Piaget's theory of cognitive development discussed earlier clearly demonstrates the significance of current knowledge in maintaining equilibrium. New information is understood by being referred to existing knowledge. This explains why learners arrive at different understandings even though they are exposed to similar learning situations. The differences in background knowledge are due to many factors for example family influence, prior education experience, ability, motivation and so on.

## 3. Social interaction facilitates learning

Although understanding is created by the learners themselves, interactions with other people influence the process of knowledge construction. Learners can get assistance from more knowledgeable persons, recognize different ideas from their peers, or internalize the process of reaching a conclusion from collaborative works. This is also the essence of Vygotsky's sociocultural theory of cognitive development reviewed earlier.

## 4. Real-world tasks make learning meaningful.

A real-world task or authentic task is a learning activity to develop understanding that can be used outside the classroom. The activity involves providing learning contexts and complex problems similar to those of everyday experience in the real world. Learners are expected to realize that real-life problems have multiple interacting parts, various solutions, and different consequences leading from the solutions (Needels & Knapp, 1994; Resnick, 1987).

Authentic learning is only one aspect characterizing constructivism. In the next chapter, this aspect is given a considerable amount of examination in the area of physics education. Inclusion of real-life materials in instruction actually incorporates other characteristics of constructivism. When an instruction is properly organized around real-life materials, learners are able to benefit cognitively from their learning.

The characteristics of constructivism mentioned previously are implemented in teaching strategies by generating the following conditions:

1. There are various examples involved in studying a topic.

Because learners have different background knowledge, providing a variety of perspectives to illustrate a concept allows some overlapping (Cassady, 1999; Eggen, 2001). Technology plays an increasingly important role in creating illustrations which are sometimes difficult to present in other ways (Mayer, 1997, 1998a).

2. Learning topics are connected to the real world.

There are many ways authentic learning can be incorporated into teaching any subject matter (Ormrod, 2003). Because of the level of difficulty and complexity of the tasks involved in authentic learning, learners should get sufficient scaffolding to accomplish the tasks successfully.

3. Learners are engaged in social interactions.

Working in a cooperative manner with their classmates as well as responding to teacher's questions facilitates the growth of knowledge. Social interactions enable learners to: (a) share ideas by proposing various interpretations of a situation or solution to a problem (Meter & Stevens, 2000), (b) promote understanding by creating a new meaning (Leont'ev, 1981), and (c) articulate thinking by putting ideas into words (Bransford, Brown, Cocking, 2000; Mason & Boscolo, 2000).

Teachers also gain some advantages from being involved in the interactions. Teachers can ask questions requiring learners to use their current understanding, help learners to focus their attention, and assess the learning process.

### **2.3.2. Misconceptions and conceptual change**

Constructivist theory emphasizes the role of existing knowledge when learners try to make sense of new information. As existing knowledge is constructed by learners, there is always a possibility that it is not the "correct" knowledge. Misconception is a term to describe the existing knowledge that is different from knowledge accepted by the community of a discipline. Research indicates that children and adults have many misconceptions regarding

the world they experience. The most extensive research on misconceptions comes from science education areas.

The sources of misconceptions are various. Learners have a certain idea of an object because of the way it appears to be seen (diSessa, 1996; Duit, 1991; Reiner, Slotta, Chi, & Resnick, 2000). An example in physics is the notion that heavier objects fall faster than lighter objects. Everyday language expressions can also confuse learners (Duit, 1991; Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991). The term “weight” is often used to indicate mass in everyday language, while they are very different variables in physics. Incorrect scientific principles can also be reinforced by misleading representations of events from fiction movies, fairy tales and television cartoons (Glynn, Yeany, & Britton, 1991). These forms of entertainment often use exaggeration to make dramatic effects, however the dramatization is not always consistent with physics principles. Even teachers’, peers’ and textbooks’ explanations may contribute to misconceptions (Duit, 1991). These agents may present the correct information, but it is interpreted incorrectly by learners. There is also a possibility that information presented by teachers and textbooks is incorrect and it is accurately integrated in learners’ existing knowledge. Learners tend to modify new information which does not fit in with their current knowledge through the process of assimilation in Piaget’s theory of cognitive development. Although the new information is consistent with physics principles, it may be dismissed as incorrect if the background knowledge is wrong.

Instructors should recognize the sources of misconceptions because the recognition the first step in helping learners with accurate knowledge construction. However, accumulating research evidence, especially in physics education, demonstrates that misconceptions are resistant to be altered into correct conceptions. There are several possible reasons for this. Misconceptions are built up over a very long time of learners’ experience of their world. The way learners understand their experiences come from various sources which are elaborated above. These sources sometimes reinforce each other, thus making a stronger structure of incorrect knowledge. Learners are likely to pay attention to information which is consistent with their beliefs and to disregard information contradicting their beliefs (Duit, 1991; Gunstone & White, 1981; Hynd, 1998; Kuhn, Amsel, & O’Loughlin, 1988). It is apparently easier to modify or even ignore ideas which do not fit in the existing structure than to modify the structure to match the new ideas. Everyday events often confirm misconceptions while explanations based on accepted scientific theories are perceived as abstract or unrealistic (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Linn, Songer, & Eylon, 1996). The flawed

beliefs are present in different interrelated structures forming personal views. Changing one element of these structures may result in modifying the whole system of knowledge (Chambliss, 1994; Smith, Maclin, Grosslight, & Davis, 1997). It takes a considerable effort to establish an organized structure of knowledge, destroying the system is not likely to happen without even more effort. New information is sometimes learned without modifying existing knowledge, so there are different incompatible views stored simultaneously (Chambliss, 1994; Keil & Silberstein, 1996; Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991). This occurs because new information is not connected to existing knowledge due to rote-learning (Chambliss, 1994; Strike & Posner, 1992) or existing knowledge is difficult to retrieve from long-term memory (Keil & Silberstein, 1996).

Effective instructions should be able to replace misconceptions with accepted principles in any subject matter. In other words, effective instructions should be able to promote conceptual change. The fact that erroneous beliefs are difficult to change explains the ineffectiveness of “teaching by telling”, that is telling learners to discard their ideas and replace them with others. As existing knowledge plays an important role in making a meaning of the new information, any misconceptions that learners hold should be dealt with before conceptual change can take place.

Researchers have identified several principles to promote conceptual change and their educational implications:

1. Misconceptions should be identified before an instruction begins.

Administering a pre-test or asking verbal questions are some ways to probe learners’ prior beliefs. Instruction then can be organized to address these incorrect ideas (Kyle & Shymansky, 1989; Putnam, 1992; Roth & Anderson, 1988).

2. Learners are shown that their beliefs are inadequate or incorrect.

Learners are more likely to discard their existing concepts if they realize that the concepts are no longer able to explain new information satisfactorily. Learners are encouraged to perform accommodation, rather than assimilation, in Piaget’s theory of cognitive development. There are some strategies that can be used to promote accommodation, such as asking questions that challenge learners’ beliefs, showing phenomena that cannot be adequately explained by learners’ ideas, pointing out the discrepancies between learners’ ideas and the reality, involving learners in discussions of pros and cons of various explanations, and demonstrating

that the correct theories are better in explaining a phenomenon than learners' existing theories (Chan, Burtis, & Bereiter, 1997; Hynd, 1998; Pine & Messer, 2000; Posner, Strike, Hewson & Gertzog, 1982; Roth, 1990; Slusher & Anderson, 1996; Vosniadou & Brewer, 1987).

3. Learners are motivated to know the correct explanations.

If learners are interested in a topic or if they recognize its utility, they will be more likely to engage in a meaningful learning process (Lee & Anderson, 1993; Pintrich, Marx, & Boyle, 1993). Further discussion on this motivational issue is presented in the next section.

4. Learners' ideas are constantly checked to make sure they are correct.

Despite being exposed to instructions designed to change their incorrect ideas, learners often continue to cling to some misconceptions. Teacher can assess the change in learners' knowledge by asking them to apply what they learn.

Once the correct concepts, ideas and skills are acquired, they are expected to be useful in helping learners to make sense of the world. This means that learners should be able to apply the concepts, ideas and skills they learn in one context to different contexts, or in other words, transfer of learning occurs.

### **2.3.3. Transfer of learning**

One can argue that if learners are not able to make use of their knowledge either in different contexts or in the future, then their learning is not very successful. A major objective of education is to enable learners to apply their skill and knowledge in new or non-classroom situations (Bransford & Schwartz, 1999). Transfer of learning refers to a situation where something previously learned influences learning in other contexts (Mayer & Wittrock, 1996). Many years of research on this topic indicates that learners do not easily transfer what they learn in other subject matters, in out-of-school situations or in their future occupations. If we want learners to reap the most benefit of education, we must ensure that transfer of learning takes place.

In order to help learners effectively utilize their skill and knowledge in a broader range of situations, it is important to recognize several factors affecting the extent to which transfer occurs.

### 1. Context of learning

Many learners think that the subjects they learn are not related to each other and their school learning has nothing to do with out-of-school experiences (Perkins & Simmons, 1988; Rakow, 1984). Learners will have difficulties in transferring their skills and knowledge to other situations if the materials are context-bound or presented in abstract forms (Anderson, Reder, & Simon, 1996; Bassok, 1996; diSessa, 1982). To promote transfer of learning, instruction should be organized in a way that topics in one subject have examples or applications in other subjects as well as in the real world.

### 2. Degree of similarity between learning contexts

Transfer is more likely to happen when learning context seems similar to a previous context (Bassok, 1990; Blake & Clark, 1990; Di Vesta & Peverly, 1984). Authentic learning may provide an advantage over other learning activities: the more learners work with examples and situations resembling those in the real world, the more likely they are able to use what they have learned in the future and in the real world (Perkins, 1992).

### 3. Variety of learning contexts

Learners are more likely to use knowledge in different situations if the knowledge is learned in several ways and involves many examples (Cox, 1997; Ross, 1988; Schmidt & Bjork, 1992). Each opportunity to practise a topic creates items and connections as learners construct their schemes. The more variety of knowledge representations that learners are exposed to, the more chance some of the representations are similar to parts of existing knowledge.

### 4. Quality of learning

Quality of learning refers to the process of knowledge acquisition. Earlier sections have demonstrated the advantages of meaningful learning over rote-learning. Meaningful learning also enables learners to apply their knowledge in other situations (Bereiter, 1995; Brooks & Dansereau, 1987; Mayer & Wittrock, 1996).

### 5. Quality of new information

New information can be presented in various forms, for instance facts, general principles, examples, explanations, and so on. Examples tend to be context-bound unless there are many and they are varied so that they can be deductively drawn to general principles. Facts, principles or procedures learned without being accompanied by reasons or explanations create limited meaningful understanding (Rittle-Johnson & Alibali, 1999). Learners find it easier to



transfer general principles to different situations than specific and concrete examples (Anderson, Reder, & Simon, 1996; Perkins & Salomon, 1987).

In summary, transfer of learning is more likely to occur if learning materials are presented in various real-world contexts accompanied with underlying explanations. The contexts include learning activities that promote knowledge construction which is expounded in previous sections. No matter how skilfully learning experiences are organized, knowledge construction may not take place if one subtle but crucial aspect of learners is not taken into consideration: motivation.

## **2.4. Motivation**

Motivation is a force that energizes, directs and maintains behaviour toward a goal (Pintrich & Schunk, 2002). Motivation and learning are believed to be interdependent: motivation needs to be taken into account in understanding how people learn (Pintrich, Marx, & Boyle, 1993). Weinstein (1998) even argues that "... motivation to learn lies at the very core of achieving success in schooling. ... a continuing motivation to learn may well be the hallmark of individual accomplishment across the life span" (p. 81).

In more detail, there are several effects of motivation on learning. Motivation directs actions toward goals (Maehr & Meyer, 1997; Pintrich, Marx, & Boyle, 1993). Motivation increases the amount of effort and energy in the course of reaching the goal (Csikszentmihalyi & Nakamura, 1989; Maehr, 1984; Pintrich, Marx, & Boyle, 1993). It also increases initiation of the actions and persistence in the efforts (Maehr, 1984). More importantly, motivation enhances cognitive processing: motivated learners tend to pay attention and learn new information in a meaningful fashion (Eccles & Wigfield, 1985; Pintrich & Schunk, 2002; Voss & Schauble, 1992). As a result of these effects, motivation improves performance. High-motivated learners are high achievers (Gottfried, 1990; Schiefele, Krapp, & Winteler, 1992; Walberg & Uguroglu, 1980) while low-motivated learners tend to drop out from school (Hardre & Reeve, 2001; Hymel, Comfort, Schonert-Reichl, & McDougall, 1996; Vallerand, Fortier, & Guay, 1997).

Because motivation is an extensive and complex issue, researchers and theorists have different views on motivation, two of which are relevant to this thesis: behavioural and cognitive views of motivation. Behaviourists consider motivation as a change in behaviour as

a result of experience with the environment (Pintrich & Schunk, 2002). Learners are motivated to perform certain behaviours because of reinforcement such as praise, comments, grades or other forms of recognition. Behavioural view of motivation has a number of criticisms. Some educators perceive that instruction should nurture learners' intrinsic motivation and rewards may reduce learners' interest in intrinsically motivating activities (Kohn, 1996; Ryan & Deci, 1996). In addition, learners' responses to a situation depend not only on how they were reinforced in the past, but also on their current beliefs, expectations and other factors.

Cognitive psychologists consider that human beings naturally tend to make sense of themselves, their environment and the world. People are motivated to restore an equilibrium when new information is not consistent with their existing knowledge structure, as in Piaget's theory of cognitive development. The motivation to understand the way the world works, which ultimately leads to the growth of knowledge, is also influenced by other factors such as perceptions, beliefs, expectations, values, interests, goals and attributions.

#### **2.4.1. Cognitive theories of motivation**

The discrepancy between new information and present understanding is not the only factor which motivates learners to improve their knowledge. Learners' characteristics in terms of how they perceive themselves and the tasks they have to perform also play an important role in making sense of motivation. Some of these characteristics are: self-efficacy or a perception about one's ability to do a task (Bandura, 1986), goal or outcome that an individual is trying to achieve (Locke & Latham, 1990), attribution or individual's explanations, justifications, and excuses for his/her success or failure (Weiner, 1992), and self-determination or the need to choose and control one's actions (Deci & Ryan, 1992; Ryan & Deci, 2000). Another characteristic which is relevant to the analysis in later chapters is expectancy  $\times$  value.

Motivation is a product of expectancy and value: people are motivated to engage in an activity to the extent that they expect to reach a goal multiplied by the value of the goal to them (Wigfield & Eccles, 1992, 2000). Expectation to succeed is affected by the perceived task difficulty, the availability of resources and support, the quality of instruction, the amount of effort involved, and the perception about oneself or self-schemas (Dweck & Elliott, 1983; Wigfield & Eccles, 1992; Zimmerman, Bandura, Martinez-Pons, 1992). Self-schemas include the perception of one's cognitive resources and personality (Pintrich & Schunk, 2002). The

value of accomplishing a task is influenced by one's intrinsic interest, the extent to which the task actualizes one's self-schemas and the utility of the task for meeting future goals (Wigfield & Eccles, 1992).

There are numerous teaching strategies associated with the five characteristics mentioned above to improve motivation in different levels of education. In elementary to high school classrooms, instructors have more opportunities to address all factors than in tertiary settings where learners are expected to know better and to take more responsibility of their learning. However, there are some areas where college instructions can be improved to promote motivation, which are presented in the next subsection.

#### **2.4.2. Developing interest**

College instructors should take all factors affecting motivation into account if they want their students to acquire the most benefit of learning. How the instructions are organized to achieve this aim would probably create several theses on their own. In relation to the topic of this thesis, the discussions on instructional efforts to promote motivation are limited to developing interest in learning activities.

Motivated or interested learners display significant cognitive engagement in what they learn (Pintrich, Garcia, & De Groot, 1994; Stipek, 1996) because interest influences attention, comprehension, and achievement (Krapp, Hidi, & Renninger, 1992; McDaniel, Waddill, Finstad, & Bourg, 2000; Mayer, 1998b). There are many possible ways a classroom instruction can be designed to make learning interesting. Learning activities and materials essentially should arouse learners' curiosity, present inconsistent or discrepant information, include variety and novelty, encourage fantasy and make-believe, reflect instructors' own enthusiasm, promote learners' involvement (for example by using open-ended questioning, hands-on activities, group-work, and peer instruction), and relate to learners' experiences (personalization) because it is intuitively sensible and widely applicable, thus giving a sense of control and meaningful (Anand & Ross, 1987; Baron, 1998; Brophy, 1987, 1996, 1999; Bruning, Schraw, & Ronning, 1999; Deci, 1992; Deci & Ryan, 1992; Hidi & Anderson, 1992; Hidi, Weiss, Berndorff, & Nolan, 1998; Kauchak & Eggen, 2003; Lepper & Hodell, 1989; Mazur, 1997; Moreno & Mayer, 2000; Ross, 1988; Skinner, 1995; Skinner, Wellborn, & Connell, 1990; Wade, 1992; Zahorik, 1994). These examples of strategies to make learning

more interesting emphasize learners' roles to build their knowledge and require the inclusion of real-life materials.

This chapter has discussed the process of constructing knowledge and various factors affecting this process. Learners actively endeavour to make sense of the world around them through the process of building cognitive structures. New information is constantly assessed against existing structures resulting in larger and more complex structures. The development of knowledge is facilitated by social interaction and motivation. Misconceptions, which can be regarded as an unwanted side-effect of learning, may need to be addressed before conceptual change occurs. Authentic learning, that is learning activities using real-life experiences, settings and materials, has a significant role in the above mentioned principles.

Most problems in learning physics can be explained by these principles. It is clear that the traditional teaching adopted by many physics instructors is not effective in fostering knowledge construction. Physics instruction should incorporate interactive engagement activities and real-life materials to improve students' conceptual understanding. The next chapter discusses in more detail how educational principles elaborated in this chapter can provide explanations to issues in physics education research.

## **Chapter 3**

### **Physics Education Research**

The examination of cognitive views of learning in the previous chapter has shown that effective learning requires active participation of the learners. This process is facilitated by activities which encourage learners to interact with their peers and to apply what they learn to real-life situations. Not all physics instructors, particularly at the tertiary level, recognize these educational principles. This chapter demonstrates that educational principles also apply to physics instruction at the tertiary level.

The discussion starts in Section 3.1 with the inconsistency between “formal” definitions of physics and students’ views of physics. According to dictionaries (Thewlis, 1973; Parker, 1993; Walker, 1999; Isaacs, 2000) and educators (Hewitt, 1995, 2004; Romer, 1993; Lindenfeld, 2002), physics provides explanations of how natural phenomena happen. Students, however, often consider physics as having little to do with the real world and more to do with plugging numbers into formulas to solve textbook problems (Redish, Saul, & Steinberg, 1998). The way students perceive physics may be attributed to the way they are taught.

Traditionally, in introductory physics courses, a lecturer presents the material based on the textbook and sometimes models problem solving. Students just sit quietly and listen to the lecturer. In small group sessions known as tutorials, students just copy the solutions presented by teaching assistants into their notebooks. The so-called traditional teaching approaches have been identified as causing serious problems as presented in Section 3.2. Research has documented various physics misconceptions that traditional teaching approaches fail to rectify (Gilbert, Watts, & Osborne, 1982; Gunstone, 1987; Halloun & Hestenes, 1985; Hills, 1989; Van Hise, 1988). Students often have difficulties in explaining real-life phenomena using the physics they learn. Physics is regarded as a collection of formulas used to solve problems in a mathematical fashion.

Since the 1990s, various instructional techniques have been proposed to improve learning outcomes. Among these are teaching strategies where students are actively engaged with their instructors, peers and learning materials. Section 3.3 discusses these strategies, called interactive engagement approaches, which have been shown to improve students’ conceptual understanding as well as their problem solving skills (Hake, 1998a). A few reports (Redish,

Saul, & Steinberg, 1998; Coleman, Holcomb, & Rigden, 1998; Mottmann, 1999; Fagen, Crouch, & Mazur, 2002), however, have indicated that some students are not comfortable with non-traditional approaches. This attitude influences learning motivation which determines the outcome of a learning process. Authentic learning may provide a better way to enhance students' understanding and motivation.

The previous chapter has identified the roles of authentic learning contexts in various aspects of learning. Physics education researchers have come up with numerous instructional strategies that incorporate examples, materials and activities taken from real-life contexts (Beichner, 1996; Heller, Keith, & Anderson, 1992; Laws, 2004; McDermott, et al., 1996; Thornton, 1987; Whitelegg, 1996). Recent editions of introductory textbooks include increasing amounts of real-life materials as examples, concept applications and problems (Halliday, Resnick, & Walker, 1993, 1997, 2001; Young & Friedman, 1996; 2000; Giancoli, 2000; Serway & Jewett, 2004; Tipler & Mosca, 2004). The purpose is not only to make learning more meaningful and interesting, it also aims to reinstate the notion of physics as the underlying principles of real world phenomena. Section 3.4 elaborates these efforts and demonstrates the role of real-life materials in improving conceptual understanding.

### **3.1. The views of physics as real-life applications**

Unlike the situation in the past when physics was studied by very few selected students, in the last four decades a growing number of students have been taking physics for many different reasons. Physics in introductory level is no longer a course taken by only prospective physicists and engineers. It now has to serve a wider audience which are varied in background knowledge, ability level, motivation and expectation. It seems that many lecturers are quite slow to respond to this situation. They may still assume that their students are those chosen few who have the appropriate knowledge, ability, motivation and expectation (see also the conflicting views in a dialogue between two physicists in Ellse & Osborne, 2004). Because the way they teach is based on their assumptions, this may result in the problems of unsatisfactory understanding and unfavourable perceptions of physics.

The growing amount of material to cover in limited time also distracts some instructors from the awareness that doing physics follows a historical sequence of observation of phenomena, experimentation, development of laws or principles, and prediction or explanation of phenomena (see also Hewitt, 2004). In traditional approach, this has been reduced to a

discussion of laws or principles followed by an application in the form of problem solving. This usually ends up with numerical answers without further interpretation. The phenomena-related aspects are often skipped in the lecture. Students may encounter some practical applications of physics in the laboratory, however the connection to the principles taught in the lecture is sometimes not obvious and is missed by many students. As a result, the physics as viewed by students is different from that viewed by instructors or researchers. This section addresses the notion of physics from dictionaries, educators and students.

### **3.1.1. The views of physics from dictionaries and educators**

A quick scanning of entries in a number of dictionaries and encyclopaedia brings out the meaning of physics such as:

- ... the study of all those parts of natural philosophy which can be explored by observations and experiments. Physicists seek to idealize the behaviour of matter and energy ... to predict ... the behaviour of a system in the future from knowledge of its present condition (Thewlis, 1962)
- The study of the properties of matter and energy, and of their interactions. It involves making observations of, and experiments and measurement on, the phenomena encountered in that study ... (Thewlis, 1973)
- ... is concerned with those aspects of nature which can be understood in a fundamental way in terms of elementary principles and laws. ... its original aim of understanding the structure of the natural world and explaining natural phenomena (Parker, 1993)
- The study of matter and energy with the aim of describing phenomena in terms of fundamental laws (Walker, 1999)
- The study of the laws that determine the structure of the universe with reference to the matter and energy of which it consists. It is concerned ... with the forces that exist between objects and the interrelationship between matter and energy (Isaacs, 2000)

In short, physics can be understood as a study of matter, energy, and their interactions by observations and experiments which results in some fundamental laws aiming to explain, comprehend, and predict natural phenomena. In a more simple description, physics is often mentioned to provide the understanding of what lies behind everyday phenomena, how things happen (move and interact), how physical world works, what natural laws are, and essentially how we make sense of our physical universe.

Educators define physics in a quite similar way, in which they include their roles as physicists and as teachers:

- I do make an effort to remember that physics deals with the real world, and that there are remarkable and beautiful phenomena to be observed around us, often with no auxiliary equipment whatever, sometimes with very little. (Romer, 1993, p. 142).

- How richer my encounter with physics would have been if we had learned to articulate concepts, distinguish them from one another, see their role in everyday experiences and view them for what they are – the foundation of all the sciences. (Hewitt, 1995, p. 85).
- We have to come back to the fact that physics is a subject of insights and ideas. We want our students to see the world with more open eyes and with greater awareness of its workings. ... Let's do our best to see to it that they also remember the wonder, the connections, the excitement of discovery, and the poetry of the universe. (Lindenfeld, 2002, pp. 12-13).
- Everything we see in the physical world involves physics, ... Our students should learn to see that all the seemingly diverse phenomena in their surroundings are beautifully connected by surprisingly few rules ... (Hewitt, 2004, p. 17).

In a study at Maryland (Redish, Saul, & Steinberg, 1998), three groups of teachers were asked about their expectations of students' attitudes, beliefs and assumptions about physics. There were 26 high school teachers and 75 lecturers. They were attending or involved in various seminars and a project in physics education. They were described as “experienced physics instructors who have a high concern for educational issues and a high sensitivity to students” (p. 215). Their responses to a number of statements pertained to the relevance of physics to students' experiences in the real world were highly in agreement (93% - 95%). These educators agree on the first two of the following statements taken from Maryland Physics Expectations survey and disagree on the other two:

- To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed (item #18).
- Learning physics helps me understand situations in my everyday life (#25).
- Physical laws have little relation to what I experience in the real world (#10).
- Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course (#22).

Another study by Häussler and Hoffmann (2000) sought the responses from education professionals in Germany to the question: “What should physics education look like so it is suitable for someone living in our society as it is today and as it will be tomorrow?” The 73 participants consisted of physics teachers, curriculum developers, educationalists, scientists and other relevant professions. They mostly agreed on the impact of studying physics on making sense of scientific and technological innovations. The content areas related to modern age concerns such as energy, nuclear physics and power plants were voted to be important. The participants also viewed the ability to make evaluations on given situations as the most desired activities to develop in physics education. Around 90% of 342 teachers in Angell et al. (2004) mentioned that understanding everyday phenomena of the world is the important aspect of physics.



Overall, the physics teachers reviewed in the studies above expressed their desire that their students appreciate the roles of physics in explaining the real world phenomena.

### **3.1.2. The views of physics from the students**

Physicists agree that physics constitutes the principles underlying real-life phenomena, however it is not always the case with students having encountered physics in their study, especially in the first year of university level. It is now a common concern among educators that students perceive physics as a collection of unrelated formulas to be exploited in solving numerical problems. Moreover, the physics they study is believed to have little or no relevance to their everyday experience. Redish et al. (1998) gave the survey containing the four statements mentioned in the previous subsection to more than 1500 students from six tertiary institutions with traditional and innovative (Workshop Physics) modes of instruction. Not only do their responses to the statements differ from the experts' consensus (61% - 76% of the students at the beginning of the instruction), they also show no improvement after one term of instruction. Indeed, the students from all participating institutions exhibit a tendency toward less favourable perceptions of the relation between physics and the real world as a result of the instruction: at the end of the term only 52% - 72% of the students agree with the experts.

A number of reports indicate that showing the connection between physics and real-life phenomena could foster students' interest. Although physics taught at schools is generally perceived as difficult, heavily content loaded or boring, secondary students believe that practical exercises and showing its relevance to life may make the subject more interesting (Woolnough, 1994; Williams, Stanistreet, Spaal, Boyes, & Dickson, 2003). As the previous chapter shows, personalization is one of many ways to foster learning interest which leads to increased motivation. A study by Angell, Guttershrud, Henriksen and Isnes (2004) indicates that 80% of a sample of grade 12 and 13 students agrees that physics is about understanding the world. 72% of first year undergraduates in Prosser, Walker and Millar (1996) would say that physics is a study of physical world to their friends who had never done physics before.

The perceived relation between physics and real-life phenomena does not automatically lead instructors to using more real-life materials in teaching. Students mention that cookbook laboratory and teacher presenting materials on blackboard are the activities most frequently occurring in classrooms (Angell, et al., 2004). While 48% of the students claim that teachers

often perform demonstrations to illustrate concepts or phenomena, 75% desire to have it more often. Other study (Haussler & Hoffmann, 2000) reports that students think there is too much quantitative aspect of physics such as calculating, observing, reading and listening. On the other hand, activities such as inventing something, handling equipment, discussing the use of a new technology and evaluating the benefit of an innovation are not given much attention.

The emphasis that the instructors place on classroom activities is readily captured by the students who consequently adjust their learning approaches. Of the first year Australian students surveyed by Prosser, Walker and Millar (1996), 75% mention attending lectures, reviewing notes, learning formulas and doing exercises as their efforts in studying physics. Only 21% try to seek understanding and see how the principles work, and only 4% attempt to relate what they study to real world experiences. Approximately similar proportion of students mentions the corresponding techniques as advice to their friends on how to learn physics. Their counterparts in the United States (Elby, 1999) exhibit the same tendency: becoming familiar with formulas and concepts is rated more important than understanding real-life applications of physics in their efforts to study for a test. The ratings for the three activities are 4.53 (familiarity with formulas), 4.29 (familiarity with concepts) and 3.35 (understanding real-life applications) in a scale of 1 (not very important) to 6 (essential).

The inconsistency between students' view of physics and their learning approach is apparent in the two studies described above. Although 72% of the students illustrate physics as relating to the real world, only 4% try to learn it by understanding their real world experiences while 75% prefer to use traditional learning methods (Prosser, Walker, & Miller, 1996). Students report spending more time on formulas than on understanding real-life applications to prepare for a test. However, they advise concentrating more on real-life applications and qualitative concepts rather than on formulas if somebody wants to understand physics more deeply (Elby, 1999).

Students seem to have an interest in the physics they study because it helps them to make sense of the world around them. This is one of the basic principles of cognitive learning theory. Students are also aware of the importance of studying concepts and real-life applications, rather than only memorizing formulas and practising calculations, if they really want to acquire a good understanding. Obviously, students apply the constructivist view in their effort to make learning meaningful. In reality, nevertheless, students prefer to memorize formulas and imitate problem solving algorithms from the textbook to pass an exam. This

approach undoubtedly contributes to students' view that physics becomes less connected to the real world. The so-called traditional instruction has been suspected to cause this and other problems in learning physics, which is discussed in the next section.

### **3.2. Problems with traditional teaching approaches**

Students enter physics courses with prior knowledge or preconceptions about how the world works. There is mounting evidence that some of this prior knowledge is not scientifically correct (Gilbert, Watts, & Osborne, 1982; Gunstone, 1987; Halloun & Hestenes, 1985; Hills, 1989; Van Hise, 1988), for example heavier objects fall faster than lighter objects, bigger objects exert a larger force than smaller objects, and an object moves because a force is acting on it.

Prior knowledge that is not scientifically accepted or “misconception” is a natural but unwanted outcome of knowledge construction. Students try to make sense of the world around them by assessing new information based on existing structures. According to Piaget, either the new information or the existing structures needs to be modified so that they fit in to one another. This adaptation process is affected by students' interpretation of new information. The interpretations are based on their past experiences, stored knowledge and motivation. Different students create different interpretations of the same information. The resulting knowledge consequently is different for each student and some parts of this knowledge may be scientifically incorrect.

Not all teachers are aware of the prior knowledge that students bring to their learning (Hestenes, 1987; Van Hise, 1988). Most of them “have failed to appreciate that *in nearly every student there is a five-year-old 'unschooled' mind struggling to get out and express itself*” (Gardner, 1993, p.5, emphasis in original). This influences the approaches to teaching physics in the sense that the preconceptions are never explicitly addressed. These approaches are called traditional because they have been adopted for a long time, until the 1990s, when new instructional approaches started to be trialled and implemented.

The traditional teaching approach is characterized by lectures requiring little or no active student involvement, laboratories with prescribed practical procedures, and tests or examinations emphasizing quantitative algorithmic problem solving procedures (Hake, 1998a). Traditionally, a lecturer presents the material from textbook, performs problem

solving examples and occasionally conducts demonstrations. Students listen to the presentation, take notes, but rarely ask questions or give comments. In recitation or tutorial sessions, students just copy solutions presented by teaching assistants into their notebooks. Arons (1997) and Hestenes (1987) recognize that conventional homework problems, test questions and most end-of-chapter exercises in textbooks put emphasis on calculation and numerical results without probing into conceptual understanding.

It has now been widely acknowledged that the traditional teaching approach contributes to the problems of misconception and unsatisfactory conceptual understanding in introductory physics. Traditional instruction fails to rectify misconceptions, especially when instructors are unaware of their existence. As a consequence, these misconceptions are rarely identified and exposed at the beginning of instruction, which makes it difficult for a conceptual change to happen. Students still hold their misconceptions after they are taught the correct concepts (Halloun & Hestenes, 1985; Hake, 1998a; Hestenes, Wells, & Swackhamer, 1992; Mazur, 1992; Cahyadi, 2002). Extensive practice with problem solving does not necessarily change the misconceptions. Kim and Pak (2002) revealed that students still possessed problematic conceptual understanding although they had worked on more than 1000 physics problems. Even students who achieve high grades often cannot apply basic physical principles to solve problems in realistic situations (Moore, 2004).

Based on research of student understanding in several areas of introductory physics, McDermott (2001) puts forward a generalization that “teaching by telling is an ineffective mode of instruction for most students” (p. 1133). Mazur (1997) states that the traditional lecture style does not encourage students to actively think or to effectively construct knowledge. A good lecturer may present physics in an interesting way, but students do not always know how to learn it appropriately (Hestenes, 1998).

From the constructivist’s point of view, the traditional teaching approach fails to promote knowledge construction because of various reasons. The sheer amount of information presented in a lecture is too much for students’ working memory to cope with. Students are not given enough time to have social interactions which facilitate their learning. Misconceptions are often ignored, and this influences the process of understanding new information. Concepts are usually presented in abstract forms with almost no real-life applications. Although students in introductory physics courses should already reach formal

operational in Piaget's stages of cognitive development, many still have difficulties in understanding abstract ideas.

The traditional approach essentially does not take into account many principles of constructivism. This was realized by physics education researchers who proposed various innovations in instruction based on constructivism. The next section examines one of these innovations which has become popular since the 1990s. It is known as the "interactive engagement approach".

### **3.3. Interactive engagement approaches**

Since early 1990s, many physics education researchers have proposed various teaching approaches to solve the problems contributed by traditional instruction. One foremost feature of these approaches is creating a condition in which students are motivated to construct knowledge by themselves, rather than the knowledge being transmitted by their instructor as in the traditional approach. These approaches have various labels such as interactive engagement, active learning and guided inquiry. The constructivist theory of learning informs the philosophy behind the approaches. This thesis uses the term interactive engagement.

Interactive engagement (IE) methods are those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors. (p. 65, Hake, 1998a)

In guided inquiry, "the teacher provides only the materials and problem to investigate. Students devise their own method procedure to solve the problem" (p. 1, Colburn, 2000). Active learning has some characteristics where the students are actively engaged, interact with their peers, receive immediate feedback, take responsibility for their learning while the instructor is more of a facilitator (Knight, 2004).

A survey (Hake, 1998a) indicates that involving students actively in the so-called interactive engagement approaches improves their conceptual comprehension, at least as shown by learning gains in Force Concept Inventory. The Force Concept Inventory or FCI (Hestenes, Wells, & Swackhamer, 1992) is a qualitative multiple-choice test "designed to assess student understanding of the *most basic* concepts in Newtonian physics" (Hestenes & Halloun, 1995, p. 502, emphasis in original). One purpose of this test is to evaluate the effectiveness of a teaching instruction by comparing results of the test given before and after instruction (Hestenes et al., 1992). The validity and reliability of FCI was established by checking

variables of its predecessor, the Mechanics Diagnostic Test (Halloun & Hestenes, 1985), and by conducting interviews with students taking FCI. The latter study reports that the test results are independent of maths background, socioeconomic level and even instructor's competence.

Although interactive engagement approaches enhance conceptual understanding, not all students feel comfortable with these. This section also presents some reports showing that students' attitudes to non-traditional approaches are not always positive.

### **3.3.1. Improving understanding with interactive engagement approaches**

Hake (1998b) lists an extensive list of references on interactive engagement approaches. Some examples of interactive engagement methods are:

#### **1. Peer Instruction (Mazur, 1997).**

The aims of this method are to encourage student interaction in the lecture and to focus students' attention on underlying concepts. Students are given short conceptual multiple choice questions and some time to think about the answers. Then, they are asked to convince their neighbours that they have correct answers accompanied by appropriate reasons.

Students' answers may provide feedback to instructors who will proceed to explain the correct answers and reasoning.

#### **2. Active Learning Problem Sets or ALPS worksheets (Van Heuvelen, 1991).**

These worksheets provide step-by-step guidance for students to systematically solve physics problems. The procedure in solving a problem involves pictorial, physical and mathematical representations as well as evaluation in the units and magnitude of the answers. Students are expected to understand the physical phenomena in the problems before writing any mathematical formulations.

#### **3. Constructivist classroom dialogue (Mestre, 1991).**

In this discourse, an instructor takes the role of a facilitator rather than transmitter of knowledge. By asking qualitative questions, the instructor first assesses students' conceptions, and then helps them see the discrepancies between their preconceptions and scientific concepts. The learning process takes place when students can resolve those discrepancies thus assimilating new knowledge into their existing intellectual resources.

#### 4. Interactive lecture demonstration (Sokoloff & Thornton, 1997).

Demonstrations can be inserted in any teaching approach without radically changing existing structures. The instructor initially describes and starts a demonstration for the class. Students are then asked to record their individual predictions, engage in small-group discussions, record their final predictions and hand in the prediction sheets. The instructor scans the predictions and carries on with the demonstration. A few students may be asked to describe and discuss the results. The instructor may proceed with presenting analogous phenomena based on the same concepts.

To assess the effectiveness of a teaching approach, Hake (1998a) defines the average normalized gain  $\langle g \rangle$  as the ratio of actual average gain  $\langle G \rangle$  to the maximum possible average gain, i.e.:

$$\langle g \rangle = \frac{\% \langle G \rangle}{\% \langle G \rangle_{\max}} = \frac{\% \langle S_f \rangle - \% \langle S_i \rangle}{100 - \% \langle S_i \rangle}$$

where  $\langle S_f \rangle$  and  $\langle S_i \rangle$  are final (post-instruction) and initial (pre-instruction) class averages.

The following are the ranges of  $\langle g \rangle$  to indicate the level of course effectiveness:

“high-g” courses are those with  $\langle g \rangle \geq 0.7$

“medium-g” courses are those with  $0.3 \leq \langle g \rangle < 0.7$

“low-g” courses are those with  $\langle g \rangle < 0.3$

Hake (1998a) presents a survey involving a total of 6542 students who were given the Mechanics Diagnostic Test (Halloun & Hestenes, 1985), the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) or the Mechanics Baseline Test (Hestenes & Wells, 1992). It was found that all of 14 traditional courses (involving 2084 students) yielded the average  $\langle g \rangle = 0.25$  (SD = 0.04) which falls in low-g region. 85% (41 courses, involving 3741 students) of 48 interactive engagement courses fell in medium-g region and 15% (7 courses, involving 717 students) in low-g region. The average  $\langle g \rangle$  of the 48 courses was 0.48 (SD = 0.14). None of the courses surveyed produced  $\langle g \rangle$  in high-g region.

Hake also identified the problems afflicting the seven IE courses which fall in low-g region. These include insufficient training of instructors new to IE methods, failure to communicate to students the nature of science and learning, lack of grade incentives for taking IE activities seriously, a paucity of exam questions which probe the degree of conceptual understanding induced by IE methods, and the use of IE methods in only isolated components of a course.

In another report, Hake (1998b) presents comments from the instructors of the problematic IE classes as well as his suggestions on how to overcome the problems. One of the suggestions is to ensure students' preparation by administering reading quiz at the start of each lecture, which should be graded and counted toward the total score.

Principles of constructivism discussed in Section 2.3 may explain why most of the interactive engagement courses succeed in improving learning gains. The social interaction in Peer Instruction encourages students to form an opinion and defend it by trying to convince their peers on the plausibility of their opinion. They have to constantly access their existing knowledge to give explanations. Theories of cognitive development from Vygotsky and Piaget (Section 2.2) are very much reflected in this approach. The Active Learning Problem Sets provide multiple ways to understand a physics problem. Various representations help students to retrieve different items from their cognitive structure and combine these to create more links thus making the structure more sophisticated. Creating multiple representations of new information or problem is also one of learning stages proposed by Bruner (Section 2.2). In Constructivist Classroom Dialogue, the instructor provides scaffolding and assists students through the process of conceptual change. The Interactive Lecture Demonstration involves principles of Vygotsky's social interaction, concepts of Piaget's process of adaptation, and authentic learning in some degree.

Despite the relative success in improving student conceptual understanding, it became apparent that interactive engagement approaches were not always warmly welcomed by students (Redish, Saul, & Steinberg, 1998; Coleman, Holcomb, & Rigden, 1998; Mottmann, 1999; Fagen, Crouch, & Mazur, 2002). Several reports on how students responded to non-traditional approaches are presented in the next subsection.

### **3.3.2. Students' attitudes towards interactive engagement approaches**

Redish, Saul and Steinberg (1998) recognized the importance of assessing students' expectations in order to facilitate the desired transformation in their attitude towards physics. Their advice to physics educators is to change the focus from "What are we teaching and how can we deliver it?" to "What are the students learning and how do we make sense of what they do?" (Redish & Steinberg, 1999, p. 24). In other words, instructors need to learn more about their students' experience of learning.



Most reports on the reforms of teaching methods (Hake, 1998b) present the improvement in student understanding. Only a few (Sharma, Millar, & Seth, 1999; Leslie-Pelecky, 2000; Steinberg & Donnelly, 2002; Scherr, 2003) discuss the student attitudes. Not all responses from students, however, are encouraging. Exposure to any form of physics instruction increases unfavourable attitudes towards learning physics (Redish, Saul, & Steinberg, 1998) and decreases students' interest (Coleman, Holcomb, & Rigden, 1998). A significant number of students still prefer to be taught in traditional style even after they attended an "active-learning" programme in an introductory physics course (Mottmann, 1999). Despite its successful and wide implementation, Peer Instruction (Mazur, 1997) only slightly improves student attitudes (Crouch & Mazur, 2001). One of the challenges faced by instructors using Peer Instruction is students' resistance to actively engage in a discussion with their peers (Fagen, Crouch, & Mazur, 2002). This may demonstrate that some students are not comfortable with a new approach in the classroom.

There are several reasons for the students' preference towards traditional teaching approaches. Elby (1999) speculated that a long history of successfully adopting rote learning habits contributes to students' beliefs that focusing on physics formulas and problem solving algorithms is essential to obtaining good grades in an examination. Students usually vote lectures and problem assignments as the most useful activities for their learning (Cahyadi, 2003; Coleman, Holcomb, & Rigden, 1998). The situation in a typical lecture may influence students' ideas of learning physics. Fritschner (2000) identified the lecturers' expectation for their students to turn up and pay attention in class, while some students were discouraged from participating in the class by the perceived behaviour of the lecturers.

Factors affecting motivation (Section 2.4) can also be used to explain students' attitudes towards any instructional approaches. Students may have low expectancy to succeed in convincing their peers because they find it difficult to elaborate their thoughts, they do not have adequate cognitive resources, or simply the topic is not interesting. In having a discussion with their instructor, students who have low self-efficacy may refrain from responding to instructor's questions. Working collaboratively in a group is useful to foster growth of knowledge, however students may think that the efforts involved in resolving several conflicting ideas do not contribute to their goal of passing an examination.

As the previous chapter has pointed out, providing students with opportunities to engage in authentic learning may produce a better learning achievement. Not only does authentic learning incorporate many constructivist principles, it also promotes student motivation by making learning interesting and meaningful. In physics education, there is a growing effort to include aspects of authentic learning in instruction. We label that effort as “exposing students to real-life materials which can take the form of objects, activities, or phenomena”. There are at least two ways to incorporate real-life materials into teaching and learning: (1) increasing the amount of real-life examples and problems in textbooks, and (2) including real-life exposure in teaching approaches. The next section elaborates these enterprises.

### **3.4. Inclusion of real-life materials**

The term “real-life materials” refers to objects, phenomena, settings and activities which can be found in the real world. In introductory physics, real-life materials are objects, phenomena, settings and activities that students commonly come across in their life. Nowadays, students can easily access information from many different sources including family, friends, schools, mass media, internet, etc. Information available to the public can also be regarded as real-life materials.

There are many ways real-life materials can be included in instruction, from simple narrations, classroom demonstrations, hands-on activities, to computer simulations. This section presents the utilization of real-life materials in two categories: (1) in textbooks, and (2) in instructional strategies. Classic introductory physics textbooks such as *Fundamentals of Physics* by Halliday/Resnick and *University Physics* by Sears/Zemansky have undergone progressive change since their first editions in terms of the amount of real-life materials included in examples, questions, and problems. Recent editions of the textbooks have more stories about natural phenomena, examples of physics applications, problems relating to everyday experiences, and colourful pictures than their previous editions. In physics education research, real-life materials have attracted increasing utilization as elements of instructional strategies. Almost all innovations in teaching use some forms of real-life materials. A lecturer can talk about some physics principles involved in skateboarding, or students can take a video of their friend doing the skateboarding and analyze the event using a computer software. Whatever the form they take, real-life materials have some impacts on the process of knowledge construction, which are discussed at the end of this section.

### 3.4.1. Real-life materials in introductory physics textbooks

A textbook is modified to accommodate the change in the nature of student population, the ever expanding technological breakthroughs and the findings from education research. Over different periods of time, introductory physics textbooks have different emphases (Holbrow, 1999). Textbooks in the mid 19<sup>th</sup> century presented detailed depictions of apparatus, demonstrations and devices, accompanied by descriptions of the mechanisms. The texts did not encourage an active involvement of the readers to make better use of the items described. This was changed towards the beginning of the 20<sup>th</sup> century when Gage, Hall and Millikan argued for the significance of laboratory-based activities in their texts. In the middle of the 20<sup>th</sup> century, however, this emphasis was no longer adopted by the next generation of textbooks which then had a wider readership including science and engineering students. Sears and Zemansky's texts *University Physics* and *College Physics* were used widely since their first publication in 1949 (Holbrow, 1999). The former, which we shall refer to as UP, presents conceptual explanations followed by examples using the application and showing how to solve problems. Another popular textbook made its first appearance following a crucial moment in science and technology era. Shortly after the Soviet Union launched its Sputnik, the first edition of Halliday and Resnick's text, *Physics for Students of Science and Engineering* or *Fundamentals of Physics* (FP) as it was entitled for the subsequent editions, was published in 1960. To accommodate the growing knowledge base of physics, this textbook has a higher level of abstraction than Sears and Zemansky's text.

In the 1980s, there was a realization that the material in standard introductory physics syllabi had grown very much but this did not result in a satisfactory student understanding of the material. An effort to find a solution was initiated by the Introductory University Physics Project (IUPP) over the period 1987 – 1995. One of the principles in developing new model courses is the establishment of story-line or context to give a sense of coherence in the content. This feature is included in *Physics in Context* textbook which serves as one of IUPP model curricula. Using the textbook, students were able to recall the concepts learned instead of reciting unrelated pieces of information (Coleman, Holcomb, & Rigden, 1998). One of the most important achievements of IUPP was “the context-based design of a syllabus that was demonstrated to be strong and attractive to students” (p. 136). The authors are arguing that presenting students with real-life phenomena, as opposed to using only narratives of principles and formulas, evokes students' interest in learning.

Some recently developed textbooks indicate a new emphasis on the exposure of real-life materials (Amato, 1996). Moore's (2003) *Six Ideas that Shaped Physics* includes "synthetic" and "rich-context" problems which are basically short stories on real objects or events. Another text, *Physics: A Contemporary Perspective* by Knight (1997), uses a story line framework to explain concepts. Two other texts, *Workshop Physics* by Laws (2004) and *Electric and Magnetic Interaction* by Chabay and Sherwood (1994), require students to engage in hands-on experimentations as the main activity of the course.

#### **3.4.1.1. The inclusion of real-life materials in two introductory textbooks**

Over the last two centuries, introductory physics textbooks have been modified in such a way that real-life materials are included in increasing amounts. New textbooks such as *Workshop Physics* and *Electric and Magnetic Interaction* have hands-on activities as the dominant feature which is almost non-existent in the textbooks of mid 19<sup>th</sup> century. Even in a single textbook, the development occurs throughout its editions, later editions tend to include more real-life materials.

This subsection reports a study by the author on the extent to which real-life materials are included in textbooks. The textbooks to focus on are: *Fundamental of Physics* (Halliday & Resnick, 1966, 1981, 1988; Halliday, Resnick, & Walker, 1993, 1997, 2001) and *University Physics* (Sears & Zemansky, 1957; Sears, Zemansky, & Young, 1976, 1982, 1987; Young & Friedman, 1996, 2000). These two textbooks have been widely used in institutions around the world, have undergone many revisions, and have been in circulation long enough to reflect the change in the emphasis of what to offer to students.

There are many ways the authors of the textbooks mentioned above include real-life materials. Tables 3.1 (p. 46) and 3.2 (p. 47) summarize the textbook authors' intentions to show connections between physics and the real world.

In the preface or introduction to the book, the authors express their intention to include many real-life phenomena into the texts. In early editions, physics is defined as the science of measurement. Recent editions emphasize the real world relevance of physics. There are several small sections such as subchapters, essays and case studies dedicated to describe applications of physics. Introduction to a chapter has also changed. The straightforward

terminology and conceptual statements in early editions are replaced with questions, narrations or photographs showing everyday phenomena in later editions.

Figures (including graphs, diagrams and photographs) in textbooks serve to clarify conceptual explanations and questions. As the textbooks progress through their recent editions, so does the appearance of figures. There are a number of ways in which figures have been modified to make physics more real and not just an exposition of abstract ideas. Figures have been given more colours and enhanced in dimensions from 2-D to 3-D, because “colour allowed us to show the various parts more clearly, to emphasize important aspects, and to give a sense of depth to three dimensional situations” (FP 4<sup>th</sup> edition, p. v). Photographs are also used to exhibit real-life objects or events in both textbooks. The ‘dot’ (●) or ‘block’ (■) is modified into real-life objects such as apples, car, flower-pots, motorists or children.

Other features such as worked examples, qualitative questions and quantitative problems containing real-life objects or situations have increased as both textbooks have been progressing through their recent editions. We consider such terms as “block”, “particle”, “object”, “body”, or “mass” as non real-life objects. Specially constructed phenomena, for example manipulating the properties of a gas, arranging electric charges in an odd distribution, and sending a current in peculiar shapes of wire are regarded as non real-life events. In the 9<sup>th</sup> edition of UP, the writers explicitly mentioned that “many examples are drawn from real-life situations relevant to the students’ own experiences” (p. iv) and “example problems ... to illustrate the application of the concepts of physics to real world problems” (p. x). These statements are reiterated in the 10<sup>th</sup> edition. The proportion of sample problems mentioning real objects or real-life events increases in both textbooks.

The proportion of end-of-chapter quantitative problems mentioning real-life objects or events slightly increases in both textbooks. The percentage of the photographs relative to the total number of figures steadily increases throughout the first four editions of FP. In the 5<sup>th</sup> and 6<sup>th</sup> editions, the proportion decreases but this is compensated by an increasing number of illustrations depicting real-life figures with natural panorama as backgrounds.

Table 3.1. Features to relate physics and real life in *Fundamentals of Physics*

Edition	Feature				
	Preface	Introduction	Special feature	Chapter introduction	Figure
1				terminologies, conceptual statements or briefly touching the previous topics	
2					
3	Questions and essays are intended to connect physics and real-world applications		Separate and self-contained essays on the interesting applications of physics such as sports, toys, amusement parks, medicine, lasers, holography, space, superconductivity, concert-hall acoustics and others.	32 out of 49 chapters have introductions that attempt to relate real-life phenomena to the concepts in the chapter, a photograph with explanatory caption	2-D figures, two colours
4	“we have devoted considerable attention to illustrating real-world applications of physics topics” (p. v), “Questions ... relate even more to everyday phenomena ...” (p. vi), “Applications and guest essays ... emphasize the relevance of what physicists do ...” (p. vi), and “Sample problems ... often built around real-world physics applications ...” (p. xii).	“physics is based on measurement”			A photograph and a caption ending with questions
5	“We not only <i>tell</i> students how physics works, we <i>show</i> them, and we give them the opportunity to show us what they have learned by testing their understanding of the concepts and applying them to real-world scenarios” (p. vii, italics in original)	Studying physics “offers ... the opportunity to learn what makes our world ‘tick’ and to gain insight into the role physics plays in our everyday lives” (p. xiii)			
6	“Problems with applied physics, based on published research, have been added in many places, either as sample problems or homework problems” (p. xx).	“The primary goal of this book is to teach students to reason through challenging situations, from basic principles to a solution” (p. xix).	Some quantitative problems are parts of a continuing story.		

Table 3.2. Features to relate physics and real life in *University Physics*

Edition	Feature			
	Introduction	Special feature	Chapter introduction	Figure
2	physics is the science of measurement	Subchapters showing the relevance of physics in several areas. These additional subchapters are intended “to broaden subject coverage” (p. v).	Terminologies, conceptual statements or briefly touching the previous topics	black-and-white photographs to show a piece of apparatus or a sequence of events
5				photographs which require special techniques to obtain and which are not commonly seen in everyday experience,
6	physics is the science of measurement and the observation of the phenomena of nature to help us to understand the physical world and its mechanisms			
7	“learn the value of physics ... in gaining insight into everyday phenomena ... understanding of the world we all live in”, “everyday experience offers abundant examples of mechanical principles”, “every physical theory must be grounded in experimental observations of phenomena in the physical world” (p. 2).		A black-and-white photograph of a real-life event, an everyday object, or a technological, no information or caption.	
9	“Physics is not a collection of facts and principles; it is the process by which we arrive at general principles that describe how the physical universe behaves” (p. 2), “... physics as a towering achievement of the human intellect in its quest to understand our world and ourselves” (p. 1), “physics is a way of looking at the universe and understanding how the universe works and how its various parts relate to each other” (p. x), and “physics is very much a part of the world around us” (p. viii).	Case studies which purpose is to “give ... examples of applying physics to real science or engineering problems” because “physics relates to the real world” (p. xi). There are 10 of these case studies which include ‘Projectile Motion with Air Resistance’, ‘Automotive Power’, ‘Energy Resources’, and ‘Superconductivity’	Questions or statements about everyday experiences	Photographs showing real-life objects or events
10	The statements above and “Physicists observe the phenomena of nature and try to find patterns and principles that relate these phenomena” (p. 1).			

The qualitative questions as end-of-chapter exercises are designed to be thought-provoking and related to everyday experiences so that they “help students to attain a deeper understanding of principles and to relate these principles to their everyday lives” (UP 6<sup>th</sup> edition, p. iii). In the later editions of FP, there are not as many questions mentioning real-life phenomena as in the previous editions due to the change in the type of questions. Since the 5<sup>th</sup> edition, a great number of those qualitative questions ask students for comparison or ordering a series. This type of question is called a “ranking task” and generally does not mention real-life objects or events. The distribution of real-life materials in the two textbooks is summarized in Figures 3.1 and 3.2.

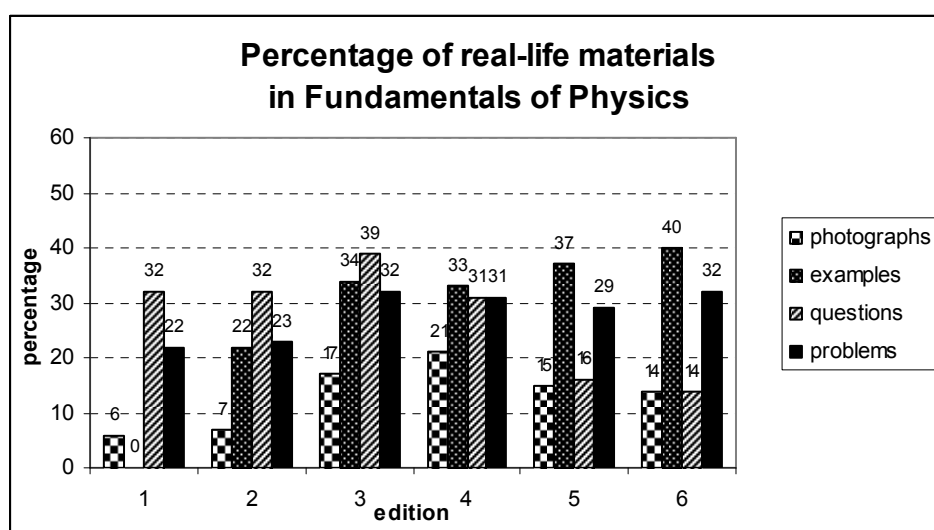


Fig. 3.1. Percentage of photographs, examples, questions and problems citing real-life objects or events in *Fundamental of Physics*.

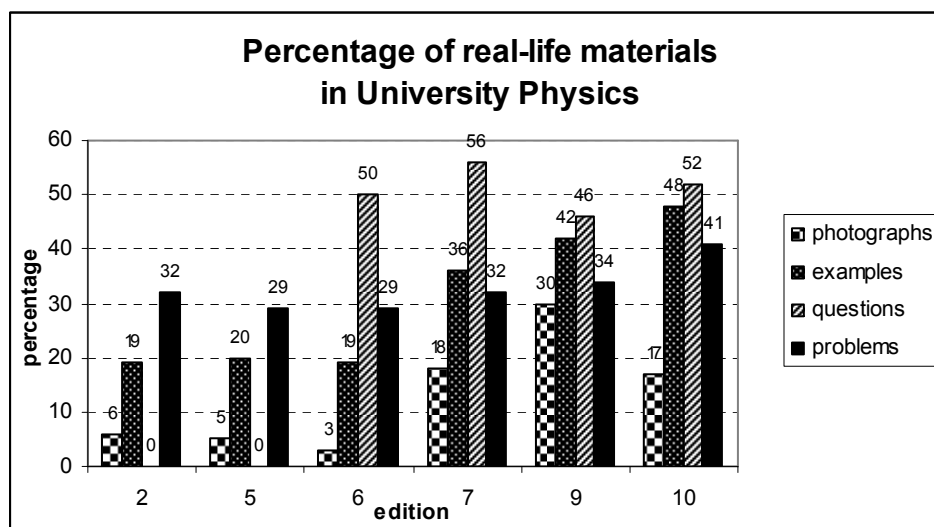


Fig. 3.2. Percentage of photographs, examples, questions and problems citing real-life objects or events in *University Physics*.



### 3.4.1.2. The real-life materials in recent other textbooks

Recent editions of other introductory physics textbooks exhibit a similar tendency toward this way of presenting physics. Giancoli (2000) attempts to show that physics is what the students experience in their everyday life by using a photograph to open each chapter. The photograph is accompanied with a caption which briefly introduces the chapter and sometimes asks a question. This is intended to capture reader's interest and motivation before a conceptual explanation is presented. Physics is mentioned as "the most basic of sciences ... deals with the behaviour and structure of matter" (p. 1). The author deliberately integrates various situations which can be explained using physics. "Physics Applied" marginal notes signify the spots of these physics applications ranging from technology, engineering, architecture, earth sciences, environment, biology, medicine and daily life. Some of "Physics Applied" notes serve as worked examples, many of which purposely show "how physics is useful in other fields, and in everyday life" (p. 1). The proportion of examples mentioning real-life objects or events is 51%. About 10% of these examples are labelled as "estimating examples" that guide students to make assumptions and order-of-magnitude estimations. This type of example always describes a real-life situation. The percentage of end-of-chapter qualitative questions and quantitative problems containing real-life objects or events are, respectively 44% and 41%.

In their latest edition, Serway and Jewett (2004) state that the purpose of their text is to assist students to achieve conceptual understanding through a presentation with many helpful features and through various physics applications in other areas and everyday life. Physics is claimed as "the most fundamental physical science ... concerned with the basic principles of the universe" (p. 1). The authors' effort to bring physics closer to real world situations is apparent in the way they present figures. Many of the figures contain photographs of a real object as the focus of attention or a person acting as an observer. The figures are completed with some graphical drawing to clarify the situation. The photographs or figures with photographs constitute 22% of all figures outside question/problem sections. In addition, each chapter begins with an interesting photograph and an explanatory caption. The percentage of qualitative questions and quantitative problems citing real-life objects or events is 47% and 35%, respectively.

Tipler and Mosca’s (2004) definition of physics is “the science of matter and energy, space and time. It includes the principles that govern the motion of particles and waves, the interaction of particles, and the properties of molecules, atoms, and atomic nuclei, as well as larger-scale systems such as gases, liquids and solids” (p. 1). The inclusion of applications of physics in many areas is obvious in their latest text as they also mention that “physics is the science of the exotic and the science of everyday life” (p. 2). Each chapter is introduced with a photograph, a brief caption and a question which serves as one of the worked examples within the chapter. The proportion of worked examples that mention real-life objects or events is 36%, a few of which are labelled as “Put It in Context”. This type of example is intended to present the problems in real world situations where an interpretation is to be made from the result of a calculation. There is a particular category for end-of-chapter exercises other than the conceptual and quantitative problems. It is called ‘Estimation and Approximation’ and is designed to “encourage students to think more like scientists or engineers” (p. xxiii). The questions or problems mentioning real-life objects or events constitute 21% of the overall end-of-chapter exercises. The authors added new photographs throughout the book to “bring to life the many real-world applications of physics” (p. xxv). These photographs make up 17% of the total number of figures outside the question/problem sections.

The distribution of real-life materials in the three textbooks (Giancoli, 2000; Serway & Jewett, 2004; Tipler & Mosca, 2004) is summarized in the figure below.

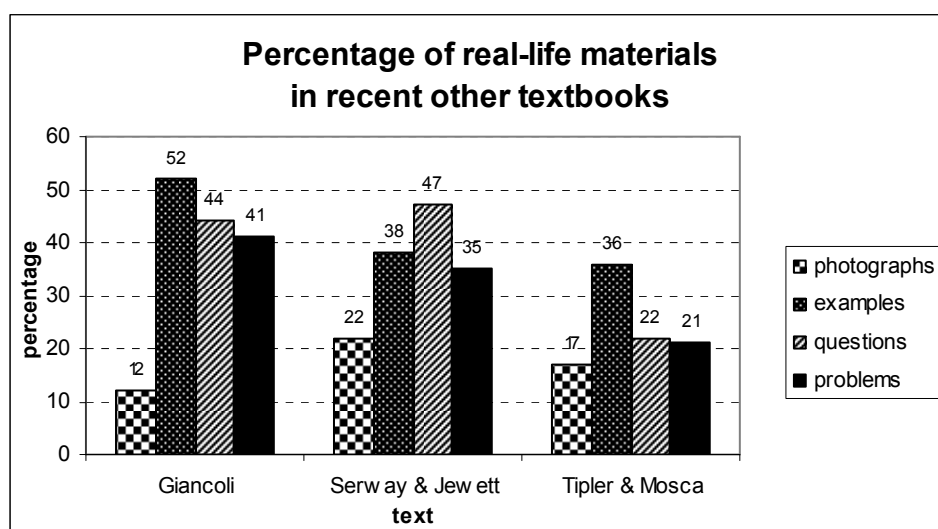


Fig. 3.3. Percentage of photographs, examples, questions and problems citing real-life objects or events in three other textbooks.

### 3.4.1.3. How to benefit from the textbooks

The inclusion of real-life materials is also designed to make physics texts visually more attractive, thus promoting student motivation and interest. As Fuller (1993) points out, physics potentially has an extensive variety of examples which can stimulate curiosity, offer challenge and arouse interest in students. As the last chapter has suggested, these are influential factors for motivating students to learn physics. Building the right motivation and interest is crucial towards helping students to achieve the learning outcome: “If students don’t pay attention because they perceive the material and its presentation to lack interest, importance, or usefulness – can we expect them to learn what we teach?” (Coleman, Holcomb, & Rigden, 1998, p. 136). Real-life materials also unequivocally demonstrate the relevance of physics in everyday life and other areas. This relevance aspect is one of the reasons why students are interested in physics (Woolnough, 1994; Williams, Stanisstreet, Spall, Boyes, & Dickson, 2003). As the previous chapter has discussed, personalization is one of many ways designed to make learning interesting. By showing that physics has utility and relevance beyond the lecture theatre or text-books we could expect students to choose physics for their further study or as a career.

The following practical suggestions are proposed in order to make the best of a textbook. These are based on the author’s analyses and the stated intentions of the authors of the five textbooks above. These suggestions can be implemented without radically modifying existing instructional approaches:

### 1. Introducing the material

It is a customary practice in traditional instruction to introduce a new topic by briefly reviewing previous materials, making a link between the previous and the new material, or going straight away to definitions, terminologies or formulas. In the latest editions of the textbooks reviewed previously, an interesting photograph serves as a chapter opener. In addition, narrations or questions of many other relevant phenomena or applications can be used to induce student’s curiosity before discussing the target concepts. The technique for getting students’ attention to start a lesson is called “introductory focus” (Eggen & Kauchak, 2004). In this age of technology, there are abundant examples of how physics can explain the underlying mechanism from simple everyday phenomena to sophisticated modern innovations.

### 2. Presenting the worked examples

This is a good opportunity to demonstrate that physics is not just about problem solving and mathematical manipulation. There are many worked examples mentioning real-life objects or events in the recent editions of the five texts. The percentage of such worked examples is 36% - 52%. Furthermore, it is important to conclude a problem solving procedure with an interpretation of the result, as most of worked examples in the texts end up with comments on numerical results or further questions.

### 3. Assigning problems for homework or tutorial exercise

The qualitative questions or quantitative problems can be chosen from those containing real-life objects or events. The proportion of end-of-chapter exercises citing real-life objects or events is between 14% and 52% for qualitative questions and between 21% and 41% for quantitative problems in the latest edition of the five textbooks. Students should also be asked to provide comments on the result of their calculation.

### 4. Creating other activities

In addition to being assigned to do problem solving, students can be encouraged to carry out activities that reflect the applications of physics in the real world. The five texts contain a number of features describing the relevance of physics in many areas. They are 21 Essays in the 3<sup>rd</sup> edition and 17 Essays in the 4<sup>th</sup> edition of FP, 10 Case Studies in the 9<sup>th</sup> and 10<sup>th</sup> editions of UP, 71 short passages of Physics Applied in Giancoli (2000), 4 Applications in Serway and Jewett (2004), and 7 Exploring web-essays in Tipler and Mosca (2004), all of which can be utilized as resources for reading assignments or discussions. Other types of activities such as library research, home experiments or group projects on the relevance of physics in life may serve to make physics closer to students' personal life and to encourage creativity.

### 5. Designing the exam problems

Exams are often the most important thing that students perceive in a course. Exam problems may reflect what an instructor expects the students to master. Exam problems may also dictate students' learning approach. If we want to emphasize that physics has everything to do with phenomena in the real world, exam problems should mirror this intention. Students can be required to give reasons to explain a phenomenon, provide relevant examples of a concept, present interpretation on numerical result, and so on.

In addition to being included in introductory physics textbooks, real-life materials are utilized as elements of teaching approaches which the next subsection elaborates.

### **3.4.2. Real-life materials in teaching approaches**

Many proposed innovative teaching approaches are designed to use real-life materials in various forms. Researchers in physics education have incorporated everyday objects, real world phenomena, technological invention stories, simulations and other tools which have real-life association as significant components in their innovative instructional methods. The methods are in various styles and varying degrees of student interaction with the material. This subsection presents a review of several methods, each of which is discussed in terms of the role played by real-life materials and the expected or reported outcomes.

#### **1. Instructor's talk**

In the traditional teaching approach, an instructor plays a central role and students are usually placed in a passive state of learning. Even in this situation, an instructor has many opportunities to introduce real-life phenomena and link them to the target concepts.

Instructors could use the introductory focus mentioned earlier to begin a lesson. They could talk about an everyday experience or a current media news items and then make a link with the target concepts. It can be followed with questions, assignments, demonstrations and laboratory experiments. The inclusion of such discussion has been shown to improve students' motivation, pass rate, conceptual retention and even course enrolment (Fonseca & Conboy, 1999; Robinson, 1991; Vondracek, 2003).

#### **2. Reading a text**

Students may be encouraged to study in an independent way while the instructor provides assistance as a learning facilitator. Real-life objects or contexts are included in specially designed reading materials, for example "bridging explanation" text (Brown, 1992) and "Supported Learning in Physics Project" text (Whitelegg, 1996). The former illustrates a related succession of events to bridge a situation correctly understood by students and the target problem. Post-test performance of students reading the bridging explanation text is better than that of students reading other types of text. Each unit in Whitelegg's text focuses on a specific real-life context which involves several physics areas. The learning strategy for each section of a unit follows a sequence of self-pretest, preliminary research to bring to discussions, text on the concepts, self-assessment questions, and a group project. A report

(Barkworth, Jenkinson, Parker, & Wright, 1998) indicates that real-life contexts clarify the connection between concepts and applications, which consequently make learning easier and more enjoyable. Another similar approach in high school physics which introduces real-life context prior to concept explanation results in a growth of physics enrolment (Whitelegg & Parry, 1999).

### 3. Problem solving

Concept mastery can also be acquired in specially constructed physics problems. A “context-rich problem” (Heller, Keith, & Anderson, 1992; Heller & Hollabaugh, 1992) is a short story set in a real situation. The question to be answered is not explicitly stated in terms of physics variables. The information given in the story may be too much or too little and some realistic assumptions are needed to simplify the problem. Context-rich problems used in cooperative groups are reported to improve students’ performance in conceptual understanding (Heller et al, 1992; Cummings, Marx, Thornton, & Kuhl, 1999). Student’s tendency to answer physics problems based on everyday observations prompted another study on conceptual understanding (Cahyadi, 2002b; Cahyadi & Butler, 2004). A group of first year undergraduate students were presented with problems of falling objects in two contrasting situations where air resistance was ignored (idealized case) and could not be ignored (real-world case). They were also asked about the effects of the object’s mass and size in the two situations described. The requirement to explain the reasoning revealed the student understanding. This type of problem encourages students to think more carefully and to select the most appropriate “resource” (Hammer, 2000) they already have. Students were more able to correctly answer the problems in idealized cases as compared to problems in real-world cases. In this study, the proportion of students accurately answering the problems in idealized cases is greater compared to the proportion in other studies i.e. Halloun and Hestenes (1985) and Sequeira and Leite (1991).

### 4. Demonstrations

Demonstrations have been included as an element of traditional instructional approach in high school as well as at the university level. Robinson (1991) views demonstrations as the “most interesting and applicable induction in science” (p. 26). Students generally like demonstrations, not only because it temporarily relieves them from writing notes or reading from the board, but it is sometimes entertaining too. However, students do not always acquire the expected understanding from watching demonstrations (Roth, McRobbie, Lucas, & Boutonné, 1997). A demonstration can be transformed into an interactive learning activity.

Crouch, Fagen, Callan and Mazur (2004) point out that, instead of letting students only make an observation, asking them to predict and record the outcome of a demonstration leads to a better understanding of concepts. The requirement to make a prediction prior to the demonstration forces students to expose their preconceptions. This is the initial step toward a conceptual change which is discussed in Section 2.3 of previous chapter. They are expected to revise their understanding when their beliefs are challenged for instance by subsequent measurement using microcomputer-based laboratory (MBL) tools (Sokoloff & Thornton, 1997). A number of studies (Sokoloff & Thornton, 1997; Cummings, Marx, Thornton, & Kuhl, 1999; Steinberg & Donnelly, 2002) confirm the benefit of this approach in terms of increased conceptual understanding.

#### 5. Video to analyze real-life events

Technological innovations such as computer and video have played an increasingly important role in education. The two modern gadgets can be combined with three aspects of learning experience – fantasy, challenge and curiosity (Malone, 1981) – to increase students' motivation. Students videotape a variety of events, collect physical data, simplify complicated events, perform mathematical modelling, compare effects of different variables on a certain event or observe the same event from different reference frames (Beichner, 1996; Fuller, 1993; Zollman & Fuller, 1994; Zollman, 1996). Students get a better understanding if they do more hands-on activities rather than just seeing demonstrations involving prediction and discussion.

#### 6. Computer to analyze data

Some approaches described earlier use the computer to enhance student learning experiences by taking real-time data on class demonstrations (Sokoloff & Thornton, 1997), simulating the experiments and then comparing the results with “real” experiments (Hasson & Bug, 1995), and connecting concrete experiences and abstract ideas (Redish, Saul, & Steinberg, 1997; Thornton, 1987; Thornton & Sokoloff, 1990). Data from hands-on activities can also be analyzed using a spreadsheet to produce a graphical relationship, to obtain an empirical correlation between variables or to verify a formula (Laws, 1991, 1997). If it is not feasible to perform the events, students can utilize scenes from video followed by analyses using appropriate computer software (Beichner, 1996; Zollman & Fuller, 1994; Zollman, 1996).

#### 7. Hands-on activities

Perhaps the most obvious ways to make students realize that physics has everything to do with the real world is having them to engage in hands-on activities. There are usually some texts to provide guidance for the students to carry out experiments accompanied by exercises and questions. Students basically need to interpret and predict the outcome of an experiment, conduct discussions in group, and give explanations to their answers. In addition, there may be pre-test and post-test to assess student understanding, homework for further practice, and computer tasks to analyze observed phenomena. Three notable examples of the activity texts are *Physics by Inquiry* (McDermott et al, 1996), *Tutorials in Introductory Physics* (McDermott et al, 2002) and *Workshop Physics* (Laws, 2004).

The effectiveness of instruction using those texts has been demonstrated in a number of studies (Scherr, 2003; Thacker, Kim, Trefz, & Lea, 1994; McDermott, 2001; Steinberg & Donnelly, 2002; Sharma, Millar, & Seth, 1999; Laws, 1991; Laws, Rosborough, & Poodry, 1999). The result of this approach is encouraging: a greater number of students show an enhanced comprehension in basic concepts, their problem solving skills do not suffer, and their attitudes towards the learning activities are positive.

Hands-on activities can also be conducted in a laboratory with a motion detector connected to a computer (Thornton, 1987) or a simulation on a computer (Hasson & Bug, 1995). The motion detector probes movements of an object (for example a toy car, a weight at the tip of a spring, or even the student's own body) and then displays motion graphs on a computer screen. Students can do various things with this tool, from predicting the resulting graphs to actually performing the motions to produce certain graphs. Because the graphs are presented in real time, students can manipulate the variables (for example position, distance, or speed) and observe the effect instantaneously. Students can also make a comparison between a real experiment and a computer simulation; this process can lead to a further discussion on real-life "noises" which are usually ignored.

Instructors can play a significant role as a facilitator of the discussion by introducing a special dialogue approach. The "Socratic Dialogue Inducing" (SDI) advocated by Hake (1992) is one of many guidelines for a constructive discussion. The laboratory activity starts with an experiment and students are asked to predict the outcome before they carry it out. They are encouraged to work collaboratively with their peers. The instructor does not provide straightforward answers; he/she poses questions to clarify the students' ideas and to guide them to the target understanding. The evaluations conducted in a preparatory class in a



community college (Uretsky, 1993) and several introductory physics courses in three universities (Hake, 1998a) demonstrate satisfactory results in students' comprehension of Newtonian concepts.

Hands-on activities can also be performed outside the classroom, for instance on-campus exploration centre (Singh, 2000) or at home (Barrett & Chiaverina, 2001). Direct experiences with phenomena are shown to help students in transforming the abstract concepts they learn into visual reality. Students are motivated by their discovery of the outcomes of experiments which are mostly designed to be counterintuitive to their beliefs. Not only do these activities promote a conceptual change, they can also foster transfer of learning.

Introducing real-life materials into teaching does not always require a major modification of existing instructional approaches. Instructors simply need to focus more on the features containing real-life materials when they use a textbook. Questions and stories on natural phenomena or current technological innovations are available in newspapers, popular science magazines such as *Scientific American*, *Science* or *New Scientist*, and books (Crane, 1992; Ghose & Home, 1994; Griffith, 2004; Jewett, 2001; Walker, 1975). Ideas for activities for students (and lecturers) can be found in journals like *Physics Teacher*, *Physics Education*, or *Science Teacher*, and books (Berry, 1987; Edge, 1987; Ehrlich, 1997; Freier & Anderson, 1981; Gibbs, 1999; Jackson, Laws, & Franklin, 2003). Activity guides derived from research are also available commercially (Sokoloff & Thornton, 1995; Sokoloff, Thornton, & Laws, 1999; McDermott et al, 1996; McDermott, et al., 2002; Laws, 2004; Leonard, Dufresne, Gerace, & Mestre, 1999-2000).

### **3.4.3. The roles and benefits of real-life materials in understanding physics**

The numerous studies cited above give some reasons to account for how real-life materials contribute to improving student comprehension and motivation in learning. These reasons are limited to some of the principles from the previous chapter in educational learning theories.

#### **1. Real-life exposure makes abstraction become concrete/real**

In a survey involving more than 800,000 undergraduates, the abstract or theoretical characteristic of science, including physics, is described as what makes learning hard or difficult (Seymour & Hewitt, 1997). Students are at a loss when they do science because they

cannot see the reality of what they are learning. Twenty-six percent of students in the survey mention this as one of many factors contributing to their decision of leaving science, mathematics and engineering majors. Physics can be in conflict with everyday experience in terms of the language, phenomena or contexts. Words such as frictionless floor, massless spring, ideal gas or rigid rod are considered to be abstract because they are never found in the reality. An arrangement of multiple pulleys to lift an object or sending a current through an elaborate shape of wire is also seldom encountered in real life. By the time students enter the university, they should have reached formal operational in Piaget's stages of development. However, many still find it difficult to relate the abstract concepts and concrete applications. In addition, physics is perceived to be a study of abstraction which hardly has anything to do with the real world.

Real-life exposure can bridge the gap between students' everyday experiences and physics concepts. The process of concretizing the abstraction can be facilitated by explaining the meaning of words in different contexts, utilizing everyday objects in laboratory, designing experiments to solve real problems, or using real-life objects and settings in physics problems. Products of technological advancement, such as the computer, can be employed in animation or interactive simulation to transform the abstraction into real-world situations. Students will usually find this learning experience to be fascinating as they have already been accustomed to various types of modern computer games.

## 2. Real-life exposure activates what is already known

Real-life exposure used in learning new information serves to trigger an activation of prior knowledge to facilitate recognition. We know that the model of information processing suggests that the brain constantly processes information received by sensory memory. Incoming sensory stimuli are compared against what is already stored in cognitive networks. If the information does not match the storage knowledge, it may be considered as meaningless and may not be processed further. If the information matches anything in cognitive structures, the brain is more likely to attend to it. The new information is then interpreted, evaluated, compared and contrasted to the stored knowledge. This, according to Piaget's theory of cognitive development, results in accommodation and assimilation of the new information into the established cognitive structure (Mintzes, Wandersee, & Novak, 1997). Constructivists suggest that meaningful learning occurs when new information is related to existing schema and this results in the growth of knowledge.

Bruner (1966) and Wolfe (2001) categorize learning at three levels: learning through concrete experience, representational or symbolic learning, and abstract learning. The first of these produces many of the strongest neural networks in the brain. Learning through concrete experience provides the foundation for the other higher levels of learning. In this scheme, real-life exposure allows knowledge created through experience to be actuated and then utilized to understand symbols, representations or abstract information. Brandsford, Brown and Cocking (2000) recognize that “all learning involves transfer from previous experiences” (p. 68). It is important, however, that prior knowledge should be exposed and properly rectified to avoid misunderstanding in later learning.

### 3. Real-life exposure shows that physics is relevant to immediate experiences

Students are young adults who often question the purposes of their activities, including study. Some may even try to relate lessons at school to their life. A time span of 10 years did not change the factors which make students attract to or repel from physics. Questionnaires completed by 825 students of Form 6 (Woolnough, 1994) and by 317 students of Year 10 (Williams, Sanisstreet, Spall, Boyes, & Dickson, 2003) reveal that the relevance of physics to their everyday experiences is one of those factors. Physics is perceived to be interesting because it has something to do with students’ lives, environmental concerns or other subject matters.

The students in tertiary level, like their younger counterparts, also appreciate the relevance of physics in the real world. When lecturers make an effort to relate physics to everyday life, the students comment that the lecture becomes interesting (Bliss & Ogborn, 1977), the physics becomes fun (Palmer, 1997), the concepts become comprehensible (Roth & Tobin, 2002), and the learning becomes meaningful (Tulip, 1997). Personalization motivates students to work more seriously because they are able to see the immediate impacts of physics to their life.

### 4. Real-life exposure makes learning interesting.

The previous chapter gives many possible suggestions to promote student interest in learning, for example arousing curiosity, connecting the topic to students’ experiences, presenting conflicting situations, including variety and novelty, as well as inducing fantasy and make-believe. Exposing students to real-life materials incorporates these ideas.

When students are motivated to learn, they direct their actions towards achieving understanding, increase their learning efforts, persist through difficulties, and tend to carry out learning in a meaningful way. These result in improved performance which affects the students' expectancy, self-efficacy, attribution and self-determination.

#### 5. Real-life exposure enables transfer of knowledge

All learning has an objective that the individual is able to apply what they learn in improving their life. Concept comprehension and problem solving skill in physics should not be viewed as tools used on test or exam to get a grade or a degree. In school settings, however, the theoretical aspect of physics occupies more time than its practical applications. Most problems in early editions of introductory textbooks used non real-life objects, phenomena or settings. These typical, often idealized, problems do not encourage students to “think outside the square”. Students often have difficulties when they are confronted with problems using the same concepts but presented in different terms using real objects in real-life settings. As physics is about understanding what we experience in the real world, it is desirable that students are able to utilize their physics concepts to achieve this.

Real-life exposure provides opportunities of applying a certain concept in different situations. Contexts of learning and their variety are the factors affecting learning transfer discussed in Section 2.3. Students could be given simple textbook-like problems to solve for the start. They are then presented with problems in real-life setting using real-life objects and phenomena. The questions asked are usually in the type of “why” and “how”, rather than “what”. Not only do students have to identify appropriate concepts involved, they also need to consider idealization, estimation, approximation and other assumptions to make the problems solvable. In the long run, this knowledge and skills are expected to be transferred to other subjects, further study, future work and more importantly to their life situation.

#### 6. Real-life exposure demonstrates the impacts of science on technological advancement of society

Education in general, and physics classes in particular, ought to focus on the understanding of the real world, and by implication, the consequences to the development of our post industrial society. Science has been central to modern civilization as is apparent, for instance in the

effect of understanding the atom to almost all current industries. Today's technology and industries have become the real impacts of the unforeseen utility of "abstract" physics. Any introductory physics text usually includes some examples of these impacts. For examples texts are to show that the study of energy levels in a crystalline solid leads to an understanding of semiconductors which is one of the vital constituents of the modern computer. As a second example a text might argue the investigation of properties of atoms through quantum mechanics guides the discovery of the laser which has various applications in medicine, communication, industry and many others.

Mastering how nature operates through technological development improves human life. Not only through manufacturing industries does physics contribute in shaping today's society, it has "enriched all the sciences ... opened a new era of discovery ... touched nearly every part of our society ... lead us into information age ... fuelled broad technological and economic development" (Appelquist & Shapero, 2001, p. 34). It is clear that the ultimate goal of scientific enterprises is toward the benefit of the society itself. Physics has affected the way we live our life: We enjoy the conveniences provided by the technological advancements and we sometimes lament over the undesired consequences of the same products of development.

A survey (Häussler & Hoffmann, 2000) on a group of various educational professionals and more than 6000 students in Germany shows their preferences of physics association with some societal issues. The former voted the highest priority of placing physics in the context of socio-economic enterprise which includes understanding scientific or technology innovations as well as acknowledging their risks and connections to economic or political developments. Likewise, the students were interested in physics mostly because they were fascinated by technological innovations and natural phenomena. Following the analysis of the responses, a physics curriculum was developed to include activities which incorporated the students' expectations that physics should have practical applications, the ability to explain natural events and obvious roles in technology. The new curriculum was demonstrated to yield a better retention rate.

#### 7. Real-life exposure provides the thinking framework to establish a democratic society

Physics teaching should make students aware of the technological impacts on the society. Students need to learn this in physics not only because they will be facing and making judgement about the consequences of scientific developments in the future, but also to

recognize these inevitable impacts on their present life onwards. The ability of making rational decisions about one's life is a reflection inherent in a democratic society. Longbottom and Butler (1999) argued on the roles of science education in providing students with scientific attributes as an early step towards establishing a democracy. Science teaching should have the goals of students acknowledging the capability of scientists, having a trust in science and acquiring some scientific characteristics. Students should be shown the immediate relevance in their everyday life, its effects on the society where they live, and the future consequences of its development. The social utility as the objective of science could not have been emphasized more when we consider the objectives of almost all science curricula (Ministry of Education, 1993; National Academy of Science, 1995; Department for Education and Employment & Qualifications and Curriculum Authority, 1999).

This chapter has presented results in physics education research including some problems associated with traditional teaching approaches. Researchers have come up with numerous proposed solutions, most of which encourage interactive engagement and/or include real-life materials. These various approaches are demonstrated to promote meaningful learning and improve understanding of physics concepts. The evidence suggests that traditional instruction should be improved by incorporating interactive engagement activities and real-life materials. Instructors should consider including these elements in their classrooms to enhance their teaching approaches.

The studies on these innovative instructions were mostly conducted in the United States and the United Kingdom. The applicability of these instructions in other countries becomes an important issue if physics education research is to make useful contributions in improving instruction in a global scale. The next chapter investigates whether this is the case.

## Chapter 4

### Case Studies on the Effects of Modified Teaching Approaches

Chapter 3 reviews the problems contributed by traditional teaching approaches and the strategies to overcome the problems. As the context of learning is an important factor to consider, teaching approaches that succeed in helping students to learn a certain subject in a certain classroom may not always work with students learning a different subject in a different classroom. How a student learns is influenced by a number of factors such as student's interest, knowledge base, and previous experience, as well as assessment, teachers, courses, departments and institutions (Ramsden, 1992). Thus, the "context of learning" is different for each student, for each classroom and probably for each country. Undertaking research in a particular educational environment may lead to a more accurate direction in how to implement effectively a teaching innovation to improve the quality of learners in that environment.

Two case studies were conducted to investigate the effects of teaching approaches consisting of interactive engagement activities. Hake (1998a) demonstrated that interactive engagement teaching methods were more effective in improving understanding than traditional methods. The first case study took place at the University of Surabaya, Indonesia, and the second case study was done at the University of Canterbury, New Zealand. The aim was to investigate the effects of the modified teaching approach and the students' reactions to the approaches. The findings were used to determine the next stage in the efforts to improve teaching and learning in the institutions. The comparisons between the two case studies are presented at the end of this chapter.

#### 4.1. The first case study: University of Surabaya, Indonesia

The first case study aims to investigate the effectiveness of a teaching method consisting of some interactive engagement elements and the students' reactions to it. The preliminary analysis of this research was reported elsewhere (Cahyadi, 2004a). The teaching elements under investigation were interactive demonstrations (Sokoloff & Thornton, 1997), peer discussions (Mazur, 1997), constructive Socratic dialogue (Mestre, 1991) and Active Learning Problem Sets or ALPS worksheets (Van Heuvelen, 1991). These teaching elements are some of the most popular interactive engagement methods reported in Hake (1998b). These examples of interactive engagement methods are described in more detail in Section

3.3. They were shown to increase the effectiveness of mechanics courses as well as improving student's conceptual understanding and problem-solving skill well beyond that achieved by traditional methods.

The participants involved were first year undergraduate engineering students at the University of Surabaya in Indonesia. Most studies on innovations in teaching approaches were conducted in developed countries. The results may not be directly transferable to classrooms in developing countries because of the different environment. It is, therefore, worthwhile to find out whether the interactive engagement approach could be similarly effective and accepted by students in a developing country. The effectiveness of the teaching approach was measured by exam scores and gain  $\langle g \rangle$  in Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) which is a standardized test on Newtonian mechanics concepts. The students' reactions to the approach were probed by a specially designed questionnaire (see Appendix 1).

The research questions are:

- How was the students' improvement of understanding Newtonian conceptions, as measured by a standardized test and exam scores, after they were taught with a method consisting of interactive engagement elements?
- What were the students' attitudes towards the modified teaching approach?

#### **4.1.1. Methodology**

##### *Participants*

The participants were first year undergraduate engineering students at the University of Surabaya which is a private university in Surabaya, Indonesia. The teaching method under investigation was applied in two classes which would be called the "experimental" classes. The two classes consisted of students majoring in Industrial Engineering (ID) in one class and those majoring in Informatics (IF) in the other. The students in both classes did not know that they would be subjected to a new teaching method. Students in other classes (1 IF class and 2 ID classes) were regarded as "control" participants. They were taught in traditional lecturing style. The number of students involved and treatments they received is shown in Table 4.1.



Table 4.1. Participants involved in the study

Type of students	Control class	Experimental class
Industrial Engineering (ID)	ID A (N=63) ID B (N=55)	ID C (N=71)
Informatics (IF)	IF A (N=72)	IF D (N=78)

### *Experimental design*

Because of the different credit points, the number of hours per week for ID and IF classes also differed. ID classes had four 50-minute sessions and IF had three 50-minute sessions every week. The lecturers in the five classes in Table 4.1 (both the control lecturers, L1, L2, and L3, and the experimental lecturer, A) had been teaching in the institution for at least seven years. All of them were very familiar with the subject matter, student characteristics and problems in the classroom. They were assigned to different classes according to their timetable preference. The difference in the control and experimental classes was due to the teaching approach.

### *Teaching approach in the control classes*

The control classes were taught in traditional style where the main component was an instructor lecturing on concepts and problem solving examples. Some lecturers occasionally administered reading quizzes and gave homework; however those activities were not on a routine basis.

### *Teaching approach in the experimental classes*

The students in the experimental classes did not know in advance that they would be subjected to a different teaching approach. In addition to receiving explanations on concepts and problem solving, the students were also involved in other activities which were designed to create an interactive engagement learning environment. These activities are:

#### 1. Daily reading quizzes.

The quizzes were administered at the beginning of each lecture. They were discussed immediately to ensure that the students got the correct understanding. The quizzes were graded and handed back in the following lecture. The questions asked were very basic in nature and usually involved some definitions or simple relationships between variables.

## 2. Interactive demonstrations.

The lecturer initially described and started the demonstration but did not finish it. The students were then asked to discuss the outcome of the demonstration with their peers. They recorded their predictions, wrote some reasons for their predictions, and handed in the prediction sheets. The lecturer scanned the predictions and proceeded with the demonstration. The prediction sheets were graded and handed back in the following lecture. Each student in the group received the same grade. This was intended to encourage the students to be seriously involved in the activity.

## 3. Constructivist dialogues.

The students verbally responded to the lecturer's questions about concepts, procedures in problem solving and explanations of some everyday phenomena. Most of the questions on concepts or phenomena were multiple choice with distracters. The questions on the procedure were usually asked verbally when the lecturer worked on sample problems on the board.

## 4. Active Learning Problem Sets (ALPS) worksheets.

The students were guided to complete ALPS worksheets. These worksheets provide step-by-step guidance for students to systematically solve physics problems. The procedure in solving a problem involves pictorial, physical and mathematical representations as well as evaluation of the units and magnitude of the answers. It was a good opportunity for the students to practise problem solving on their own during lecture time. The worksheets were not graded and some of them were provided for additional practice at home.

### *Measuring instruments*

There were three measuring instruments to indicate the effectiveness of the interactive engagement teaching method. They were:

#### 1. Force Concept Inventory (FCI) to measure conceptual understanding.

All students in both control and experimental classes were given the same FCI test and mid semester exam. As this study concentrated on student understanding of Newtonian concepts, the analysis was done with the topics covered in the first half of the semester. The FCI was administered twice, the first time (pre-test) was on the first day of the semester, and the second time (post-test) was in the 4<sup>th</sup> or 5<sup>th</sup> week when the topic of Dynamics was completed. The administration of the test was atypical: the lecturer read the questions and displayed the

answer choices in the overhead-projector screen. The total time taken to do the test was about 40 minutes for each class. The lecturer in the experimental classes told the students that their FCI post-test scores would contribute toward their overall grades. In the control classes, only the lecturers in ID B class did this.

## 2. End-of-term exam to measure problem solving skill.

The exam was constructed by all lecturers involved and others who taught other classes outside the five classes involved in this study. The exam problems were discussed thoroughly in separate meetings by lecturers teaching ID classes and those teaching IF classes. Because of the difference in credit points, the exam problems were also different for ID and IF classes. Each lecturer contributed one problem and graded the answers to his/her problem for all students. This was intended to ensure the objectivity and consistency for the exam grading.

## 3. A questionnaire to reflect students' attitudes towards the method.

Besides the FCI test and exam, the students in experimental classes were asked to complete an anonymous questionnaire specially designed to find out their responses towards the teaching method. The items contained in the questionnaire refer directly to elements of the teaching method. The lecturer in the experimental classes constructed the questionnaire which can be found in Appendix 1. Before distributing the questionnaire, the lecturer explained its purposes which were basically to assess their reactions to the method and to make further improvement.

### 4.1.2. Results and analysis

Table 4.2 presents the average FCI scores in pre-test and post-test, the gains  $\langle g \rangle$  as well as the average exam scores for each class.

Table 4.2. FCI and exam scores of control and experimental classes

Type of class	Class (lecturer)	N	FCI pre-test mean (SD)	FCI post-test mean (SD)	$\langle g \rangle^{**}$	Exam score mean (SD)
Control class	ID A (L1)	63	21.7 (8.3)	33.0 (11.3)	0.14	46.6 (21.1)
	ID B (L2)	55	19.5 (7.7)	28.3 (9.4)	0.11	39.4 (21.3)
Experimental class	ID C (A*)	71	19.7 (7.4)	44.7 (10.3)	0.31	50.3 (19.9)
Control class	IF A (L3)	72	21.9 (9.1)	26.2 (11.4)	0.06	46.7 (19.0)
Experimental class	IF D (A*)	78	23.6 (14.2)	41.7 (14.9)	0.24	59.2 (20.0)

\* the author taught these experimental classes.

\*\* the average normalized gain  $\langle g \rangle$  is calculated using the following formula, where  $\langle S_f \rangle$  and  $\langle S_i \rangle$  are FCI pre-test and post-test mean scores, respectively.

$$\langle g \rangle = \frac{\% \langle G \rangle}{\% \langle G \rangle_{\max}} = \frac{\% \langle S_f \rangle - \% \langle S_i \rangle}{100 - \% \langle S_i \rangle}$$

### *Conceptual understanding*

The narrow range of FCI pre-test scores indicates that the five classes were approximately similar in their initial knowledge state and that the students were quite randomly distributed across the parallel classes. Different lecturers taught various control classes using mostly lecture format. However, this did not much influence the improvement of student understanding as shown by the low gains of the control classes. Uniformly low levels of student performance have been observed across different physics classes taught by professors and teachers differing considerably in their conventional teaching strategies (Halloun & Hestenes, 1985; Hake, 1998b). The experimental classes, on the other hand, exceeded the control classes in the average gain by a factor of 2.5 for ID students and 4 for IF students. Thus the experimental classes achieved a significantly greater improvement in Newtonian understanding compared to the control classes. This improvement is due to the nature of the four activities mentioned above which emphasized the importance of understanding the concepts rather than only focusing on solving problems mathematically. Section 3.3.1 has elaborated the constructivist principles to account for this enhanced comprehension.

As indicated by  $\langle g \rangle$ , it is apparent that only one of the experimental classes falls in medium-g region ( $0.3 \leq \langle g \rangle < 0.7$ ) and the rest fall in low-g region ( $\langle g \rangle < 0.3$ ) of the course effectiveness. This result is in line with Hake's (1998a) report that most of interactive engagement courses achieved  $\langle g \rangle$  in medium region. The gains from the two experimental classes are in the borderline between low-g and medium-g, or lower than those reported in numerous studies in Hake (1998a). Hake mentioned several reasons which are detailed in Section 3.3.1. Some of those are identified in this case study. The lecturer gained the knowledge of interactive engagement method through the literature only, instead of observing other people's teaching or being involved in modified instruction prior to the implementation in her class. Although interactive engagement elements were used in a significant amount of teaching time, the instruction was not changed radically and aspects of traditional approach were still apparent. On the other hand, the lecturer, in many occasions, reminded the students that there would be some qualitative questions in the exam. In addition, reading quizzes and reports following peer discussions were always graded and returned in the next class session.

### *Problem solving skills*

An independent sample *t*-test was performed to investigate whether exam scores of the experimental classes are significantly higher than those of the control classes. The total exam score of the two control ID classes is 43.2 (SD = 21.2) which is significantly lower than that of the experimental class [ $t(187) = 2.28, p < 0.025$ ]. The effect size of the treatment is 0.34. The statistical calculation also shows that the exam score of IF experimental class is significantly higher than that of the control class [ $t(148) = 3.91, p < 0.005$ ]. The effect size is 0.64 which is twice as large as that of the ID classes. It can be concluded that the students in the experimental classes performed significantly better in problem solving than those in the control classes. Although the class time for problem solving exercises was reduced, the enhanced conceptual understanding contributed in a constructive way to the problem solving skills. This is also confirmed in many reports discussed in Section 3.4.2 that activities to improve conceptual understanding do not negatively affect the problem solving competence.

The average exam scores of the two experimental classes is around 55%. The exam questions should not be considered as beyond the students' ability since all questions were carefully scrutinized by the lecturers involved. As other studies (Fullan, 2001; Chang, 2005) have suggested that 3-5 years are needed to successfully change instructional practices, the first-time implementation probably cannot be regarded as a failure even if it produces results worse than those of traditional approach. There is another plausible reason for these rather low exam scores. It is related to how the students in the experimental classes reacted to the interactive engagement elements, which is discussed in the following.

*Attitudes towards the method*

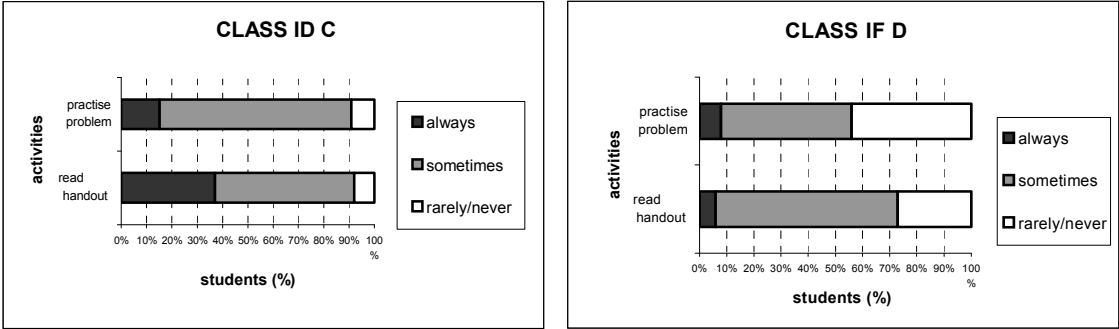


Fig. 4.1. Frequency of activities done by the students at home

The frequency of how the students conducted the two activities at home, i.e. practising problem solving and reading hand-outs, may be connected to the occurrence of those activities in class. In Figure 4.1, the percentage of students who rarely or never read hand-outs

is higher in IF D class (29%) than that in ID C class (9%) because reading quizzes in the former class were administered less frequently than in the latter. This is a direct consequence of fewer contact hours in ID C class. There are more students in IF D class (44%) who rarely or never practised problem solving at home than those in ID C (9%). This may be explained in terms of the number of problem samples discussed in class: IF D students observed fewer examples than did ID C students due to fewer contact hours in IF D class.

The smaller number of students diligently reading the hand-outs in IF D class compared to that in ID C class (Figure 4.1) could be explained by behavioural view of motivation. ID C received more reinforcement in terms of more frequent reading quizzes. This served as a kind of recognition of students' efforts to read the hand-outs at home. Cognitive theory of motivation mentions the importance of expectancy  $\times$  value as one of learners' characteristics in Section 2.4.1. More frequent reading quizzes meant more values in terms of the grades contributing toward the overall results. This motivated the students in ID C class to put in more effort to read the hand-outs. The similar phenomenon is also reflected in the number of students practising problem solving at home. The less problem solving examples given in IF D class encouraged only about 56% of the students to practise at home as compared to more than 90% of the students in ID C class.

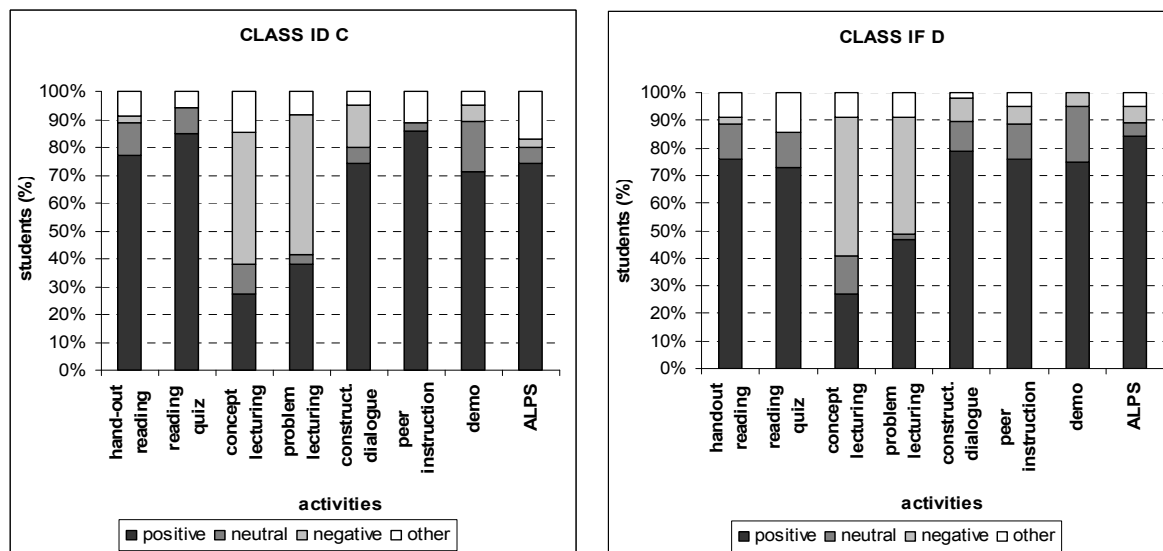


Fig. 4.2. Students' comments to various activities

Figure 4.2 shows that students in the two classes have similar distributions of comments on several activities. The terms "positive", "neutral", "negative" and "other" refer to the answer choices 1, 2, 3 and 4, respectively, in the questionnaire (Appendix 1). Most students (72 – 85%) felt that hand-outs reading, reading quizzes, constructivist dialogue, peer instructions,

demonstrations and ALPS worksheets affected them in some positive way. According to them, those activities were useful, motivating, interesting and stimulating. There are two activities, however, which were perceived unfavourably by the students. About 50% of students mentioned that the lecturer did not thoroughly and clearly explain the concepts and problem solving. This is an inevitable consequence of conducting many activities in a given time period. Lecturing on concepts and problem solving, which occupy most of the time in traditional classrooms, had to suffer a cutback in time allocation.

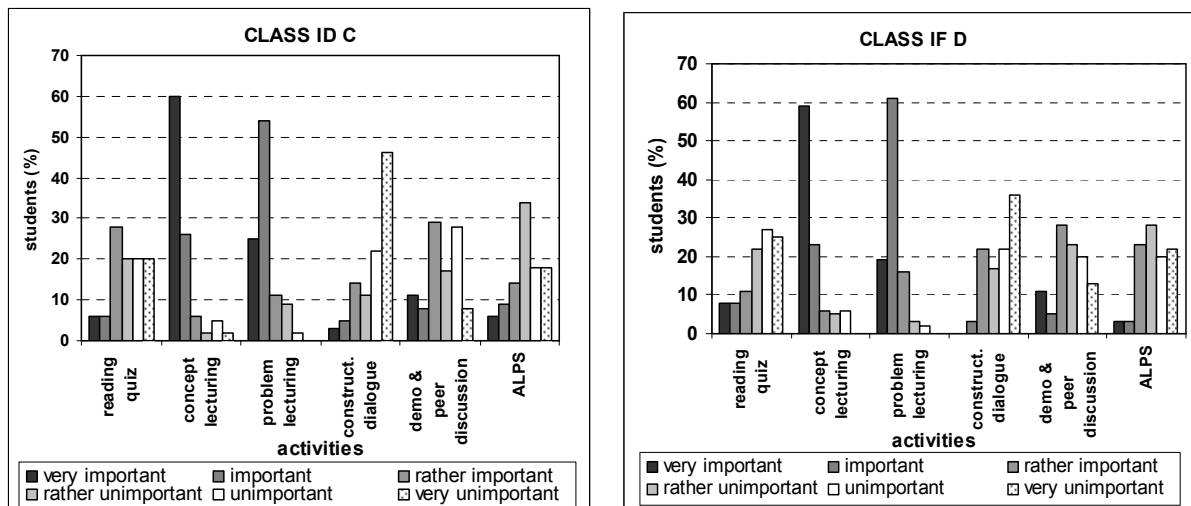


Fig. 4.3. Students' perceptions of the importance of various activities

Figure 4.3 shows a similarity of how students from the two classes perceived the importance of certain activities. Approximately 80% of the students rated the lecturing on concepts and problem solving as important or very important. This rating is closely related to the responses in Figure 4.2. The student's preference to traditional teaching and insufficient time for the lecturer to meet this demand apparently led the students to express such perceptions. These two reasons may also explain why 60 – 70% of students rated constructivist dialogue as an unimportant or very unimportant activity. Most students might not be aware of the occurrence of the dialogue or they might feel uncomfortable to be directly confronted with verbal questions to assess their understanding. Other activities are rated in between these two extremes.

The students' responses in Figures 4.2 and 4.3 indicate that they still embraced the traditional teaching paradigm. Basic principles of cognitive learning theories (Section 2.1.1) and characteristics of constructivism (Section 2.3.1) have suggested that prior knowledge and beliefs affect knowledge construction. The students in all classes, including those in the two

experimental classes were accustomed to traditional teaching approaches. Teaching approaches influence the strategies students use in their learning (Kember & Gow, 1994). Consequently, the students in this case study had adopted the so-called surface learning approach where memorization and problem solving drills are the dominant practice. The modified teaching approach necessitated them to modify their learning strategy which may create a conflict with their beliefs about effective learning. This finding is consistent with studies by Mottmann (1999) and Chang (2005) where students in interactive and constructivist classes preferred to be taught in the traditional fashion.

Figures 4.2 and 4.3 reveal a consistency in terms of the students' preference of teaching approach. However, the two figures also expose an interesting phenomenon. Although the students perceived that the interactive engagement elements were interesting (Figure 4.2), they *did not* regard these elements to be important for their learning (Figure 4.3). Section 2.4.2 elaborates the principles and activities to develop interest so that learners are motivated to be involved in significant cognitive engagement in the activities. This case study shows that interest does not always cause motivation. The students found that hand-outs reading, reading quizzes, constructivist dialogue, peer instructions, demonstrations and ALPS worksheets were useful, motivating, interesting and stimulating. Those activities were novel and, in some ways, broke the monotony of traditional lecturing. Nevertheless, they viewed these activities as unimportant and they demanded to have more lecturing on concepts and problem solving which were perceived as important or very important by 80% of them. Based on this perception, it is likely that the majority of students still adopted surface learning approach despite the emphasis on understanding concepts during class activities. As a result, the exam scores were not markedly superior compared to those in traditional classes.

#### **4.1.3. Conclusion**

This study demonstrates the effect of a teaching method consisting of interactive engagement elements on student understanding of Newtonian concepts. The teaching method was implemented in two experimental classes, each of which consisted of students majoring in certain areas of engineering i.e. industrial engineering and informatics engineering. In order to compare the effect of the treatment, there were control classes which were taught in a traditional teaching approach.



The improvement of comprehension of Newtonian concepts in the experimental classes was significantly better than that in the control classes, as was shown by average gains in FCI scores. In terms of problem solving skills measured by exam scores, the experimental classes were significantly better but not overly superior compared to those of the control classes. Students in the two experimental classes expressed a positive appraisal to the new teaching approach. However, the students were also shown to prefer the traditional teaching paradigm. The view that teaching should consist of mainly lecturing affected the learning strategy, which consequently was reflected in the exam scores.

#### *Suggestions for implementation in the future*

Instructors are advised to consider the following suggestions if they plan to adopt interactive engagement approaches. Instructors should explain the rationales and purposes of the interactive engagement activities. This should be done at the beginning of and throughout the term. As the class schedule is occupied with various activities, there should be additional hours to deal with problem solving and unanswered questions. Tutorial classes supervised by teaching assistants may be the best solution to this problem. The interactive engagement activities should be reflected in tests or exams. It will encourage students to seriously participate in the learning process.

#### **4.2. The second case study: University of Canterbury, New Zealand**

The aim of this case study is similar to that of the first case study described above, but the setting was in a New Zealand university. An introductory physics course was modified to include assessed group work in tutorials, WebCT reading quizzes, peer discussions during in-class demonstrations and pre-lecture downloaded hand-outs. WebCT is an internet based courseware provided by the university to post and access custom-made online resources. The activities in this case study were not identical to those in the first case study; nevertheless, they were similarly designed to encourage greater student involvement in the course.

New Zealand students are similar in many ways to students in the countries where the teaching innovations were originated. It is still informative to investigate the effects of the teaching modification because of different learning contexts between classrooms in New Zealand and those in other Western countries. Some results of this case study have been reported elsewhere (Cahyadi, 2004b).

The research questions for this case study are:

- How effective was the modified teaching approach in improving students' understanding of the course materials?
- What were the students' attitudes towards the modified teaching approach?

#### **4.2.1. Methodology**

##### *Participants*

PHYS113 (Waves, Thermodynamics and Materials) is a prerequisite course for Engineering Intermediate and first year Physics at the University of Canterbury. Entry to this course requires a reasonable physics background which is measured by the minimum of 58% average in each of Bursary (final exam of high school) physics and mathematics with calculus. Those without this background are required to pass PHYS111 (Introduction of Physics to Engineering and Sciences) in semester 1 and take PHYS112 (Waves, Thermodynamics and Materials) in semester 2. This case study investigated the effects of a modified teaching method in PHYS112. At the time when the study was conducted, the composition of the PHYS112 class was 70% graduated from PHYS111 and 12% failed from PHYS113 in semester 1. In other words, the class (198 students) consisted mostly of students with a weak ability in physics and some others (18%) choosing PHYS112 for other reasons over PHYS113.

##### *Experimental design*

The instruction and activities conducted in PHYS111, PHYS112 and PHYS113 had been traditional. The lecturers spent most of the time presenting course materials and occasionally performed demonstrations. In tutorial sessions, tutors modelled problem solving on the board. Students in the lecture and tutorials mainly listened and copied the notes without being encouraged to respond or interact with their peers. Inspired by the movement in physics education research, it was decided to make some modification to PHYS112 course. The new elements introduced as the modification were:

1. Assessed group work in tutorials

Group work was initiated in PHYS111 class in the previous semester where students were given worksheets containing qualitative problems to discuss for non-assessed tutorial work. Small group discussions on conceptual and quantitative problems were continued to be encouraged in PHYS112 tutorial sessions; this time the student work was graded. The students were explicitly told that they needed to have a strong conceptual comprehension as well as the skill in problem solving to perform well in the examination.

## 2. WebCT reading quizzes

To reinforce the importance of being prepared for the lecture, a new activity was introduced. Students were expected to do a reading quiz on WebCT at the beginning of every week. The multiple-choice questions in the reading quizzes involved basic and simple ideas on the week's topics. The grades of the quizzes combined with those of the tutorial and homework contributed to 10% of the total mark for the course.

## 3. Peer discussions during in-class demonstrations

In order to engage the students more actively, a Peer Instruction (Mazur, 1997) style of approach was adopted in the second half of the semester. From time to time, the lecturer posed multiple-choice qualitative questions on the overhead projector (OHP). Students were given time to discuss with their neighbours and were asked to show their answers by putting up a  $10 \times 10 \text{ cm}^2$  card. Every student was provided with a set of six cards, each of which showed an over-sized letter (A, B, C, D, E or F) indicating an answer choice. This activity was intended to break the monotony of passive listening, to force students to think about concepts and to give explanations in their own words to their peers. Most in-class demonstrations were accompanied by this activity. In such case, the lecturer stopped the demonstration at some point and then asked the students to predict the outcome. After the students put up the card indicating their chosen letter representing their answer, the lecturer proceeded with the demonstration followed by some explanations.

## 4. Pre-lecture downloaded hand-outs

There was also a change in the presentation of the lecture material. In PHYS111 course of the previous semester, students copied the material written by the lecturer on OHP slide during the lecture. In the first half semester of PHYS112, the topics were outlined on prepared OHP slides, the copies of which could be obtained *after* the lecture. Despite the expectation to read the textbook before the class, some students seemed to experience difficulty with this kind of presentation. To address this concern, the presentation was changed again in the following

half semester. Students could view on WebCT and print out *before* the lecture the information containing important items of the material taken from the textbook. The purpose was to give the students a good overview of the day's material, to free them from writing too much thus enabling them to engage in more constructive activities such as thinking over the questions and having discussion with their peers, and to provide more time for the lecturer to do other activities.

### *Measuring instruments*

There were two measuring instruments used to address the questions of this case study.

1. Exam scores of PHYS112 to measure the improvement of students' understanding.

There were no pre-test/post-test scores nor other parallel classes to compare with. The comparison was then made between the improvement of PHYS112 final exam scores in the year when the study was conducted (2003) and those in the previous years (2000 – 2002) when the teaching method was traditional. The word "improvement" means how PHYS112 exam scores were related to PHYS111 exam scores for the same students. Because PHYS112 exam in 2003 contained some questions on the topics of the first half of the semester where only two of the new teaching elements were implemented, data of PHYS112 exam scores were taken from the scores of questions on the topics of the second half of the semester where all new teaching elements were applied.

2. Responses to a survey to probe students' reactions to the modified approach.

At the end of the semester, students were asked to fill in a course survey developed by the Survey and Testing Unit of the University of Canterbury. A total of 107 students (54% of the class) completed the survey. There were 14 statements to be rated using the 5-point Likert scale of 1 (strongly disagree) to 5 (strongly agree). Only responses to statements relevant to the elements of the modified teaching were analyzed. In addition to those statements, there were two open ended questions asking students to give comments on the strengths and weaknesses of the new approach. These comments may reveal a multiple-faceted view of students' opinions towards the new approach. The wording of the questions is:

- Which aspects of this course were most helpful in your learning?
- How could this course be changed to assist your learning?

The students' comments were first qualitatively categorized into several issues relevant to the new elements of teaching. Then, the number of students making comments with respect to each issue was counted.

#### 4.2.2. Results and analysis

##### *Comprehension of the learning material*

PHYS111 and PHYS112 exam scores in 2000 to 2003 are presented in Table 4.3. In each of the four years, average exam scores of PHYS112 are lower than those of PHYS111. This could be due to the larger amount of material, more varied topics and higher level of difficulty in PHYS112 course compared to PHYS111. The modified teaching approach introduced in 2003 did not succeed very much in helping PHYS111 students to improve their exam scores in PHYS112. However, compared to the previous years, especially 2001 and 2002, there is a little improvement in PHYS112 average exam scores in 2003.

Table 4.3. Exam scores of PHYS111 and PHYS112 in 2000-2003

Year	N	Lecturer PHYS111/PHYS112	Teaching method	PHYS111 mean(SD)	PHYS112 mean(SD)
2000	93	L1/L3	Traditional	49.04 (11.53)	38.13 (17.44)
2001	108	L2/L3		57.25 (11.22)	39.43 (15.78)
2002	125	L2/L3		55.40 (9.18)	38.94 (14.18)
2003	128	L4/L5+A*	Modified	51.08 (10.03)	40.91 (19.75)**

\* the author taught PHYS112 in the second term

\*\* mean (SD) of the scores of questions on the topics of the second half of the semester

Analysis of covariance (ANCOVA) was used to identify whether that slight improvement is statistically significant to distinguish the effects of the modified teaching approach. The teaching approach in 2000 – 2002 is considered to be traditional, so data from those years are combined into one group, namely the control group. The average exam score in 2003 is regarded as experimental group data. Therefore, there are two groups or treatments as the independent variable. Each group has data of PHYS111 average exam scores as the covariate and PHYS112 average exam scores as the dependent variable. The statistical analysis reveals that PHYS112 average exam score in 2003 is significantly higher than the scores in the previous years [ $F(1, 451) = 9.27, p < 0.01$ ].

As PHYS112 exam contained conceptual questions and quantitative problems, it can be concluded that the elements of the modified instruction effectively improved students'

conceptual understanding as well as their problem solving skills. This is in line with many theories and reports discussed in Chapters 2 and 3. The students' ratings and comments on the course survey provide some insights about the benefits of each element of the modified instruction.

*Attitudes towards the method*

The number of students responding to the open questions in the survey was significant: 77 students or 72% of those completing the survey. The students could be assumed to put forward their profound concern when they took the trouble of writing instead of just circling the numbers indicating their rating. Responses to statements relevant to the modified teaching approach are presented in Table 4.4. The ratings use the 5-point Likert scale of 1 (strongly disagree) to 5 (strongly agree). The figures in the Agreement column are obtained by adding the number of students responding "agree" or "strongly agree" to the statements in the survey.

Table 4.4. Students' ratings on elements of modified teaching approach

Statement	Average	Agreement
The (tutorials/seminars/student-led discussions) were a valuable aid to my learning	3.1	37%
The computer/WebCT/Internet resources were adequate to support my learning	2.7	33%
The lecturer made good use of examples and illustrations to explain difficult concepts	3.6	54%
As aids to learning, the lecturer's hand-outs have been valuable	3.9	72%

The students' responses to the open questions about the strengths and weaknesses of the elements of the new approach are presented in Table 4.5. A few examples are included to give some ideas of positive and negative comments for each element of the teaching approach.

The comments on tutorials suggest the impact of the change on some students. There was a significant increase in the number of assessed quantitative problems that students had to do every week, from one problem in the previous course (PHYS111) to 5-6 problems in the present course. The quantity of work and type of activities may pose challenges for the students if they are not used to them.

Table 4.5. Students' comments on elements of teaching approach

Elements of teaching	Positive comments	Negative comments
Assessed group work in tutorial	20 comments, for example: - "lots of material available to us which was helpful, eg answers to tuts, homework" - "marked homework, tutorial questions" - "the problems were well suited for exam prep questions" - "my tutorial teacher was extremely helpful"	20 comments, for example: - "It was far too much work for what they are worth, the homework questions were too hard and take too long to do" - "The tutors need to show how to do the problems in a small class" - "The tutors don't know anything and don't help" - "Tuts shouldn't be compulsory ... we are adults now"
WebCT reading quizzes	6 comments, for example: - "get you to have a good look thru the textbook" - "provided an incentive to read the book" - "allowed me to have a better understanding"	20 comments, for example: - "it's useless and not helpful" - "it's a waste of time" - "it is too easy to forget especially when you don't have easy access to computers" - "10 questions is too few to gain a high grasp of the topic"
Peer discussions during in-class demonstrations	8 comments, for example: - "it was real helpful in understanding concepts by applying them to situations" - "the multichoice questions asked during the lectures were good"	4 comments, for example: - "They used up valuable lecture time" - "now course is behind schedule" - "time could be spent going in to greater depth to increase understanding of the material"
Pre-lecture downloaded hand-out	22 comments, for example: - "made listening and learning a lot easier rather than spending the whole lecture trying to write notes" - "gave something to refer to if I got stuck"	12 comments, for example: - "I found it difficult to stay awake if I had the printed material in front of me" - "there was nothing more that I could learn from actually attending the lecture" - "it is very expensive to print that many notes out"

Only a few students seemed to recognize the purpose of WebCT reading quizzes because the adverse comments outnumber the positive comments. Their comments may reflect the rather unfavourable student rating on WebCT aspect in Table 4.4. Reading before the class was not formally encouraged in the previous physics course (PHYS111). The on-line quizzes, being new to most students, may have caused some anxiety. The students at this stage may not be aware that preparing for a lecture and familiarity with the computers are essential for their study. A few comments that WebCT reading quizzes were a waste of time and easy to forget to do possibly indicate a lack of motivation to spend more study time outside the class for some students. The characteristics of motivation emphasizing expectancy  $\times$  value (Section 2.4.1) may also provide an explanation. The students felt that multiple choice questions on WebCT were too simple or trivial to be useful for studying for exams. In addition, the effort and time to read at home were perceived to be far too much but each quiz was rewarded very

insignificantly towards the overall course grades. The students might not know nor pay any concern about the long term benefit of being prepared for the lecture.

The substantially higher number of positive comments on demonstrations indicates that some students were still at the concrete operational stage, although they should have been at the formal operational stage according to Piaget's cognitive development. This finding is consistent with Lawson and Snitgren (1982) and Thornton and Fuller (1981). When they were asked to have discussions with their peers, students were quite willing to do so, although their enthusiasm seemed to fade toward the end of the semester. This fading enthusiasm could be attributed to fading interest in a novel activity, increasing level of difficulty of the material, accumulated amount of work from other courses, or anxiety to study for the upcoming exam. Also, there was no recognition formally attached to the activity as the students' answers with the flash cards were never recorded nor graded. Because of the lack of reinforcement, most students lost their motivation to show the flashcard or even to have discussions with their peers in the last weeks of the semester.

Although a few students expressed their desire to have the material presented in the old way, the majority seemed to be comfortable with the new system. It is true that the explanation of the material still took a considerable amount of time, i.e. about 75% of the 50 minutes in each lecture. Students perceived the utility of the hand-outs which could be printed out from WebCT before each lecture. The appreciative comments on pre-lecture downloaded hand-outs reflect the limitation of working memory. By not having to write all information presented during the lecture, students could attend to other activities such as thinking about concepts, discussions with their peers and responding to questions posed by lecturers.

Students were apparently more inclined to put forward their concerns about certain activities if they were assessed. There were more expressions of complaint about tutorials and reading quizzes than the comments appreciating those activities. On the other hand, the number of students mentioning that peer discussions and in-class demonstrations were useless is very small compared to that appreciating their benefits, as shown by remarks written in the survey. This indicates that students will pay more attention and feel more involved if their work is recognized in some way. It may also suggest that the assessed tutorial work and reading quizzes have succeeded in encouraging (or forcing) the students to do more practice with problem solving and to read at home.



### *Further developments*

Since the introduction of the modified teaching approach in 2003, many lecturers teaching first year physics courses have adopted some elements of the approach in their instruction. In 2004, students in PHYS111 tutorials were given detailed instructions to work out open-ended real-life problems in groups while PHYS112 tutorials continued to use qualitative multiple choice questions which were assessed. PHYS112 was still the only course requiring students to work on WebCT quizzes and engaged students in peer discussions using the flash-card. The tutorial format for PHYS111, PHYS112 and PHYS113 was formally organized in a uniform fashion in 2005 where tutors facilitated group discussions on assessed qualitative and quantitative problems. The three courses utilized WebCT to administer weekly quizzes. In addition, all lecturers teaching PHYS111 and PHYS112 post their hand-outs on WebCT either before or immediately after the lecture. PHYS112 was still the only course that encourages student engagement in the class. In 2006, all elements of the modified teaching approach, with the exception of peer discussion in the lecture, were adopted in the three courses. One lecturer in PHYS111 and another in PHYS112 used the flash-card and show of hands, respectively, to engage students during the lecture. There was only one lecturer who did not post hand-outs on WebCT. The latest development occurred in 2007 where a lecturer in PHYS113 utilized “clickers” or electronic student response system to elicit students’ answers thus improving the interactive engagement in the class. Preliminary responses from the students were encouraging. These developments will hopefully enhance the quality of teaching and learning in all first year physics courses in the department.

### **4.2.3. Conclusion**

This case study reported the impacts of a modification in an introductory physics course. The purposes of the modification were to get students well prepared for the course, to engage them more actively during the lecture and to improve their comprehension of the course material. New elements of the teaching method were introduced in PHYS112 course in 2003. Although the average exam score was lower than the average exam score of PHYS111 for the same students taking both courses, the modified teaching approach contributed somehow to the improvement of students’ understanding of the course material. Compared to the previous three years’ data of exam scores of PHYS111 and PHYS112 where the instructions were traditional, the deterioration of the exam score was significantly less in 2003.

Many reports noted that students could be resistant to any reform in teaching approach because they have been comfortable with existing methods. Based on a course survey administered at the end of the semester, computer-related task was not perceived to be very helpful while hand-outs were voted to be helpful by the majority of the students. They showed more concern with the tasks which were new and assessed. A few comments regarding the activities perceived to be not helpful indicate a problem of motivation and time management. In general, the students appeared to be quite adaptive to the change in teaching approach. Coupled with the results of improvement in understanding mentioned above, the modified teaching can be considered as a promising initial step in helping the students to learn better.

The elements of teaching modifications derived from physics education research have been progressively adopted by lecturers teaching first year physics courses in the department. These lecturers may perceive the benefit of the approach to improve their teaching and to assist their students in learning physics.

#### **4.3. Comparisons between the two case studies**

The two case studies presented in this chapter investigated the effects of research-based instructions in introductory physics classes. It was the first time that non-traditional teaching approaches were implemented in the departments where the courses were taught. In both studies, the interactive engagement activities produced marked improvement in students' comprehension of learning materials. As the result of the modified instruction, students' conceptual understanding and problem solving skills were significantly improved compared to those of the students taught with traditional instruction. Although the population of the students differed in terms of culture and geographic location, their attitudes towards the modified instruction were strikingly similar. While both groups welcomed the application of new elements of the instruction, they revealed their preference to the traditional paradigm of teaching and learning. They still held the view that the lecturer should play the dominant role of presenting the material and the students are the passive audience with almost no preparation for the lecture.

Despite the similarities discussed above, there are some differences in the two case studies. In the University of Surabaya, no elements of the modified instruction required the use of the computer. The reading quizzes and lecture hand-outs in the University of Canterbury study, on the other hand, demanded regular use of the computer. This may cause some students

additional anxiety that those in the other study would have never experienced. There was no separate tutorial session for physics courses in the University of Surabaya; the problem solving practice was included in the lecture session. This was not the case in the University of Canterbury where tutors or teaching assistants were available to help out with problem solving. As most tutors were not accustomed to non-traditional instruction, their skill and knowledge affected the success of implementing the modified approach. It is therefore essential to provide proper training for the tutors (and lecturers); the topic of which is discussed in Chapters 6 and 7.

The most important difference between the two case studies is the continuation of the implementation of the modified approach. The researcher who initiated and executed the instructional change in the University of Surabaya left the institution upon the completion of the first case study. Although several relevant seminars and workshops were conducted prior to the researcher's departure, no other physics lecturers have been motivated to continue the practice. This does not happen in the University of Canterbury as the previous subsection has revealed on "Further developments". Since the implementation of the modified approach, the researcher and her supervisors have been staying in the institution and more importantly, has influenced other lecturers and has been involved in a training programme which is detailed in Chapter 7. The lack of a knowledgeable personnel affected other conditions for change such as resources, participation, supports and essentially motivation to improve the instruction in the University of Surabaya. More discussions on instructional change are presented in Chapter 6.

This chapter shows that research-based instructions can be applied in the countries other than those where the instructions were originated and trialled out. Students' comprehension of learning materials improved significantly compared to those taught with traditional instruction. Nevertheless, the modified instructions did not alter their paradigm of traditional instruction. This strongly held beliefs is explored further in the next chapter. The brief discussions above, on the need of educating the instructors and taking into account conditions for educational change, provide ideas for the next stage in improving teaching and learning.

## **Chapter 5**

### **A Case Study on the Instructors' and Students' Perceptions of Real-life Materials**

Chapter 3 has presented evidence of the advantages of using real-life materials in improving student understanding. Various reports in Section 3.1 indicate that students and their instructors have positive views of the relation between physics and real-life phenomena or applications. Nevertheless, the reports assessed in Section 3.1.2 suggest that these notions have not been applied in teaching and learning practice in the classroom. The methods of instruction often remain in traditional style where the major components are an instructor who presents the material in front of the class and students who do cookbook labs or memorize formulas.

Some questions inevitably arise from the previous expositions: Are the teaching techniques adopted by the instructors the only ones they know of? Do the instructors keep their definitions of physics in mind when they are teaching? How do they try to manifest their meaning of physics in their teaching? More importantly, how do the students respond to such efforts if they exist? The case study in this chapter attempts to answer those questions with the expectation of achieving a better understanding of the nature of the students' and instructors' perceptions of the relation between physics and real-life phenomena. If students and instructors already have the perception that physics provides the explanation of real-life phenomena, they can be encouraged to include more real-life materials in teaching and learning by using the methods described in Chapter 3.

#### **5.1. Methodology**

##### *Participants*

The participants in this study were lecturers and tutors who had been teaching first year physics courses and students who were taking PHYS111 (Introductory Physics for Physical Sciences and Engineering) and PHYS113 (Waves, Thermodynamics and Materials) at the University of Canterbury. In the first term, PHYS111 includes vectors, force and Newton's laws of motion, work and kinetic energy, centre of mass, collisions in one dimension, rotational motion, oscillations, simple harmonic motion, pendulums, and waves. PHYS113 includes friction, potential energy, circular motion, angular momentum, conservation of

energy and angular momentum, equilibrium, and waves of all types (Physics and Astronomy Department Website, 2005). PHYS111 is a required prerequisite for students with less than 57% average in the final year high school national examination in physics and mathematics with calculus. Students with an average in the range 57-59% are interviewed prior to finalization of enrolment to select the best option. For students who have achieved an average of at least 60% in the two subjects, or can provide evidence of an equivalent level of preparation, direct entry to PHYS113 will be offered.

To recruit the participants, the researcher sent an invitation by email (Appendix 2) to 10 lecturers and 17 tutors who had taught first year physics courses. Six lecturers accepted this invitation but there were only five tutors offering to be involved in the study. Tables 5.1 and 5.2 present the profiles of the participating tutors and lecturers.

Table 5.1. Profile of lecturer participants

	Lecturer					
	1	2	3	4	5	6
Years of teaching	30	10	1	5	36	3
100-level courses taught	102, 103, 112 - 116	114, 116	114	106, 111	102, 103, 111, 113	111, 112, 114, 116
Number of students	300 - 400	200, 35	150 - 200	40 - 50, 100	250	200, 300, 50

Table 5.2. Profile of tutor participants

	Tutor				
	1	2	3	4	5
Years of teaching	1	4	1.5	1.5	1.5
100-level courses taught	111 L + T, 113 L	113 T, 114 T	111 T, 113 T	112 T, 113 T	112 T, 114 T
Number of students	20	25 - 30	15 - 20	20 - 25	~ 20

Note: L = laboratory, T = tutorial

The researcher also sent an invitation email (Appendix 3) to all students in two first year courses, PHYS111 and PHYS113. The researcher subsequently visited the tutorial classes of the two courses in the second week of term 2 to briefly explain the activities that participants would be asked to do and the duration of their involvement. Eleven students from PHYS111 and 36 students from PHYS113 expressed their willingness to take part in the study. One of those from PHYS111 and two from PHYS113 did not turn up.

The final grade distributions of the student participants are shown in Figures 5.1 and 5.2. The average final grade of a total of 110 students in PHYS111 was 60.0, while that of the ten participants was 61.6. A total of 460 students in PHYS113 produced an average final grade 64.2; the 34 participants from this course had an average 68.4. While the number of participants is not large enough to represent the whole population, the distribution of their final grades fairly reflected those of their respective course.

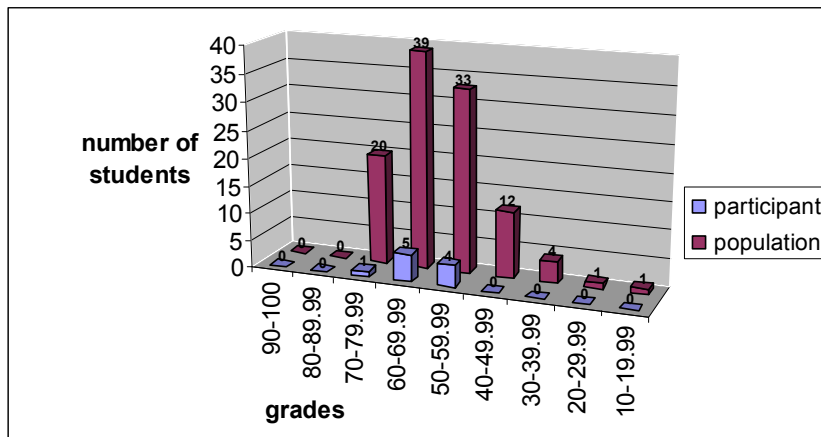


Fig 5.1. Profile of PHYS111 student participants based on grade distribution

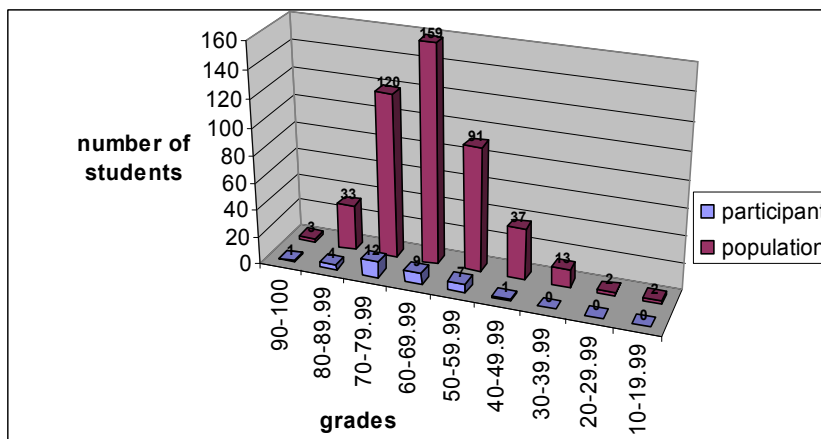


Fig 5.2. Profile of PHYS113 student participants based on grade distribution

### *Interview questions*

A list of questions for interview was constructed to find out the perceptions of instructors (lecturers and tutors) and students on the efforts to connect physics and real-life phenomena in teaching and learning. Appendix 4 presents the questions for instructors, and Appendix 5 contains the questions for students. Table 5.3 shows the question numbers and the issues they address.

Table 5.3. Issues addressed by the questions for interview

Issues	Questions for students	Questions for instructors
1. Problems concerning students' conceptual understanding	B.3 and B.4	A.1 and A.2
2. Awareness of resources	B.1 and B.2	B.1 – B.6
3. Views on good teaching	C.2	A.3, C.1 – C.3
4. Description of physics	A.1 and A.2	D.1
5. Links between physics and real-life phenomena	A.3 – A.5	D.2
6. Efforts to connect physics and real-life phenomena	B.5	E.1
7. Effects of real-life materials in teaching on students	C.1	E.2

### *Data Analysis*

The participants were interviewed individually. The lecturers and tutors took 25 - 45 minutes and the students took 15 - 30 minutes. The interviews were tape-recorded after verbal consent was granted by the participants. The lecturers were offered an opportunity to check the transcripts of the interview.

The data were transcripts of responses elicited in the interview. The analysis of the data was done qualitatively, which involved the process of reading/memoing, describing, classifying and interpreting (Gay & Airasian, 2000). The data were grouped into several categories for the purpose of classification. The interview transcripts were grouped in accordance with the interview questions. Each group contained responses from all participants. Within each group, the participants' responses were then classified into certain ideas. Data interpretation started as early as the process of classifying the data by ascribing each category with a certain idea.

## **5.2. Results and analysis**

### **1. Problems concerning students' conceptual understanding**

The instructors mentioned several conceptual difficulties experienced by their students. Students were perceived to have some troubles along the way from understanding basic principles or definitions to applying these to textbook problems or real-life situations. Some examples of their comments are:

- To evaluate and identify what the fundamental principle to start with, a lot of students seem to have difficulty with that (Lecturer 1)
- It's probably a definition thing, they're just making up their own definition some of the time and thinking about the problem in the wrong way (Tutor 2)

In between, they viewed that students were often confused in distinguishing different variables, which could be related to inadequate understanding of the definitions of those variables.

More than half of the instructors recognized students' tendency to employ formulas straightaway to do any problem solving. They felt that a quantitative problem was easier for the students than a qualitative problem, as the latter usually requires conceptual understanding.

- Question III is quantitative, if students know the formula, they substitute the number and find the answer (Tutor 5)
- I suspect that many of them will be more comfortable looking at that one (*the second one*) than they would at this (*the first, why?*) Because, well, a lot of them, well, maybe the students like formulas and they like to apply formulas and put some numbers in the formulas. (Lecturer 1)

Mazur (1997) observed a similar situation with his students: they were able to solve the so-called standard textbook problems better than the conceptual problems on the same topic.

The instructors' perception that students relied too much on formulas is confirmed by the reactions of the student participants when they were shown two pairs of problems. The student participants promptly mentioned the formula in Question 2 (see Appendix 5) as soon as they spotted it. There were more participants giving this kind of response (59%) than those recognizing the real-life setting (29%) in Question 1. Because of the appearance of the formula, 49% of the participants argued that Question 2 was easier than Question 1 as opposed to 36% who stated otherwise, although they did not attempt to solve the problems. Students' tendency to associate physics with formulas is in line with Arons' (1997) and Hestenes' (1987) recognition that most end-of-chapter exercises in textbooks are dominated by requiring formulas and calculations without so much understanding the underlying concepts.

As to the quantitative problems, 25% of the participants commented on the expected characteristics of the answers such as numerical or interpretative answers. The rest observed other superficial differences in the two problems such as variables, units, and even the familiarity with the problems. These superficial aspects caused the participants to perceive



that the problem in the experimental setting was easier than the problem in the real world setting. There were 45% of the participants having this notion as opposed to only 9% believing otherwise. This is reasonable because the real world problem requires more effort to solve, which includes finding a numerical answer and then interpreting it. Transfer of learning theories discussed in Section 2.3.3 also explain why students perceived that the existence of a formula or superficial aspects of the problem contributed to making the problem easier. These factors were identified to be present in the context of learning they had prior to the interview. Section 2.3.3 suggests that context of learning and degree of similarity between learning contexts affect the extent to which a transfer occurs. The students can be inferred to have seen many problems similar to Question 2 and Problem 1 in Appendix 5.

## 2. Awareness of resources

Resources for the instructors are different from those for the students. For the instructors, some of the resources to improve their teaching are information on various teaching approaches and textbooks which Chapter 3 has shown to contain increasing amount of real-life materials. For the students, the resources to connect physics and real-life phenomena are textbooks and their instructors. Students' responses to various aspects of the textbook (photographs to introduce a chapter, worked examples, qualitative questions and quantitative problems) are discussed in this section. Students' comments on how the lecturers connected physics and real-life phenomena are presented in Sections 6 and 7.

The most conspicuous change of the textbook recognized by the instructors was the increasing number of colourful pictures and diagrams. Some instructors were also aware of some materials being removed from or added to recent editions of the text. Only six instructors had used more than two editions of the text and could comment on the influence of its development on their teaching. Two of them used additional materials accompanying the text and the others adjusted their presentation style to the orientation prescribed by the text. Nine instructors perceived the increasing amount of real-life materials in the text while seven responded that the textbook did connect or at least tried to connect concepts and real-life phenomena, although they were not sure whether their students could see this connection. Although the instructors believed that real-life materials had increased in textbooks, none of them claimed to utilize this development in their teaching. This could be due to the instructors' perceptions of the benefits of real-life materials to their students. Section 7 discusses this in more detail.

All instructors in this study were aware of different teaching approaches or knew other people using different teaching approaches. Their knowledge of various techniques was acquired from collegial communications or from attending a department-based professional development course. Some examples of the variety of their teaching techniques were demonstrations and the use of PowerPoint presentations. These, however, can be categorized as traditional methods which place the instructor as the central figure in conveying all information. Apart from the approach of delivering lectures in a one-way communication, discussion involving students was the only other method that the instructors mentioned to use. Section 6.2 elaborates various ingredients to change an instruction. Instructional resources are one of the components that need to be altered (Fullan, 2001). There are also some conditions to facilitate a successful change (Ely, 1990) including personnel having sufficient knowledge and the availability or accessibility of resources including pedagogical knowledge. As the exposure to information on educational issues was quite limited, the instructors were unlikely to incorporate innovative teaching elements in their instructions.

When the student participants were shown photographs at the beginning of some chapters in textbook, all but six expressed their awareness of the existence of these photographs. Students put forward various comments on what they perceived to be the purposes of the photographs, including stimulating interest (45%), relating physics to real-life (37%), motivating them to know more (29%) and introducing the topic of the chapter (18%). Several ways of developing interest are presented in Section 2.4.2. The real-life context, even though it is just a photograph to introduce every chapter, did interest the student participants to some extent.

The different contexts in two worked examples shown to the student participants were recognized by roughly two thirds of them. They mentioned that one was in a real-life setting or an application example and the other was more theoretical. The ability to make that distinction could be attributed to the pictures which contrast the two examples. 34% of the students asserted that the example involving real-life situation was easier to understand than the other example, while 16% mentioned otherwise. However, only 8 students used real-life context as the reason for the former statement. The familiarity with real-life situation and the topic involved could influence their decision about which example was easier. The use of real-life pictures and representative diagrams also helped students to relate learning materials to their experiences. This kind of visual imagery (Schwartz, Ellsworth, Graham, & Knight, 1998) facilitates learning of an otherwise abstract concept.

The student participants were less able to distinguish a real-life situation from a more theoretical one in a question or problem. Although only 29% of them explicitly mentioned the real-life situation in one of the qualitative questions, some others (20%) were prompted to ponder the answer or to relate similar personal experiences. These comprised half of the student participants. 14% also commented that the question was interesting. Question 2 was designed as a theoretical or conceptual question. This characteristic was not identified by any participants although 29% recognized the real-life setting in Question 1 on the same page. When a pair of quantitative problems were shown, only 18% of them recognized the different contexts, although 25% commented on the expected nature of answer, i.e. numerical versus interpretative answer. The two quantitative problems are typical ones from textbook, the first is described in a lab setting and the second is in a real-life context. The questions asked are accordingly different: one asks for a numerical answer and the other asks for an interpretation of a situation.

Examples, questions and problems in real-life contexts provide an authentic learning experience which constitutes an important aspect of constructivism discussed in Section 2.3. The large proportion of the participants expressing a particular situation, their relevant experiences and their interest on Example 2 or Questions 1 (Appendix 5) indicates that the real-life context did make a difference in terms of attracting their attention. Model of information processing in Section 2.1.2 points out that attention plays a crucial role in selecting which information is to be further processed. As attention is influenced by existing knowledge, physics examples in real-life contexts make it easier for the students to learn.

### 3. Views on good teaching

Having identified that principles or definitions should be correctly established in the first place, almost all instructors made this effort as their priority in helping students. Their methods of teaching, however, were basically traditional in which they tried to make their explanation as clear as possible in a variety of ways including using analogies and contradictory situations. There were only three instructors who employed a two-way communication approach and engaged students by having them discuss or answer questions. As the previous section has mentioned, the instructors had limited exposure to information on pedagogical research. Consequently, their intentions to improve their students' conceptual understanding were not synchronized with any improvement in their teaching. As Fullan

(2001) has advocated, the change in teaching approach is one component to consider in an educational change.

On the idea that teaching by telling is ineffective, opinions from the instructors were split equally between those who were for and those who were against it. The reasons supporting the idea that teaching by telling is ineffective were “there’s no interaction going on” (Tutor 1), “you won’t really process a thing, anything” (Tutor 3), “you have to repeat it many many times to get it through” (Lecturer 2), and “students capture 20% in one hour period” (Tutor 5).

These instructors may realize the limitations of working memory, which are expounded in Section 2.1.2. Lecturer 2 even mentioned the need to use rehearsal to overcome those limitations. Tutor 1 recognized Vygotsky’s principle of the roles of social interactions.

On the other hand, teaching by telling was not always ineffective because:

- you have quite a range of both abilities and interests, and ways in which students feel comfortable with learning (Lecturer 1)
- if you want to go to a lecture and you want to learn, then you learn lots from a lecture. I think if you don’t want to be in the lecture and you don’t want to learn, you won’t learn a lot. So that’s gonna lot more to do with the students than the lecturing style (Tutor 2)
- I think that’s a different learning style again. Some people don’t wanna do that, they’re doing really by just sitting and listening, others that can’t do that, don’t do it that way (Lecturer 3).

The instructors expressing those comments acknowledged the variety of learning styles that students adopted. They perceived that there may be some students who learn better when the instructor uses “information presentation” teaching approach. This may be true for a small number of students, including some of the instructors themselves who are highly motivated and able to learn in a meaningful fashion. However, many sections in Chapters 2, 3 and 6, particularly Section 2.1 on cognitive views of learning, 2.2 on theories of cognitive development, 2.3 on constructivism, 3.2 on problems with traditional teaching approaches, 3.3 on interactive engagement approaches, and 6.2.1 on components of change, have suggested that the majority of students will not benefit much from “teaching by telling” strategy.

The students’ opinions of good teaching can be implied from their suggestions to improve teaching. A large number of these suggestions (73%) were associated with familiar elements of a lecture such as concept explanations, problem solving examples, lecture notes, teaching pace and tutorial times. There were 9 students who wanted more than just improving the

customary practice of traditional lecturing. They wished to have more real-life related exercises, for example clarification of physics connection to real-life applications and practical activities such as going for a field trip, showing videos or using interactive software. This finding is very much similar to the case studies presented in the previous chapter. The students appeared to be still comfortable with traditional teaching approach. Their suggestions focused on improving aspects of the approach which hardly have anything to do with real-life learning contexts. This issue is revisited and contrasted with students' opinions on the use of real-life materials in Section 7.

#### 4. Description of physics

Nine out of eleven instructors expressed the description of physics they teach as understanding the real world or strengthening basic knowledge. Opinions of the remaining two instructors were not far from this idea, they were: preparing students for their further study and providing skills of scientific thinking. Some examples of their statements were:

- the physics they're learning actually applies to the real world (Tutor 1)
- the way of trying to understand the world and make predictions (Tutor 3)
- describes a world that they haven't really experienced yet but it's the world around them (Lecturer 2)
- how the universe works in all its ways (Lecturer 5)
- taking your life situations and describing them using math (Tutor 4)
- you're trying to teach them in the basic content concepts (Lecturer 1)
- physics is a basic fundamental science (Lecturer 5)

These instructors share similar meaning of physics with many educators reported in Section 3.1.1. Physics was described as the principles underlying real-life experiences and real world mechanisms.

Around 60% of the student participants perceived physics as having something to do with real-life, for example "that sort of why things happen, how they happen and sort of the reasons behind it" (Student 5), and "the study of matter and how it acts or what happens when something acts on it. I think it involves everything as sort of real-life" (Student 28). The rest described physics in other terms such as familiarity with the lesson, topics they study, their feelings toward the course and activities involved in learning. There were, surprisingly, only 3 students maintaining that physics dealt with problem solving, formulas and calculation. The proportion of students expressing the view that physics is related to real-life is almost similar to those in other studies (Angell, Guttershrud, Henriksen, & Isnes, 2004; Prosser, Walker, & Millar, 1996).

In responding to whether the student participants have heard other people's ideas about physics, almost half of them described personal feelings towards physics. These were dominated by unfavourable notions such as bored students or a difficult subject. Some others referred back to their own definitions of physics (4 students) or mentioned the well known connotation of physics as being associated with formulas and problem solving (4 students). Physics has been well-known as a difficult subject that easily turns a student off. This attribute of physics is confirmed by the participants' statements of other people's ideas. The students in this study appeared to embrace more positive views of physics compared to other people from whom they chanced to hear the comments on physics.

## 5. Links between physics and real-life phenomena

This section presents the participants' responses to the questions of how close the physics they taught or learned is to phenomena happening in real-life.

As a logical implication of having the descriptions of physics mentioned in the previous section, almost all instructors suggested a close connection between physics concepts and real-life phenomena in their teaching. Some examples of their views are:

- actually many more examples in mechanics you can relate to real-life than there are in any others (Lecturer 1)
- first year, I think, physics can be explained in terms of everyday events much more clearly and much easier. Because physics is just how the world works so there're examples of everything in physics (Tutor 1)
- it's the brilliance of 100 level physics in some sense in that it is the real world if you're willing to make the connections (Tutor 2)

The student participants recognized a close connection between the physics they had been studying and phenomena in real-life. They either expressed explicitly this close connection which could be represented by "pretty much everything I studied so far happens in real-life" (Student 7), quoted spontaneously relevant examples: "This morning I saw a plane flying over and I remembered how the jet stream was formed for the low pressure system behind the plane we learned on the other day" (Student 10) and "I go fishing a lot, and so I sit watching the water outside the boat and I'm thinking oh that's diffraction" (Student 22), or mentioned some conditions of the connection: "you don't actually walk around, you don't think about the principles of forces and stuff that's happening to you" (Student 17).

There were only 4 students who thought that physics was not very close to phenomena they experienced.

Both the instructor and student participants agreed that physics was closely related to real-life phenomena. This is in line with many similar reports presented in Section 3.1.

The majority of student participants put forward phenomena in mechanics as examples of how physics can be connected to real-life phenomena. Some of these examples were a car taking a corner, opening a door, and loop-the-loop. This may relate to the fact that their course in the previous term was dominated by topics in mechanics. Moreover, real-life phenomena involving principles in mechanics are more conspicuous and abundant in everyday experiences compared to those in other topics. The types of phenomena described were taken from lecture demonstrations and students' own experiences in everyday life. This, again, substantiates the role of prior knowledge, including past experiences, in the learning process described in Sections 2.1.1 and 2.3.2.

## 6. Efforts to connect physics and real-life phenomena

In connecting physics and real-life phenomena in their classes, all of the instructor participants mentioned talking about it. Eight showed the connection by doing demonstrations and two by showing pictures. Students did not mention any methods other than what the instructors put forward in the interviews. Students were never asked to perform experiments outside the laboratory. In some very rare occasions, the lecturers advised the students to observe certain natural phenomena such as the colour of the sky at dawn. Since this activity was not enforced or assessed, the students did not care to carry it out.

Section 3.4.2 has detailed various teaching approaches utilizing real-life materials. Instructor's talks and demonstrations are two of those approaches. Other methods require knowledge, skill, equipment and even changes to existing methods. These comprise some components of change (Fullan, 2001), conditions of change (Ely, 2003), and aspects of innovation-decision process (Rogers, 2003). As Section 6.2 illustrates, a significant educational change will not occur unless those requirements and others are taken into account. Since there were not many substantial efforts to seriously consider all of the components, conditions and aspects of change around the time of the study, it is understandable that the instructors did not have a rich variety of methods at hand.

## 7. Effects of real-life material in teaching on students

All instructors agreed that the students became more interested when they were exposed to real-life materials in class, however not all believed that student understanding was improved. There were only five instructors who expected that real-life materials could make some improvement. The six others were either not convinced nor certain of the advantages of using real-life materials in their teaching. Some of their arguments were:

- Usually the real-life stuff is so complicated that it doesn't help (Lecturer 2)
- They say oh well that's great, so what? Can't get you anything. (Lecturer 3)
- Some are hard to accept that real-life is not the same as that in the textbook (Lecturer 6).

The low confidence that some instructors expressed on the benefits of using real-life materials in teaching may be attributed to their lack of such knowledge. As information on educational issues was acquired from limited sources, these instructors may not have recognized many advantages of utilizing real-life materials, which are elaborated in Sections 3.4.2 and 3.4.3. The instructors who deliberately made some effort to include real-life examples in their teaching may encounter some barriers listed in Section 6.1. As a consequence, the teaching approaches they adopted were not as effective as one could expect.

75% of the student participants found that examples on real-life phenomena were helpful. The students became interested when they were shown the applications of physics concepts in real-life situations, many of which they had experienced. There were only very few (6%) who did not see the advantages of having real-life examples. These individuals maintained their beliefs that theories and problem solving should dominate learning efforts. Almost all student participants (91%) also recognized the usefulness of demonstrations performed by their lecturers. Some of their comments were:

- it's sort of a break, you know, from processing information, it's the time you can sit back and yeah that's good (Student 11)
- sometimes you just read it from the book and can see how it works, and you can't really, you know, is it true? Is it right? And when you actually see life, and it's actually wow (Student 42)
- when you do the math later on for a problem you can refer back to and see whether it fits in with what you've seen and you've sort of experienced (Student 8).

The large number of appreciative expressions on the use of real-life examples and demonstrations are consistent with some studies (Woolnough, 1994; Williams, Stanistreet, Spaal, Boyes, & Dickson, 2003; Angell, Guttershrud, Henriksen, & Isnes, 2004; Haussler &



Hoffmann, 2000) presented in Section 3.1.2. The exposure to real-life phenomena may entail such factors as arousing curiosity, connecting topics to students' experiences, presenting conflicting situations, creating variety and novelty, and inducing fantasy. All of these factors are examples of strategies to make learning more interesting as Section 2.4.2 has suggested.

The student participants also believed that the two activities involving real-life materials were beneficial for understanding physics. This view is similar to the finding in Elby's (1999) study on students' choice of learning approach. In the study, becoming familiar with formulas and concepts was rated more important than understanding real-life applications when students wanted to prepare for a test. However, they were willing to spend more time on real-life applications to get a deep understanding in physics. Elby concluded that the students' reason for understanding physics well is different from that for passing a physics course. The present case study reflects this conclusion. The student participants recognized that real-life examples and demonstrations were useful but their suggestions to improve physics teaching focused on aspects of traditional teaching as Section 3 has mentioned. These attitudes could be due to the traditional teaching approaches they had been accustomed to, the assessment (homework, tests, and even school exams) they had been exposed to, and basically, the insignificant demands to appreciate the role of physics in real-life throughout the whole course.

### **5.3. Conclusion**

This case study shows that students and instructors embraced the idea that physics is related to real-life phenomena or their own experiences. While the instructors had the intention of connecting physics to real-life phenomena in their teaching, they mostly lacked the knowledge of how to implement innovative teaching approaches. The teaching methods that they used were largely traditional: instructors try their best to transmit knowledge to their students. During this enterprise, real-life phenomena were presented in narratives or demonstrations. Because those activities were not central to the process of teaching and learning, many instructors were sceptical about the benefits of real-life materials in improving student understanding. Their insufficient information about various teaching methods, particularly those utilizing real-life materials, also contributed to such beliefs.

The students, on the other hand, enjoyed the practice where real-life materials were presented, especially in pictures displayed in the textbook or demonstrations in the lecture. These formats were more easily recognized than real-life settings in the texts, questions or problems.

Students also asserted that real-life examples and demonstrations were helpful in improving their comprehension of concepts. However, they perceived that the emphasis of the instruction was not so much on the connection between physics and real-life phenomena, but rather on traditional aspects such as formulas, problem solving and well-structured lecture notes. This is in line with reports (Prosser, Walker, & Millar, 1996; Elby, 1999) on inconsistency between students' perceptions of physics and their preference in studying physics.

The positive perception of the relation between physics and the real world can be utilized as a promising start to create favourable conditions to include more real-life materials in instruction. If students and instructors already have the perception that physics provides the explanation of real-life phenomena, they can be encouraged to include more real-life materials in teaching and learning by using the methods described in Chapters 2 and 3. It is also important to take into account the students' and instructors' attitudes towards non-traditional instruction because unfavourable attitudes result in some implementation problems. The fact that both students and instructors have been accustomed to traditional instruction explains their distrust of new instructions. The modified approaches described in Chapter 4, although successful in improving students' comprehension of the learning material, did little to change their paradigm of traditional instruction. We argue that instructors have a crucial role of providing an environment conducive to altering this paradigm.

The next two chapters focus on the instructors as a primary agent in instructional improvement. It starts with a literature review on educational change. This provides the background knowledge for determining further efforts to improve teaching and learning.

## **Chapter 6**

### **Educational Change**

The previous chapters discuss issues of teaching and learning in physics education. Traditional instruction has been identified to contribute to problems associated with learning. Students adopt ineffective learning strategies such as rote learning and mechanistic problem solving but make minimal efforts to comprehend the situation or relevant concepts. As a result, physics is often viewed as a huge collection of formulas with almost no utility in everyday life. This phenomenon has been observed to happen not only in physics education; science instruction in general also suffers similar problems. Science is often presented as a large collection of facts, theories, and rules to be regurgitated in the test or examination, rather than principles and techniques to understand natural phenomena. Science teaching usually emphasizes the content coverage instead of the depth of comprehension. Several studies have pointed out that traditional science instruction is responsible for the decreasing popularity of science among students, the declining number of students majoring in science, the widespread science illiteracy among non-science majors, and the inadequate preparation of the younger generation to cope with rapid changes in society (Tobias, 1990; Magner, 1992; Millar & Osborne, 1998; Seymour & Hewitt, 1997).

There have been numerous efforts to improve the quality of science education. The previous chapters have elaborated some of these efforts in physics. Basically, they emphasize active involvement of students in the learning process by creating conducive environments. Textbooks have been revised and teaching techniques have been modified to incorporate educational principles. Interactive engagement approaches and inclusion of real-life materials are the most prominent elements identified in innovative physics instructions.

The movement towards improving recent practice has also been noticed in other areas of science and at all levels of education (Magner, 1992; Lazerson, Wagener, & Shumanis, 2000; Cuban, 1990; McIntosh, 1996/1997). There seems to be a shift in the paradigm of effective teaching: from an “instruction paradigm” where instructors transfer knowledge, to a “learning paradigm” where instructors facilitate learning (Barr & Tagg, 1995). Many terms are used to label these contrasting approaches including “teacher-centered versus student-centered” learning (Cuban, 1984). The paradigm shift is giving students more responsibilities for their own learning.

There has been widespread realization of educational problems, an extensive body of research to create education innovations, refinement of teacher training programmes, and recurring waves of educational reforms. Despite these, the way an instructor teaches seems to be insignificantly affected. School teachers as well as university lecturers continue to talk most of the time in front of the class, allowing almost no student involvement in learning process. The explanations for the persistence of traditional instruction are discussed in Section 6.1.

This chapter also investigates the complex nature of educational change, in particular, the process that a lecturer undergoes in changing his/her instruction. Section 6.1 discusses the reasons for teachers refusing to take part in the reform. Section 6.2 analyzes factors to facilitate the change and Section 6.3 presents some examples of professional development programmes to help instructors to improve their teaching. If the previous chapters focus more on the learners and instructional methods, this chapter is all about the instructors.

### **6.1. The persistence of traditional teaching**

The awareness of the problems contributed by traditional instruction rose as early as mid 1800s. Memorization and recitation were suggested to be replaced by approaches fostering students' interest to understand the world around them. The connection between learning experience and the real world was an important element of instructional innovations in almost all educational reforms for over 150 years (Cuban, 1990). Other elements in innovative approaches in higher education such as immediate feedback, active involvement and collaborative learning (Lazerson, Wagener, & Shumanis, 2000) are consistent with constructivist view of learning presented in Chapter 2. An instruction is more effective if the lecturer is willing to allow their students to play a greater role in their learning. It means that lecturers should "step down from the podium and embrace innovative teaching methods that hand authority back to the students" (Utley, 1997, p. 8). However, this turns out to be more difficult than rectifying students' misconceptions, as is discussed later.

Despite waves of reforms targeting primary to high schools, traditional instruction persisted for almost a century (Cuban, 1982). Some changes did occur in a number of schools. Primary teachers were found to be more willing to modify their approaches compared to high school instructors. The dominant teaching practice, however, still centers on the teacher as the transmitter of knowledge. Education reforms appear to have insignificant effects on primary

school level and even less on high school (Cuban, 1982). If this implication is extrapolated, reforms in the university level have almost zero possibility of success. Is this true?

We have been unable to locate a similar study on higher education. This does not mean a lack of reform efforts targeting colleges and universities. There were at least six major reform visions of improving higher education instruction (Lazerson, Wagener, & Shumanis, 2000). In the 1980s, Astin (National Institute of Education, 1984) suggested several principles to be adopted in college instruction, including greater student involvement in their learning. Similarly, Harvard's Bok and Light advocated the importance of interactive engagement and immediate learning feedback (Light, 2001). Boyer (1991) from the Carnegie Foundation for the Advancement of Teaching launched his vision of "Scholarship of Teaching". Boyer viewed teaching as a scholarly activity; the same status which has already been ascribed to research for a long time. Cross (Angelo & Cross, 1993; Cross & Steadman, 1996) concretized this vision by encouraging lecturers to conduct research on their classrooms. The latest efforts in this sequence were suggestions that teaching should be treated like research in terms of public and investigative characteristics (Hutchings & Shulman, 1999; Shulman, 2000).

In physics education, many researchers have proposed and implemented innovations in teaching as presented in Chapter 3. A growing number of physicists have been involved in improving physics instruction: In the United States, over 100 faculty members from 80 physics departments are active researchers in physics education (Finkelstein, 2006). Even Nobel Prize Winners in Physics, Lederman (Burnstein & Lederman, 2001) and Wieman (Wieman & Perkins, 2005) for example, advocate the change in teaching practice which encourages more student participation.

Many higher education institutions have endeavoured to attain some of those reform visions. Most large colleges and research universities have Teaching and Learning Centers. Teaching awards and grants become as common terms as research fundings. Some lecturers, individually or collaboratively, adopt new elements in their teaching. These changes, however, cannot yet be categorized as reforms if no value has been added to student learning. In fact, some researchers (Lagowski, 1993; Lazerson, Wagener, & Shumanis, 2000) are in doubt that the changes have produced the desired outcomes visioned by the reformers.

Higher education institutions are a complex system with many interacting components. One of these components is faculty member or academic staff or lecturer. There is no doubt that

lecturers play the most important role in improving instruction (Lagowski, 1993; McIntosh, 1996/1997; Van Driel, 2001). Educational reforms will not be successful without considering the pivotal status of lecturers as the primary change agent. Yet, many lecturers, like their counterparts in primary and high schools, adhere to traditional instruction despite the increasing pressure to allow greater student participation in learning process (Utley, 1997). These lecturers, who are mostly researchers, strive to keep abreast with changes and development in their disciplines. When it comes to teaching, however, they seem oblivious to educational research findings and suggestions to improve their own teaching.

There are many reasons for the lecturers' reluctance to reform their instruction. At the individual level, many still embrace the idea that teaching is transmitting knowledge from the instructor to students. The focus is on certain amount of subject knowledge to cover instead of the depth of understanding that students should achieve. Technology, which sometimes constitutes as a component in innovative teaching technique, is often perceived as replacing the lecturers' roles and diminishing their jobs (Utley, 1997). Typical introductory classrooms with large number of students and sheer amount of curriculum material reinforce the belief that lecturing is the only feasible method of teaching. Some lecturers ascribe recurring issues such as student's motivation and preparedness as problems in primary and high schools (Lederman & Niess, 2000; Lazerson, Wagener, & Shumanis, 2000). Time and energy required to improve a course can be in conflict with other professional duties especially research. The superior prestige of research is still prevalent in the culture of many higher education institutions. Reformers view this culture as a significant impediment to encourage lecturers to seriously think about their teaching.

Even the lecturers who are willing to consider modifying their instructions still face many barriers (Briscoe, 1991; Henderson, 2005; Sunal & Hodges, 1997; Van Driel, Beijaard, & Verloop, 2001; Fedock, Zambo, & Cobern, 1996). Those barriers include (a) prior knowledge about instruction built from years of traditional practice, (b) limited time and energy needed to plan, execute and evaluate the change, (c) many students who are unprepared and unmotivated, (d) inadequate resources such as new knowledge, curriculum materials and expert guidance, (e) lack of training prior to implementing the change and ongoing professional development, (f) lack of support from colleagues and administrators, (g) little or almost no incentive, rewards, or recognition associated with efforts to change teaching, and (h) insignificant contribution of excellence in teaching to promotion or tenure.

Given those many obstacles faced by lecturers in their endeavours to improve their teaching, it is no wonder that they are likely to revert to their previous instructional practice. It also comes to no surprise that many university classrooms, especially those in introductory science courses, still use traditional approaches. Is there anything that can be done to promote educational reform in higher education?

In order to answer the question above, particularly in looking at how to encourage individual lecturers to consider improving their instruction, there are some issues to examine. The next section scrutinizes several factors involved in implementing an instructional change.

## **6.2. Theories of educational change**

There are various theories of educational change (Ellsworth, 2000). However, “the problem with any model is the temptation to apply it within all situations; it is not feasible to create a change model for every situation within higher education” (Kezar, 2001, p. 114). This section attempts to provide some basic understanding of what it takes to enable an educational change by examining three theories focussing on different aspects of change. The theories presented here offer simple frameworks which have found their applications in recent studies of change in higher education. A number of case studies are used to illustrate these applications.

### **6.2.1. Components of change**

A significant educational change is achieved if there are changes in three components simultaneously (Fullan, 2001): (a) beliefs, ideas or knowledge underlying teaching practice, (b) materials or instructional resources, and (c) teaching approaches. An instructor may focus on some of these components and ignore the other. However, the resulting change will not be substantial. Changes in beliefs and conceptions about teaching are the foundation to achieve a lasting reform. Educational reforms are likely to fail if instructors’ beliefs, intentions and attitudes are ignored (Haney, Czerniak, & Lumpe, 1996).

Similar to prior knowledge that students bring to their school learning, instructors have a set of beliefs and knowledge about teaching. The characteristics of this knowledge are action-oriented, person- and context-bound, tacit, integrated and beliefs influenced (Johnston, 1992; Handal & Lauvas, 1987; Pajares, 1992). The knowledge comprises ideas of subject matters, teaching practice and student learning. These cognitive resources have been developed

through formal learning and practical experiences throughout an instructor's career. Like the students' misconceptions which often provide workable explanations to everyday phenomena, instructors' beliefs and knowledge serve them in the same way in their teaching.

Several papers investigate ways in which university instructors conceptualize teaching (Dall'Alba, 1991; Martin & Balla, 1991; Samuelowicz & Bain, 1992, 2001; Martin & Ramsden, 1992; Kember & Gow, 1994; Trigwell & Prosser, 1996; Åkerlind, 2004). Most of these studies use phenomenographic approach (Marton, 1986) for the investigations. The conceptions or belief orientations are categorized in many different ways as presented by Table 6.1. Despite the differences, the studies suggest that the conceptions can be arranged in a continuum from information presentation to learning facilitation.

Table 6.1. Some examples of categories of teaching conceptions

Dall'Alba (1991)	Martin & Balla (1991)	Samuelowicz & Bain (1992)	Martin & Ramsden (1992)	Kember & Gow (1994)	Trigwell & Prosser (1996)	Åkerlind (2004)
presenting information	presenting information focusing on delivery or content organization	imparting information	presenting content or process	knowledge transmission focusing on subject	transmitting concepts of the syllabus	teacher transmission
transmitting information		transmitting knowledge	organizing content or process	knowledge, transferring information, using educational media or preparing for specific jobs	transmitting teachers' knowledge	teacher-student relations
illustrating the application of theory to practice	developing active learning focusing on motivation, discussion and experience	facilitating understanding	organizing learning environment		helping students to acquire concepts of the syllabus	student engagement
developing concepts and principles and their interrelations	relating teaching to learning.	changing students' conceptions	facilitating understanding through engagement with content and process.	learning facilitation focusing on motivating students, fostering pastoral interest, facilitating teaching, using interactive approach, or improving high level thinking processes.	helping students to acquire teachers' knowledge	student learning.
developing the capacity to be expert		supporting student learning.			helping students to develop conceptions	
exploring ways to understand					helping students to change conceptions.	
bringing about conceptual change.						

Conceptions of teaching are identified to affect approaches to teaching (Trigwell & Prosser, 1996). Lecturers who perceive teaching as transmitting information approach their instruction



as teacher-focused strategies. Likewise, lecturers who view teaching as helping students to develop and change their conceptions are likely to adopt student-focused strategies for their instruction. Environmental constraints such as the number of students in class and the limited resources, however, may cause an inconsistency between the lecturers' conception of teaching and their claimed purposes of various teaching activities (Murray & MacDonald, 1997). Teaching approaches adopted by lecturers influence learning strategies used by their students (Kember & Gow, 1994). Departments oriented towards knowledge transmission motivate their students to learn using surface approaches, whereas departments oriented towards learning facilitation encourage meaningful learning strategies.

As Chapters 2 and 3 have articulated, meaningful learning is achieved when students actively construct knowledge on their own. This suggests that knowledge transmission conception does not effectively promote meaningful learning. Traditional instruction is associated with teaching as a transfer of knowledge. Educational reform efforts necessitate a conception shift from "teaching as a transfer of knowledge" to "teaching as a facilitator of learning". Nevertheless, beliefs and conceptions are in many cases very difficult to change (Marentič-Požarnik, 1998). Lecturers who hold the view of their role as knowledge transmitter are less likely to implement a significant teaching modification in their courses even after they participate in a professional development programme (Sunal, et al., 2001). Lecturers who determine to adopt innovative teaching approaches often have trouble in discarding their old conception of teaching. Rather than changing their instruction in a radical way, most lecturers are inclined to modify only parts of the materials and techniques to accommodate their traditional teaching view (Thompson & Zeuli, 1999). Lecturers sometimes find this view in conflict with their intention to facilitate learning. They often slip back to lecturing approach (Briscoe, 1991; Henderson, 2005; Fedock, Zambo, & Cobern, 1996) especially when they feel time is pressing to cover the material.

Similar to the process leading to a conceptual change in student learning discussed in Chapters 2 and 3, instructors need to undergo such a process in changing their conceptions of teaching. The first step of this procedure is to expose their ideas and knowledge about teaching. It can be done through discussions or interviews at the beginning of or throughout a professional development course (Dall'Alba, 2005; Sunal, et al., 2001; Van Driel, Beijaard, & Verloop, 2001; Van Driel, Verloop, Van Werven, & Dekkers, 1997; Prosser & Trigwell, 1997) or an instructional change programme (Briscoe, 1991; Henderson, 2005; Fedock, Zambo, & Cobern, 1996; McKenzie, 1996). Instructors then need to be made aware of the

limitations of teaching approaches associated with their teaching beliefs. This could be achieved by introducing the instructors to education literature which include various teaching and learning conceptions (Trigwell & Prosser, 1996; Prosser & Trigwell, 1997), principles of good teaching (McKenzie, 1996), research on student learning, etc., and engaging them in discussions either with their peers or more experienced persons. The latter signifies Vygotsky's view of the importance of social interaction to foster learning. The next crucial step is "hands-on activity" where instructors are encouraged to implement what they learn in real situations (Briscoe, 1991; Sunal, et al., 2001; Van Driel, Verloop, Van Werven, & Dekkers, 1997; McKenzie, 1996; Fedock, Zambo, & Cobern, 1996; Henderson, 2005). Discussions with experts or other experienced persons on the implementation plan are a good starting point. This kind of collaborative work should be maintained throughout the programme. The approach, to some extent, resembles students conducting hands-on activities in groups, the benefits of which have been demonstrated in previous chapters. It is important to make sure that instructors are actively involved in the whole process, from the planning to the evaluation of the programme. An instructional change is rarely successful if instructors are simply told to teach differently (Tikunoff & Ward, 1983; Wallat, Green, Conlin, & Haramis, 1982). It is apparent that "teaching by telling" does not always work, even for instructors. The reason is pointed out by the constructivist view: each instructor has a framework of beliefs and knowledge about teaching with which new information, for example new materials or new approaches, is assessed. In order to create a significant instructional change, instructors need to modify their cognitive frameworks in a way that the new curriculum makes more sense and is perceived to be more useful than the existing curriculum.

Up to this point of discussion, instructors are similar to their students in terms of knowledge construction. They need to alter their beliefs and conceptions about teaching in order to effectively implement a change in their practice. The conceptual change is important, but it is only one of many conditions to promote a lasting and significant educational reform especially in a complex system such as a higher education institution. The next subsection discusses a theory on some conditions for change which has been validated across a variety of educational and cultural settings.

### **6.2.2. Conditions of change**

There are some conditions that need a serious consideration to promote a successful change (Ely, 1990): (a) there is dissatisfaction with the present condition, (b) the personnel have

adequate knowledge and skill relevant to the change programme, (c) resources (tools and materials) are accessible, (d) there is time available to familiarize, plan, implement and evaluate the new programme, (e) there are rewards or incentives for taking part in the programme, (f) participation in communication and decision making is encouraged, (g) there is endorsement and continuing support for implementation, and (h) there are leaders who provide encouragement, inspiration and the above conditions.

This theory of conditions of change, to some extent, has been confirmed in many educational settings (Ellsworth, 2000). Similarly in higher education, those conditions of change contribute to the success of several change programmes as illustrated below.

A qualitative study on the experiences of four science lecturers involved in an in-service programme for elementary and secondary teachers (Fedock, Zambo, & Cobern, 1996) reveals that most of Ely's conditions exist. The lecturers were concerned about the quality of science instruction in pre-college levels. They derived this notion from the poor scientific understanding their students bring to their courses. The first condition of change is thus fulfilled. Although these lecturers were never involved in any training or professional development course, they worked closely with an education research team and had access to resources on learning, school programmes and teaching techniques. Through constructive dialogues with a science education expert and mentor teachers, the lecturers made decisions along the way, from designing the instruction to its evaluation. Allowing lecturers to actively participate gives them a sense of ownership in the programme. The lecturers also received grant funding for their participation. The leadership factor was not present in this study because the in-service programme was not related to the lecturers' institutions. Nevertheless, the existence of other conditions was sufficient to motivate the lecturers to initiate and implement a new teaching approach. The programme was considered as successful in terms of instructional modification attempted by the participating teachers and the intentions to adopt the new strategy in their college classrooms by the lecturers.

Another study followed the progress of 10 lecturers from one year of undertaking a course in higher education to the following year of implementing new instructions (McKenzie, 1996). In addition to training, time, resources and supports from colleagues, increased confidence and willingness to take risks were recognized to contributing to the change in teaching conceptions leading to the change in teaching approaches. The awareness of other problems,

such as the class size, student ability, structure of subject matter and other commitments, also served as a motivation to attempt the change rather than rejecting it.

When an instructional change is carried out within an institution, all Ely's conditions should be taken into account. Kozma (1985) surveyed two programmes designed to promote instructional innovations by interviewing 145 people from 28 higher education institutions. It is concluded that there were several issues pertinent to an innovation being widely and continually adopted. Funding is necessary to compensate for the time needed to design and use the innovation for the first and subsequent times. Innovations involved in collaborative projects are more likely to be used broadly and persistently, and eventually integrated in the regular activities of the institutions. Innovations should address the needs of institutions rather than as the means by which administrators justify the funding allocation. The administrators themselves should take an active role as instructional leaders and provide environments conducive for effectively implementing innovations.

Another important factor contributing to promote an educational reform is the vision of institution's mission being shared by administrators and faculty staff (Lagowski, 1993). A vision, alongside with leadership and incentives, is regarded as the basic requirement for an institutional reform. Lazerson, Wagener and Shumanis (2000) argued that institutions need to incorporate teaching improvement to incentive and promotion system similar to research in the discipline. By fostering a conducive environment fulfilling the conditions proposed by Ely (1990), institutions raise the prestige of teaching enterprise to be as important as research.

The three components and the eight conditions of change constitute parts of the whole change process. In addition to these factors, there are characteristics and mechanism of the change that deserve careful attention in understanding this issue. The next subsection presents a model of adopting an innovation.

### **6.2.3. A model of innovation-decision process**

According to Rogers (2003):

The innovation-decision process is a process through which an individual (or other decision-making unit) passes from gaining initial knowledge of an innovation to forming an attitude toward the innovation, to making decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision (p. 168).

The stages through which this process occurs are illustrated in Figure 6.1 (Rogers, 1995, p. 163). This model is derived from numerous research on innovation adoption in various fields such as education, farming, public health, communication, etc.

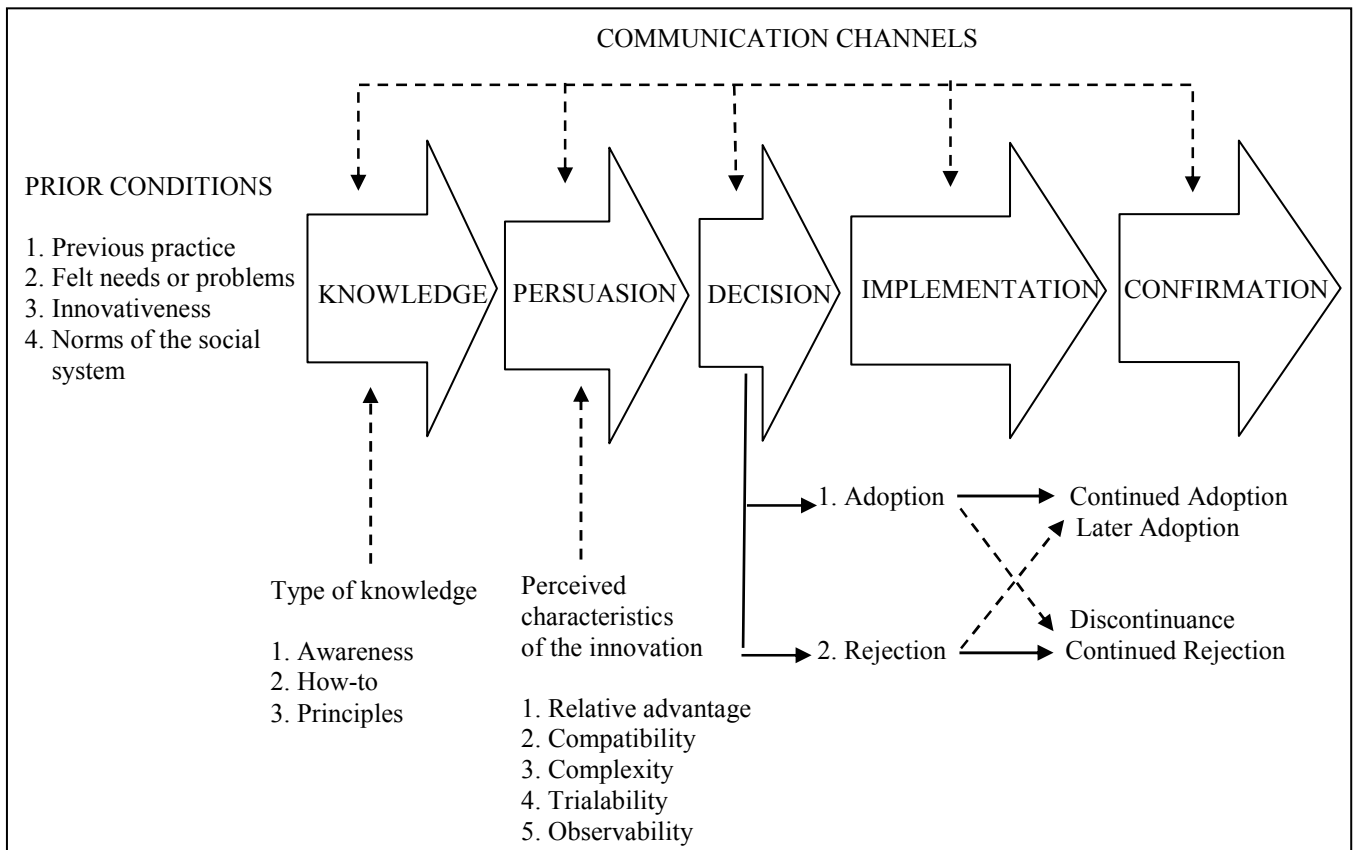


Fig. 6.1. Rogers' model of innovation-decision process

The prior conditions which motivate a lecturer to consider adopting a new instructional approach include the feeling of dissatisfaction with the current approach. This condition is also identified by Ely (1990) discussed earlier. Additionally, the lecturer is influenced by previous teaching experiences, values and visions of the institution, and innovativeness of the new approach. At the knowledge stage, the lecturer comes to know the innovation and gets some ideas about it. There are three types of knowledge: awareness knowledge (information that the instructional approach exists), how-to knowledge (information on how to implement the instructional approach properly), and principles knowledge (information on why the instructional approach works).

After sufficient knowledge is acquired, the lecturer develops a favourable or unfavourable attitude towards the innovation. Also affecting the formation of this attitude is five perceived characteristics of the innovation shown in Figure 6.1. Once the attitude is created, the lecturer can now decide whether to adopt or reject the innovation. There are two kinds of rejection:

active rejection where a lecturer decides not to adopt an innovation after he/she thinks about it, and passive rejection where the lecturer never seriously thinks about adopting the innovation. At the implementation stage, the lecturer puts the innovation into practice. The lecturer may implement the innovation in its original form or modify it which is known as re-invention. The lecturer often seeks more information about the innovation after the implementation. This may lead to one of the four further decisions depicted in Figure 6.1, i.e. continued adoption, later adoption, discontinuance, or continued rejection.

The model of innovation-decision process focuses on individual level. It does not mention for instance external factors such as some of Ely's conditions of change. This model should be considered in conjunction with Fullan's components of change and Ely's conditions of change to carry out a comprehensive analysis on an educational change process. This is illustrated by the following case study of a lecturer endeavouring to change his physics instruction.

A physics lecturer who had been dissatisfied with his instruction intended to improve his teaching (Henderson, 2005). He appeared to have some prior conditions suggested by Rogers (2003) i.e. the needs to change his practice and an experience of 30 times teaching the course. To gain some awareness knowledge about the new approach, he attended a national programme on improving introductory physics instruction. In addition, he had regular discussions with an experienced high school teacher. The persuasion stage was affected by relative advantages, compatibility and complexity of elements of the new teaching approach. Each element undertook a loop starting from persuasion stage (favourable or unfavourable view towards certain element) through a decision to use and the implementation of that element, to confirmation stage where the element was evaluated in terms of the three factors involved in persuasion stage. As a result, some teaching elements were discontinued, some others were modified from the original design, and a few were executed as they were initially planned. At the end of the semester, the lecturer felt that student understanding was similar to that of the previous years when traditional method was applied. This was confirmed by the performance of students in the test which was not significantly improved. Furthermore, some aspects of teaching method and outcome were not properly addressed nor achieved.

Rogers' model of innovation-decision process, to some extent, applies to the above case study. However, some of Fullan's components and Ely's conditions of change were not present. It is not clear whether the national programme that the lecturer attended succeeded in changing his existing beliefs and conceptions about teaching which is one of Fullan's

components. The lecturer sometimes reverted to previous teaching practice when he found that the new method was problematic in the implementation. He frequently expressed his intention to cover the material and thought that the previous teaching approach facilitated this better. The focus to cover the material is one aspect of teaching conception which regards teaching as knowledge transmission. Some of Ely's conditions were apparent in the case study, such as dissatisfaction with current practice, resources, participation and support. However, there was inadequate knowledge and skills to properly implement the change. There was also insufficient time to assess the current method, to practise with new materials, to try out and to evaluate the new procedure.

This section on theories of educational change discusses components, conditions and process of change mainly for university teachers. As the previous chapters have indicated, many of the reformed teaching approaches necessitate smaller classes for tutorials and/or laboratories (Cummings, Marx, Thornton, & Kuhl, 1999; Hake, 1992; Laws, 1991; McDermott, 2001; Redish, Saul, & Steinberg, 1997; Sharma, Millar, & Seth, 1999; Steinberg & Donnelly, 2002). These classes are usually supervised by teaching assistants (TAs) who can be tutors in tutorials or demonstrators in laboratories. In order to promote an educational change in introductory physics courses, it is therefore important to consider duties, problems and training of TAs which are presented in the following section.

### **6.3. Teaching assistants' duties, problems and training**

The typical responsibilities of physics TAs in undergraduate tutorial sessions are modelling problem solving, recording attendance, marking homework, administering quizzes and responding to students' inquiries. TAs also supervise students in laboratories, grade lab reports, invigilate examinations and carry out review sessions (Druger, 1997). In short, TAs' roles are to assist the course lecturer in various areas of instructional, curricular and assessment activities (Kurdziel & Libarkin, 2003). TAs' duties may be extended beyond the classroom such as seeking out students who need extra help (Doucette, 1994), providing office hours, developing curricular material and taking care of a class webpage (Goff & Lahme, 2003). TAs are not only helping to lessen lecturers' burden of teaching a large group of students, they also act as a "crucial intermediary" between lecturers and students (Stoeker, Schmidbauer, Mullin, & Young, 1993). They assist students by clarifying lecturers' ideas and inform the lecturers about students' state of understanding. Effective TAs facilitate an otherwise one-way communication between students and their lecturers. Fingerson and Culley

(2001) find that TAs also motivate lecturers to seek ways to promote students' active participation.

Despite the aim to provide TAs with appropriate knowledge and skills, orientation programmes organized by universities or departments for new TAs sometimes do not fully support their teaching tasks. Experienced TAs can be in denial concerning problems with their work. As a result, the performance of TAs is often unsatisfactory (White, 1998). Many TAs are not aware that they are failing to help students learn effectively. Etkina (1999) observed that TA concerns focus on students' skill in plugging numbers into equations or taking experimental measurements. They rarely assess whether students have comprehended the concepts underlying the problem solving or the meaning behind experimental data. Interviews with first-year TAs (Gilreath & Slater, 1994) and responses to a training programme application (McComas & Cox-Petersen, 1999) reveal TAs' hopes and expectations to be better teachers. They would like the lecturers to advise them on how to teach. In addition, they want to improve their teaching skills so that they are able to effectively clarify physics concepts to their students.

Various TA training programmes have been proposed to prepare new TAs as well as to improve skills of senior TAs. McComas and Cox-Petersen (1999) categorize training and support for TAs in four levels: (1) the so-called laissez-faire approach where no formal programme is offered, (2) non discipline-specific workshops often conducted by the university, (3) discipline-specific workshops provided by departments, and (4) lecturer-specific apprenticeship where TAs work closely with their mentors. Most TA training programmes provide general information about departments and specific duties that TAs have to perform. Gilreath and Slater (1994) describe lab demonstrator training programme consisting of simulated laboratories and micro-teaching assignments which were videotaped and discussed with their peers. Peer videotaping and classroom observations were also included in a science TA programme (Druger, 1997). A unique Graduate Science Teaching Assistant Enhancement Programme (McComas & Cox-Peterson, 1999) involves science TAs collaborating with science education graduate students. The collaboration includes classroom observations, regular discussions and workshop activities. Promoting awareness of physics education research is one of the purposes in other TA training programmes (Ishikawa, Potter, & Davis, 2001; Etkina, 2000). In addition, those programmes also include reflective practice where TAs relate their experience and findings from physics education research, hands-on activities where TAs practise Socratic dialogues or model good problem-solving technique,



and getting feedback on their lab or tutorial sessions. Etkina (2000) also mentioned other activities such as requiring TAs to design effective instruction approaches, to present physics education research papers, and to develop essays to reflect their experiences. Other programmes to prepare physics TAs are extensively listed in Jossem (2000).

There are clearly several reasons explaining the persistence of traditional instruction and several factors which can facilitate educational change. Many lecturers continue teaching in traditional fashion because of their beliefs, knowledge, and job priority as well as the lack of resources, training and institutional support. Educational change is promoted by altering pedagogical beliefs and improving instructors' knowledge. In addition, institutions should provide resources and compensation, encourage participation, and essentially improve the status of teaching as a scholarly activity. Numerous examples of professional development programmes for instructors, including teaching assistants, have been presented. Programmes that incorporate educational principles elaborated in Chapter 2 are likely to produce benefits in terms of improved pedagogical knowledge. Reflective practice reveals current understanding of teaching and learning based on everyday experiences. Discussions with peers, mentors or instructors facilitate knowledge construction as was suggested by Piaget and Vygotsky. Teaching practice provides opportunities to engage in authentic learning situations to promote meaningful learning as advocated by constructivists. These principles and practice for effective pedagogical transformation can be incorporated in a professional development course as discussed in the next chapter.

## Chapter 7

### A Professional Development Course for Teaching Assistants

The case study in Chapter 5 and other studies (Angell, Guttershrud, Henriksen & Isnes, 2004; Prosser, Walker & Millar, 1996; Haussler & Hoffmann, 2000) reveal that students and instructors have indeed the perception of the relation between physics in the classroom and real-life phenomena or applications. This view can be utilized as a fertile ground to create a conducive environment for more inclusion of real-life materials in teaching and learning. The question now is how to acquaint instructors with innovative teaching techniques which include using real-life materials. This chapter presents an approach to introducing instructors to issues in physics education research.

The students of present generation are different in many respects from their counterparts of a few decades ago. In the past, students were expected to be independent and well-prepared upon entering their tertiary study. Current students, particularly first-year undergraduates, have been described as generally less ready for college than their predecessors (Leamson, 2001). Not only has the student population changed, the state of affairs of teaching and learning has been affected as well. Chapter 3 presents numerous innovative teaching methods to help students learn physics more effectively. Many of the reformed teaching approaches necessitate smaller classes for tutorials and/or laboratories (Cummings, Marx, Thornton, & Kuhl, 1999; Hake, 1992; Laws, 1991; McDermott, 2001; Redish, Saul, & Steinberg, 1997; Sharma, Millar, & Seth, 1999; Steinberg & Donnelly, 2002). These classes are usually supervised by teaching assistants (TAs) who can be tutors in tutorials or demonstrators in laboratories.

Physics TAs are mostly graduate students who are conducting research into specific areas of physics (Etkina, 2000; Gilreath & Slater, 1994; Ishikawa, Potter, & Davis, 2001; Jossem, 2000). As many lecturers are not aware of students' problems (Hestenes, 1987; Van Hise, 1988; Gardner, 1993); it is likely that TAs are equally unaware. TAs often do not acknowledge their students' physics concepts nor are they aware of the difficulties faced in trying to alter these concepts by conventional instruction. As Section 6.1 has revealed the persistence of traditional teaching, it is possible that the majority of TAs were subjected to "information transmission" as the only teaching approach when they did their undergraduate study. As a consequence, these TAs are more likely to adopt "information transmission" method in their teaching. This is an unfortunate situation because TAs could and should have

more intensive interactions with students in small classes as compared with the lecturers in big lecture theatres.

There was also a more pressing need for knowledgeable TAs in the department. The second case study in Chapter 5 describes a modified teaching strategy which included tutorial sessions. It was observed that the TAs involved in the course had some difficulties in interpreting their responsibilities associated with the teaching modification despite the weekly meetings to enlighten them about their tasks. In order to promote the effectiveness of the approach, it is important that everybody involved, including TAs, understands the rationales and principles underlying the modification.

This chapter presents a departmental based endeavour to upgrade physics TAs. Specifically, it describes a course set up in the Physics and Astronomy Department, University of Canterbury (Cahyadi & Butler, 2005; Cahyadi, Butler, & Reid, 2005). The course is an adaptation of a Master of Science education course. It provides TAs with some basic knowledge upon which they can build their teaching expertise. This knowledge, which includes prior beliefs, teaching conceptions and information on physics education research, is an essential part of effective instructional change (Fullan, 2001; Ely, 1990; Rogers, 1995). The course may be seen as a unique model for training physics TAs in which the TAs, as novice researchers, were exposed to research in education relevant to their teaching.

The course PHYS329/425: Introduction to Physics Education Research was established with a long term goal of improving the quality of undergraduate physics teaching in the department. In particular, the aim of the course is to introduce TAs to issues in physics education research. On completion of the course, TAs are expected to be aware of typical students' preconceptions and state of understanding; be sensitive to the skills and preconceptions of students in their class; appreciate the scale of educational and cognitive research; and acknowledge the impact of this research on efforts to reform teaching.

TAs need to be knowledgeable about problems in physics education, not only to induce motivation to improve their teaching skills but also to prepare them to become future academics. By introducing the scholarship of teaching early in a TA's career as a prospective member of academia, the course should assist them to position themselves in this dynamic aspect of education and help them to take actions for making further improvements. Although

the course was tailored for physics TAs, the objectives, design and evaluation could be adapted to suit any departmental TA development programme.

## **7.1. Methodology**

### *Participants*

All current tutors and demonstrators are encouraged to enrol for the course every year. Academic staffs in the department are also invited to attend the course. Two or three lecturers present the course. In the first year of the course, fifteen TAs and five academic members participated either as enrolled students or non-enrolled attendees. The subsequent years saw varying numbers of participants: five in 2005, eight (including one teacher trainer) in 2006, and four (including one lecturer and one post-doctoral researcher) in 2007.

### *Experimental design*

### *Instructional approach*

The course runs in the first semester with a term break in the middle of the semester. The class meets weekly for 100 minutes to read and discuss various issues in physics education from journal articles and a textbook (Redish, 2003). In the first meeting, the participants are asked to do the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) to probe their basic physics concepts. It is an assessment of Newtonian concepts which they use in most tutorial sessions. The test also serves as a starting point for discussions on students' misconceptions and other problems in learning physics.

The participants are motivated to interpret the reading materials and to share their teaching experiences. In the last three years, the discussion strategy was improved by having two participants prepare hand-outs containing summary of the reading and questions every week. They lead the discussion by briefly mentioning the ideas in the reading materials, asking questions or relating their experiences relevant to the topic. In this way, the participants are given the responsibilities for their own learning. The exercise is expected to make them realize that what the students do is the most important thing to emphasize in teaching and learning.

### *Reading materials*

The reading materials for the course consist of journal articles and a textbook (Redish, 2003). The latter contains a summary of research on cognitive development, curriculum design, student preconceptions and expectations, as well as some guidance on using a variety of teaching tools. The topics of the first half of the course are students' misconceptions (Halloun & Hestenes, 1985; Hestenes, Wells, & Swackhamer, 1992), students' expectations (Redish, Saul, & Steinberg, 1998), learning difficulties (Kim & Pak, 2002), cognitive problems (May & Etkina, 2002), assessment (Dufresne & Gerace, 2004), and the effects of instruction (Hake, 1998; Biggs, 1999; Ramsden, 1992). The second half of the course addresses a rationale to teach science (Longbottom & Butler, 1999), physics education in the UK and Europe (various articles from *Physics World*), various teaching strategies (Hake, 1992; Laws, 1991; and the last five chapters in Redish, 2003) and teaching international students (Biggs, 2003). As the course progressed through the years, relevant articles in recent issues of *American Journal of Physics*, *Physics Teacher*, *Physics Today*, *Physics Education* and other publications were added as the reading materials.

### *Assessment*

The assessment consists of contributions to weekly seminars, a short presentation on relevant topics and two essays. While all participants are expected to actively contribute in the seminars, only the enrolled students are required to give the presentation and submit the essays. The last two meetings are allocated for short presentations for the enrolled students. At the completion of the course, every presenter submits a comprehensive essay based on the presentation. The students are allowed to choose any topic of interest in physics education for their presentations and essays. They are advised to include some analyses based on weekly discussions, course readings and their experiences.

### *Evaluation of the course*

The first year's course was subject to an evaluation, the results of which were utilized to make improvement in the subsequent years. Several items were used to evaluate the course:

1. Email correspondence to reflect the participants' attitudes towards the course.

As the course was in its first time running in the department, the lecturers conducted weekly meetings to discuss what had occurred during the course and how to improve the situations. Following these discussions, emails were sent by the lecturers to the class. The content of the emails reflected the lecturers' responses towards the participants' attitudes during the course.

2. Short presentations and essays submitted at the end of the course to identify how the participants made sense of the course materials.

The short presentations and essays were examined in terms of the topics, the extent to which the topics were analyzed, and the references used to support the analysis or arguments.

3. A questionnaire administered six months after the end of the course.

The questionnaire was a standard course survey which is a customary practice in the institution. The Survey and Testing Unit (STU) assisted in administering the questionnaire. Participants were made clear of the assurance of their anonymity and information about the purposes of the questionnaire. The latter included seeking feedback on the effectiveness of the course and the participants' plans to implement what they learned in the course.

## **7.2. Results and analysis**

### *The attitudes towards the course*

The majority of participants were graduate physics students who conducted at least one semester of teaching in tutorial or laboratory sessions. However, very few had come across articles or discussions on issues in physics education. At the beginning of the course, some participants were observed to be rather apprehensive about the reading topics. From their comments in the first few meetings, they perceived the method, analysis and conclusion presented in many of the research articles as inappropriate. There was little awareness that physics education was an area different from the physics they were doing as research. Some of them felt so much resentment that they refused to follow the initial plan of the course which required the participants to hand in weekly journals.

The purposes of the journals, as written in the course outline, were to:

provide you with a way of recording your ideas during the semester. It will also provide the convenors of the course with feedback about the development of your understanding of the course content and of any questions that you might want answered. In this weekly

journal you will record the significant ideas you have got from the reading and any questions you have about the material by answering the following questions:

Prior to the seminar:

1. What is the most significant information / ideas / concepts that you have got from this week's reading?
2. Describe an aspect of this week's reading that applied to your own work or your professional development.
3. What problems do you see in the research referred to in this week's reading? How could it be improved or changed?

After the seminar:

4. On reflecting on this week's seminar, are there any further comments, new ideas or problems you would like to raise?

(The first version of the course outline, posted in the first week).

An email was sent out to the participants in the second week reminding them to complete and hand in the weekly journals. However, only one participant complied with this request.

Another email was again sent out in the fifth week to encourage participants to submit the journals. As there was no response, this requirement was then discontinued.

Some participants were quiet and put forward almost no responses during discussions. Since the requirement of submitting the weekly journals was no longer applied, the lecturers came up with another strategy of making sure that all participants were involved and willing to contribute to discussions. In the fourth week of the course, the lecturers sent an email to the class containing the following excerpt:

... we must ensure that all are engaged in discussions, and one way to assist that would be to ask each of you to stand up and present a few words each week. We therefore ask that you come prepared to give a 2 minute description (plus/minus a factor of 3) of what a section of the assigned reading says, and your critique of the ideas in that section. You may choose to report and comment on relevance, rigour or alternative points of view. (Email correspondence, posted in the fourth week).

The strategy seemed to be working in terms of the involvement of all participants during discussions. However, most of them misinterpreted the word "critique" and presented only the summaries of their assigned reading material. The course outline was therefore revised by adding the following elaboration:

The focus of the weekly discussion will be on relating the research to your own learning, teaching and classroom experience. In order to encourage this, for the next weeks the convenors will give a two-sentence summary of each section followed by student's critique of his/her assigned section. What matters here is not right or wrong accounts, rather accounts that are more or less coherent, more or less convincing and more or less thoughtful. (The third version of the course outline, posted in the sixth week).

A further clarification of what the participants were expected to do in the course was sent out in the week after the term break.

The objective of our Wednesday discussions is to produce an informed judgement (a critique in that older sense), of the critical (in the sense of being crucial or of critical importance) arguments and data in the readings. ...

As an attendee you are then asked to

1. State the most significant information / ideas / concepts that you have got from your assigned section of this week's reading.

AND then to do one of

2. Describe an aspect of your assigned section of this week's reading that applies to your own work or your professional development.

3. Describe problems you see in your reading. Comment on how could it be improved or changed.

4. Relate an idea of the reading, or another relevant new idea or problem, to other literature (including the textbook).

You will note that these items 1-4 are (reworded) items of your weekly journal.

(Email correspondence, posted in the seventh week).

After a few weeks into the semester, the participants seemed to get more comfortable with the line of thought evolving from the readings and discussions. They were able to put forward their ideas relevant to the reading topics. Moreover, most participants attempted to relate their prior experience as an undergraduate student and current work as a TA to the discussion issues. At this point, the participants were beginning to appreciate the way the course was organized. A few comments in the questionnaire reflect their impression of the course:

- ... a bit disorganised at first, but got better nearer the end.
- Many students seemed to be feeling bullied into the course which caused resentment and bad feeling. However once all that settled down it was OK and better than I thought.
- The course was a good example of how NOT to teach. The content was useful.
- I think the principles involved are worthy and grad students should be exposed to the research into teaching, especially if expecting to be a tutor.

Some participants wanted more practical examples of better teaching approaches although these were already touched on in some discussions.

- More time should be spent on teaching methods of teaching better.
- MUCH more discussion about practical ways in which to apply what the research has learnt.

One participant who was obviously inspired by the reading topics suggested having some alternatives for conducting the course: "it would have been nice to see more imaginative delivery and variation in style ... more student-centred learning activities".

The course was designed to incorporate educational principles proven to be beneficial in several TA training programmes identified in Section 6.3. The course was not designed to



prescribe a long list of effective teaching methods; rather it endeavours to facilitate a transformation of pedagogical knowledge of participants. The instructional method, therefore, involves eliciting participants' beliefs and referring to their experience as undergraduate students as well as working with their students. One of basic principles of cognitive learning theories (Section 2.1.1) is that prior knowledge and beliefs affect knowledge construction. Existing beliefs, including principles of physics and views on teaching and learning, are demonstrated to be difficult to change as Sections 2.3.2 and 4.2.1 have discussed. Identifying prior knowledge and beliefs is the crucial first step to facilitate a conceptual change. This is in parallel with the first principle of rectifying misconceptions discussed in Section 2.3.2.

### *The comprehension of the course materials*

The short presentations and essays submitted at the conclusion of the course reflected the participants' comprehension of the course materials. The titles of the essays suggest the important aspects of teaching and learning they wanted to focus on. The topics they selected ranged from a philosophical critique of ancient Greek teaching (essay title "Lessons from ancient Greece") to a set of practical recommendations of organizing a tutorial session ("A tutor's perspective on changes made to the teaching of Phys111"). The participants were able to examine a variety of ideas, including:

- students' misconceptions ("Students' misconceptions of Newtonian mechanics: intrinsic or taught?")
- suggestions to improve physics teaching ("The concepts and changes behind better physics student learning", "Physics education: how do we make it work?")
- conditions of physics education ("Teaching and learning physics – an overview", "Maximae and minimae in the multi-dimensional surface of physics education")
- and even the state of education in general ("Current problems in the technique of teaching and learning").

Participants used the reading materials and discussion topics to establish their suggestions to improve the situations they were focusing on. Most participants utilized other references outside the given articles to provide convincing supports for their arguments. One of the aims of the course, i.e. to familiarize participants with physics education research, seems to have been accomplished. This achievement could be due to the way the course was organized which required an active involvement of the participants in discussions.

The main activity of the course was discussions of articles and textbook chapters on physics education research. The discussion approach adopted in the course incorporates several learning principles reviewed in Chapters 2 and 3. Similar to their students, the participants' working memories have short duration and limited capacity (Section 2.1.2). Traditional lecturing style is definitely not an ideal approach if the participants are expected to learn something from the course. In discussions, there were many opportunities where participants came across ideas or experiences which contradicted their beliefs. This is more likely leading to the process of resolving the conflicts to reach equilibrium state. As Piaget has suggested in his theory of cognitive development (Section 2.2.1), this process is essential in promoting the growth of knowledge.

The social interaction occurring during discussions facilitated the development of understanding. Vygotsky's sociocultural theory (Section 2.2.2) points out the beneficial role of sharing ideas and experiences among the participants. Being involved in discussions also guided the participants in the process of understanding how learning, including their students' learning, takes place. This can be considered as a guided participation which prepares the participants to do their job more effectively.

Discussing experiences of teaching (as a TA) and learning (as a student) to some extent can be considered as an authentic learning experience. The real-life relevance of the discussion topics is one of the characteristics of constructivism (Section 2.3.1). The discussion topics are chosen to be relevant to the participants' work experience as TAs. This is intended to enable participants to optimally apply what they learn to their own classes, thus fostering transfer of learning (Section 2.3.3). As interactive-engagement approaches have been demonstrated to effectively improve students' cognitive knowledge (Section 3.3.1), involving the participants in discussions is expected to improve their pedagogical knowledge.

#### *The intended utilization of the knowledge gained from the course*

The survey results indicate that most of the course objectives have been met. Comments from the participants about the intended utilization of the knowledge they gained from the course can be categorized into the following entries:

##### 1. Impact of the course

The course had produced some impacts on the participants as was revealed by the following examples of verbatim transcript:

- It made me more aware of the language I used to explain physics concepts (i.e. using words like ‘power, force, heat etc’ in their correct physics contexts). I hadn’t realized the impact of everyday English on physics and how this may confuse students to whom English is a 2nd language.
- ... the course was very effective at making me think about my teaching methods and to grapple with poor performance of students in physics.
- As someone supervising tutors I found that the tutors who had been on the course were more open to think critically about the teaching/learning taking place in a tutorial. As a result I could have a more constructive dialogue with suggestions and feedback and they were more open to new ideas. This made my job easier.

## 2. Plan for the near future

Most responses described the participants’ intentions to carry out some actions as a result of attending the course. The following presents the plans revealed by the survey:

- I am also teaching the physics Prep course next month. Some of what I learned from the course will be used during this time.
- I will continue to reflect on my teaching practice and read others’ ideas and choose whether or not to implement them just as I did before the course.
- Hoping to get into academia, I intend to apply what I learnt ASAP.
- I strongly recommend the course to all the academic staff in the Department of Physics and Astronomy. ... I could then use that course as a model to other departments to develop similar course.

TAs are not expected to initiate an instructional change, nevertheless their involvement in any teaching reform, if required, is encouraged. TAs need to be conversant with issues in the education research of their discipline if they want to work professionally. They need to know some findings from research on education including cognitive theory of learning. They also need to be familiar with subject specific educational research including typical conceptual misunderstandings and rationales underlying instructional modification. Supplying the participants with such reading materials is aimed to familiarize them with physics education research and to provide some resources for teaching ideas (Ishikawa, Potter, & Davis, 2001).

The role of the selected reading materials is justified in terms of theories of educational change expounded in Section 6.2. The reading topics provide information on various beliefs, materials and teaching approaches which are the three components needed to be considered in any educational change (Fullan, 2001). The feeling of dissatisfaction with the present condition as well as the relevant knowledge and skills which the course can provide are two of the conditions to promote an educational change (Ely, 1990). Other conditions are beyond the capacity of the course as a professional development programme. Some of the reading

topics do not only introduce the participants to various teaching innovations (awareness knowledge), but they also show some implementation strategies (how-to knowledge) and rationales of those innovations (principles knowledge). These three types of knowledge should be acquired in the early stage of adopting an innovation (Rogers, 1995). By being actively engaged in discussing issues in physics education, the participants are expected to play their parts effectively in any reformed teaching they may be involved in the future.

### *Preliminary achievements from the course*

In the year following the course, an outcome was realized on a departmental scale: All first-year tutorials were organized to have a uniform format (Cahyadi & Butler, 2006). Prior to this, the tutorials were conducted by tutors who normally modelled problem solutions on the board. Their students just copied the solutions into their notes. Some tutors may have asked questions or asked students to work out problems on the board. Others tended to keep on talking and writing throughout the session. Students were not encouraged to have a discussion with their peers or do their own thinking. Lecturers had a meeting with the tutors only at the beginning of the semester. Very few lecturers maintained contact with their tutors on a regular basis afterwards. Subsequent to being exposed to issues in physics education from the course described in this chapter, some lecturers realized that such tutorial schemes did not help students to understand what they learned.

A new format of tutorial is designed to require active involvement of students in their own learning. Students are grouped in two or three to discuss the problems assigned as homework or as an exercise in the tutorial. Tutors no longer do the talking and writing for the class. They instead pose questions in a Socratic dialogue style to guide students in solving the problems on their own. Students are often required to explain concepts in their own words to others. It has been found that tutors readily modify their tutorial instruction method to the new format. As most of the tutors involved in first year courses have been participating in PHYS329/425, they do not have any difficulties in making sense of and implementing the new tutorial approach.

A year prior to the first course, an instructional reform was initiated in an introductory physics course (Cahyadi, 2004b) which included tutorial sessions. The tutors involved in the course were found to have trouble in understanding what to do even though they attended weekly meetings to enlighten them about their tasks. Not only did they oppose the advice to do less

talking and writing on the board, they also considered student discussion as a waste of time. This attitude changed after they completed the professional development course. Because they had been exposed to research on student preconceptions and other problems, they could appreciate why it is necessary to let students engage actively in their learning. They recognized that there were many other ways of promoting effective learning, some perhaps better than the way in which they were taught.

### **7.3. Conclusion**

The principal aim of the course described in this chapter is to familiarize TAs with issues in physics education research so as to gain a deeper understanding of teaching and learning than they had before. The short presentations, the essays submitted at the completion of the course and the course survey suggest that most of the short term objectives were attained. The finding that the TAs participating in the course were more open to ideas indicates they appreciated the effort to reform teaching. The participants recommended the course to academic staff and encouraged other departments to develop similar courses, which shows their perception of the benefits of the course. By being actively engaged in the readings and discussions throughout the course, the participants developed an understanding of the methodology, and respect for the utility of research in physics education.

Having been enlightened by well-researched students' difficulties and various proposed solutions, TAs will ideally establish their own conceptual framework that accommodates the improvements. TAs are expected to be more willing to be involved in the improvement of the quality of undergraduate physics teaching in the Physics and Astronomy Department, University of Canterbury. When a new format of tutorial was introduced in the year following the first course, the TAs readily adjusted their instruction in which interactive engagement was encouraged.

It is too early to claim that the course has made an impact on the first-year students with whom the TAs are working. The course is the first of its kind in the department and perhaps in the institution. There is still a long way to go towards the goal of improving the quality of undergraduate education in the department. The course has established an awareness of issues in physics education and encouraged the participants to devise action plans for applying what they have learned. Improvements to the course are continually planned and implemented. Further support for the TAs is also needed to enhance the teaching and learning excellence.

## Chapter 8

### Overall Conclusion

This chapter presents important findings from the studies involved in this thesis. These findings are summarized as the answers to the research questions in the first three sections of the chapter. Based on the findings, some contributions to physics education research are proposed. There are also some limitations identified in the studies and suggestions for further research. This chapter is concluded with implications of the studies for future practice to improve teaching and learning.

*The effects of research based instructional approaches on students' comprehension of the learning material.*

Chapter 4 presented the effects of research-based instructional approaches on students' comprehension of the learning material. Compared with those in other classes taught by traditional approaches, students in the classes with interactive engagement approaches demonstrated a significant cognitive improvement. In the two institutions where the modified approaches were implemented, the students achieved significantly higher conceptual gains (measured by a standardized test) and subject matter comprehension (measured by exams). The improvement was due to the nature of activities that encouraged students to actively engage with the learning materials, their peers and their instructors. The approaches also emphasized the importance of understanding concepts rather than only focusing on mathematical problem solving. The effectiveness of the modified approaches claimed by numerous reports was corroborated in the two case studies.

Since the introduction of the modified teaching approach in 2003, some elements of the approach have been progressively adopted by lecturers teaching first year physics courses. These elements include group discussions in tutorial, prepared hand-outs posted on WebCT, weekly online quizzes, and in-lecture peer discussions followed by responding to questions.

*The attitudes of students and instructors towards research based instructional approaches or resources.*

The two case studies in Chapter 4 also examined students' reactions towards the modified approaches. The students perceived the new teaching elements to be interesting and

stimulating. They were also in favour of the resources to facilitate their learning such as pre-downloaded hand-outs. The perception that the interactive engagement activities were interesting, however, did not make the students think that they were important. From their responses in the surveys, students preferred to have more lecturing on concepts and problem solving than other activities. The students also did not like spending time preparing for lectures by working on the online quizzes. These findings suggest that the students still embraced traditional paradigms of teaching and learning where a lecturer was viewed as the information presenter and a learning process as absorbing or recording information without significant effort to understand the information.

Interviews with students and instructors in Chapter 5 revealed that they acknowledged the role of physics in explaining underlying principles in real-life phenomena. While the instructors intended to show the relation between physics and real-life phenomena in their teaching, they employed traditional teaching methods in which real-life exposures were not the central activities. The lack of knowledge of innovative teaching approaches led the instructors to their scepticism about the effectiveness of including real-life materials to improve students' understanding. The students asserted that activities using real-life materials were interesting and useful for their learning. However, they considered elements of traditional instruction, such as concept explanations, problem solving examples and lecture notes as very important in good teaching. Students' attitudes in this study are in line with the responses to the surveys described above. The students enjoyed being involved in interactive engagement activities or being exposed to real-life materials. Nevertheless, they favoured traditional instruction which focuses more on an instructor presenting explanations and problem solving examples.

The students involved in the studies had been exposed to traditional instruction for many years. The instructional change limited only to these classes was hardly sufficient to convince them that effective learning needs more than just what is provided by traditional teaching. Likewise, many instructors were comfortable with the traditional teaching they had been using in their classes. Insufficient knowledge about learning problems and research-based solutions led to insignificant motivation to improve their own instruction. The literature review in Chapter 6 identifies the pivotal role of an instructor as the primary change agent in any instructional reform and specifies several initial requirements for an educational reform. This indicates the necessity for instructors to have knowledge particularly in educational theory.

*Other efforts to promote a more conducive teaching and learning environment.*

The results from the studies described above suggest the need for instructors to be conversant with teaching and learning issues. If the majority of instructors implement research-based instructional approaches, students will be inclined to believe that those approaches are the norm, rather than atypical and isolated practice in the institution. This will lead to better attitudes than those revealed in the above mentioned studies. One way of introducing instructors to issues in physics education is establishing a professional development course in their departments, as presented in Chapter 7. The course incorporates educational principles confirmed to be effective in facilitating the transformation of pedagogical knowledge. The instructional method emphasizes interactive engagement of the participants in discussions and making connections to their teaching and learning experiences. The course has been running for four years to date.

Based on the evaluation of the first course, the participants were shown to have become aware of issues in physics education and were motivated to devise action plans for implementing what they had learned. Efforts to enhance teaching in first year courses in the department have been facilitated by the readiness of teaching assistants graduating from the course to improve their own instruction. More lecturers are also willing to be open-minded and receptive to ideas to improve their teaching. This is evident from the fact that all elements of the modified teaching approaches investigated in Chapter 4 have been implemented in almost all of first year courses.

*Contributions of this thesis to physics education research.*

A great many studies in physics education focus on the implementation of research-based instruction to improve student cognitive abilities. The modified teaching approaches aim to alter students' beliefs and knowledge about physics and learning approaches. Their cognitive abilities will improve if they adopt a constructivist learning approach and view physics as the underlying principles of real life phenomena. The case studies in this thesis have succeeded in enhancing students' comprehension of the learning material by using some research-based teaching activities. However, a successful implementation of a modified instruction is inadequate to create a significant educational reform because most students and instructors firmly embrace the paradigm of traditional teaching and learning.



Just as students need to change their beliefs about learning, instructors also need to go through a change in their beliefs and knowledge about teaching. In order to achieve this aim, a professional development programme should provide opportunities for conceptual change to take place. A university-based short course or a very specific workshop on a certain teaching method is not sufficient to bring about a transformation in pedagogical beliefs and knowledge. The programme should incorporate interactive engagement activities and making connections to real-life experiences in teaching and learning. This induces the instructors' awareness of problems in learning physics. Instructors should also be well-informed about various innovative instructions to solve the problems. The awareness and knowledge will help them to recognize the deficiency of their traditional instruction and motivate them to improve their teaching practice.

This thesis has initiated effective methods to achieve an excellence in teaching and learning in introductory physics. The focus of this investigation is on the two most crucial components in teaching and learning enterprises: instructors and students. As to the students, research-based teaching approaches were implemented in local environments and were successful in improving students' comprehension of the learning material. As to the instructors, a professional development course was set up in a department and succeeded in encouraging instructors to improve their teaching. The emphasis of educational enterprises should be shifted to educating instructors. Instead of only modifying their teaching practice, instructors should also undergo a transformation in beliefs and knowledge in pedagogy. It is only when all instructors are willing to undergo such a transformation that a significant achievement in teaching and learning will be realized.

*Limitations of the studies in this thesis and issues for further research.*

The improvement in students' cognitive abilities in Chapter 4 was due to the modified teaching methods. Their attitudes probed by the surveys are concerned with their reactions towards the methods and not so much with the effects of the methods on their beliefs and learning approach. Future research may want to look at students' learning approaches and attitudes before and after the implementation of a modified instruction.

The teaching modification reported in Chapter 4 consisted of some elements of innovative approaches. This did not include an extensive usage of real-life materials which Section 3.4

has reviewed. If the interactive engagement approach was successful in improving student comprehension, does the inclusion of real-life materials also achieve the same outcome on the students? Future research may focus on this idea, including looking at how technology can offer valuable aids to using real-life materials as well as supporting the interactive engagement environment.

The students interviewed in Chapter 5 were from a small self-selected sample. Although their distributions of final grade fairly reflected those of their respective population, their perceptions on issues probed in the interviews may not represent the perceptions of the population to which they belonged. There were also other introductory physics courses that were not included by this study. Those courses are not calculus-based, have fewer students and run in a different semester. Students in these courses may have different opinions about physics and teaching approaches. Further research could scrutinize the differences in the attitudes of students attending different types of introductory physics courses.

The benefits of the professional development course presented in Chapter 7 were interpreted from participants' final essays and a course survey. Those completing the survey were only a small sample of participants in the first course. Most teaching assistants graduating from the course are willing to adopt constructivist practice in their tutorials. The report in that chapter did not extend the investigation to identifying the effects of changing the participants' teaching approach on their students' achievement. This could be a potential topic for an extension of this study.

Although a number of lecturers have adopted some elements of innovative instruction in their teaching, many others are still teaching in traditional fashion. They may never be exposed to issues in physics education research or, if they are, they may fail to recognize the implications of this research in their teaching. Further research can explore other efforts to familiarize lecturers with educational issues. Various means can also be examined to persuade lecturers to improve their instructions.

Each of all studies in this thesis was conducted at one point in time. Teaching and learning enterprises are an interdependent process of progression over a period of time. More data could be collected from an extended length of time in future research involving a transformation in beliefs and practice of a group of instructors and their students' change in learning concepts and approaches.

*Implications for future practice.*

Improving teaching and learning needs more than simply implementing a new method in a few classrooms. Without a transformation in pedagogical beliefs and knowledge, instructors can easily slip back to their previous teaching method. Instructors should undergo this transformation prior to adopting a new teaching approach. While applying the new approach, instructors should also impart principles underlying the practice to their students. This could be done by continually reminding the students about the reasons, purposes and proper ways of doing the activities.

Students, having been accustomed to traditional teaching practice, are not easily convinced that a new method is more effective for their learning. When they learn that other classes or courses are still traditionally taught, they may feel a resentment towards the new method which is usually more demanding in terms of efforts and commitment. They may not realize that their cognitive abilities are improved as a result of the new instruction. In order to promote the status of a new instruction, all introductory classes or courses should modify the current teaching practice. The students will notice that there is a transformation in teaching and learning practice upon entering a university. It is only then that they will be motivated to go along with the new practice and willingly change their beliefs and adjust their learning strategies.

Getting all instructors, especially those teaching in introductory courses, to transform their beliefs and practice is not an easy enterprise. It is the role of leaders in the department or institution to initiate this effort by providing encouragement and concrete supports. They can, for example, help to set up department-based professional development courses designed for addressing subject specific educational issues. They can require all teaching assistants and new lecturers as well as encouraging continuing lecturers to attend the courses. In addition to facilitating the implementation of research-based instructions, they can offer various inducements such as academic recognition and professional promotion. There have been endeavours to promote the “Scholarship of Teaching” since the 1980s (Lazerson, Wagener, & Shumanis, 2000), however the superior prestige of research is still prevalent in the culture of many higher education institutions. Encouraging those leaders to place, in practice, more important emphasis on teaching and learning will probably be a continuous challenge to enhance the quality of education.

## Appendices

### Appendix 1. Questionnaire to find student's attitudes towards interactive engagement teaching approach

#### A. How often do you:

##### 1. read the handout outside lecture hours:

- a. always, before each lecture according to the schedule
- b. sometimes, only if I remember and time permitted
- c. rarely or almost never

##### 2. practise problem solving:

- a. routinely every week
- b. sometimes, usually if the lecturer already grumbles or gives homework
- c. rarely or never, it is never graded, unless being asked to hand in

#### B. What do you think about:

##### 1. reading handout at home:

- a. useful, to help understanding the lecture better
- b. no effect, the lecture is still hard to understand
- c. useless, a waste of time at home, the lecturer explains the topic in the class anyway
- d. other: .....

##### 2. the reading quiz

- a. enables to encourage student to read handout at home
- b. no effect, whether doing the reading or not doesn't make a difference
- c. totally useless, a waste of time in the class
- d. other: .....

##### 3. concept explanation from the lecturer

- a. quite clear, it reflects what is written in the handout
- b. nothing new, the concept is already understood
- c. not clear at all, the explanation is too brief
- d. other: .....

##### 4. problem solving explanation from the lecturer

- a. quite clear, although it is only a brief explanation
- b. no effect, the examples in the handout are easy to understand
- c. not clear and not detailed enough, because it is explained briefly
- d. other: .....

##### 5. constructivist dialogue

- a. induces the thought about simple things which need to be understood
- b. doesn't stimulate any thought, it is not worth discussing such simple matters
- c. causes a confusion, some concepts are different from those taught at high/secondary school
- d. other: .....

6. peer instruction

- a. forces student to think because he/she has to explain it to other students and write the outcome of the discussion
- b. doesn't make students think, because they don't know the concepts/formulas to use
- c. totally useless, a waste of time in the class
- d. other: .....

7. in class demonstration

- a. interesting because it relates the theory and the reality
- b. entertaining break, instead of listening to the lecturer, reading from the board or taking notes
- c. confusing instead, the phenomena are not in line with the prediction resulted from discussion
- d. other: .....

8. ALPS worksheets

- a. guide the students in the start of solving a problem
- b. not related to the taught concepts or problems
- c. useless, a waste of time in the class
- d. other: .....

C. Recalling that the exam will consist of conceptual understanding (50%) and problem solving (50%), sort the following activities by their degree of importance. Put a label *1* (very important) to *6* (very unimportant) in front of each activity.

- |                                   |  |
|-----------------------------------|--|
| _____ reading quiz                | _____ constructivist dialogue            |
| _____ concept explanation         | _____ peer instruction and demonstration |
| _____ problem solving explanation | _____ ALPS worksheets                    |

D. Other comment:

.....  
.....  
.....

**Thank you for your cooperation!**

## Appendix 2. Email advertisement for recruiting participants (lecturers and tutors)

You are invited to participate as a subject in the research project :

### **Lecturers' and students' perceptions of the real-life materials in teaching and learning physics.**

The aim of this project is :

To obtain information on how lecturers and students think about the use of real-life materials (objects, phenomena, activities) in teaching and learning introductory physics.

Your involvement in this project will involve being interviewed on your ideas of the use of real-life materials in teaching and learning physics. The interview will take no more than 45 minutes in your office, my office (Room 716) or other place you prefer. You have the right to withdraw from the project at any time, including withdrawal of any information provided.

As a follow-up to this investigation, you will be asked to check the transcript of the interview if you desire.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure anonymity and confidentiality, you will be labelled with pseudonym.

The project is being carried out as a requirement for a PhD thesis by Veronica Cahyadi under the supervision of Prof. Phil Butler. They can be contacted at 3642987 ext 6563 or [veronica.cahyadi@canterbury.ac.nz](mailto:veronica.cahyadi@canterbury.ac.nz) (Veronica) and 3642521 or [phil.butler@canterbury.ac.nz](mailto:phil.butler@canterbury.ac.nz) (Phil). He/she/they will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed *and approved* by the University of Canterbury Human Ethics Committee.

If you agree to take part in this project, please answer to this email so that we can arrange a convenient time for the interview.

Thank you.

### Appendix 3. Email advertisement for recruiting participants (students)

You are invited to participate as a subject in the research project :

#### **Lecturers' and students' perceptions of the real-life materials in teaching and learning physics.**

The aim of this project is :

To obtain information on how lecturers and students think about the use of real-life materials (objects, phenomena, activities) in teaching and learning introductory physics.

Your involvement in this project will involve being interviewed on your ideas of the use of real-life materials in teaching and learning physics. The interview will take no more than 30 minutes in my office (room 716) or other place you prefer. You have the right to withdraw from the project at any time, including withdrawal of any information provided.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure anonymity and confidentiality, you will be labelled with pseudonym.

The project is being carried out as a requirement for a PhD thesis by Veronica Cahyadi under the supervision of Prof. Phil Butler. They can be contacted at 3642987 ext 6563 or [veronica.cahyadi@canterbury.ac.nz](mailto:veronica.cahyadi@canterbury.ac.nz) (Veronica) and 3642521 or [phil.butler@canterbury.ac.nz](mailto:phil.butler@canterbury.ac.nz) (Phil). He/she/they will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed *and approved* by the University of Canterbury Human Ethics Committee.

I will visit your tutorial sessions to make the appointment and arrange a convenient time for the interview.

Thank you.

Appendix 4. List of questions for structured interview (for lecturers and tutors)

*Introduction*

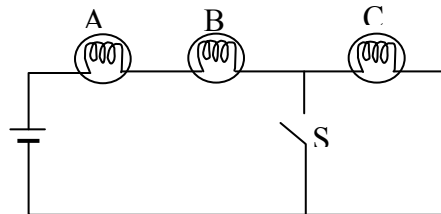
1. Are you a lecturer or a tutor for 100-level physics courses?
2. How long have you been teaching 100-level physics courses?
3. What 100-level physics courses have you been teaching?
4. How many students are there in your classes normally?

*A. Problems concerning the students' conceptual understanding*

A. 1. How do your 1<sup>st</sup> year students answer the following questions: (*show questions I and II first, then III and IV*)

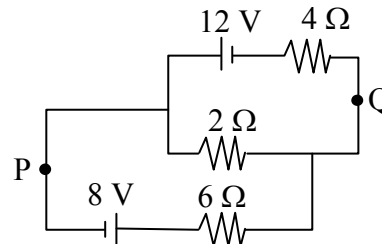
I. A series circuit consists of three identical light bulbs connected to a battery as shown here. When the switch S is closed, do the following increase, decrease, or stay the same?

- a) the intensities of bulbs A and B
- b) the intensities of bulb C
- c) the current drawn from the battery
- d) the voltage drop across each bulb
- e) the power dissipated in the circuit



II. For the circuit shown, calculate:

- a) the current in the 2- $\Omega$  resistor
- b) the potential difference between points P and Q
- c) the power dissipated by the 6- $\Omega$  resistor



III. A 2-kg cart, traveling on a horizontal air track with a speed of 3 m/s, collides with a stationary 4-kg cart. The carts stick together. The impulse exerted by one cart on the other has a magnitude of:

- a. 0
- b. 4 N.s
- c. 6 N.s
- d. 9 N.s
- e. 12 N.s

IV. A large truck collides head-on with a small compact car. During the collision:

- a. the truck exerts a greater amount of force on the car than the car exerts on the trucks
- b. the car exerts a greater amount of force on the truck than the truck exerts on the car
- c. neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck
- d. the truck exerts a force on the car but the car does not exert a force on the truck
- e. the truck exerts the same amount of force on the car as the car exerts on the truck

A. 2. What kind of conceptual difficulties do you often find in your students?

A. 3. How do you try to help students with their conceptual problems?



*B. The development and the use of textbooks*

- B. 1. What are the textbooks and their editions that you have been using for the last ten years?
- B. 2. What features of the textbook that you utilize in your teaching?
- B. 3. How has the textbook changed during that period of time?
- B. 4. How does the development of the textbook influence your teaching?
- B. 5. Does the textbook present more and more real-life materials?
- B. 6. Does the textbook adequately connect the concepts and real-life materials?

*C. New instructional approaches*

- C. 1. Have you been trying different approaches in your teaching?  
If no: why not?  
If yes: what are they?
- C. 2. Have you heard anybody in the department or in other institutions experimenting with different teaching approaches?
- C. 3. People say that “teaching by telling is ineffective”, in other words “lecturing in front of passive audience contributes very little to their understanding”. What do you think?

*D. Connection between physical principles and real life phenomena*

- D. 1. How do you describe the “physics” that you teach?
- D. 2. How close are physics concepts and real-life phenomena in your teaching?

*E. The use of real-life materials in teaching*

- E. 1. How do you try to connect physics concepts and relevant real-life phenomena?
- E. 2. How do the real-life materials (phenomena, objects, events) in your teaching affect students in terms of:
  - their attitudes or motivation
  - their understanding

Notes: the sources of the physics problems in this questionnaire are the following:

I. Mazur (1997) p. 5

II. Mazur (1997) p. 5

III. Halliday, Resnick, & Walker (2005), Testbank, Instructor Resources CD

IV. Hestenes, Wells, & Swackhamer (1992), FCI question no 2

Appendix 5. List of questions for structured interview (for students)

*Introduction*

1. What 100-level physics courses have you been taking?
2. When did you take those courses?
3. How often did you attend the lecture?
  - a. almost every lecture
  - b. about half of the total number of lecture
  - c. only a few lectures (less than 10 lectures)

*A. Connection between physics and real-life phenomena*

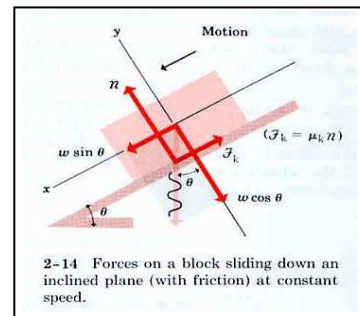
- A. 1. How do you describe the “physics” that you have studied?
- A. 2. Have you heard other meanings of “physics”?
- A. 3. How close are physics your have studied and phenomena happen in real-life?
- A. 4. How close that relation should be?
- A. 5. With the physics that you have studied, can you use it to explain phenomena happen in everyday life?

*B. Experiences in encountering real-life materials in introductory physics course*

- B. 1. Have you ever noticed the photographs at the beginning of each chapter in the textbook?  
What do you think about them?
- B. 2. What do you think about these two worked examples: (*shown*)

Example 1

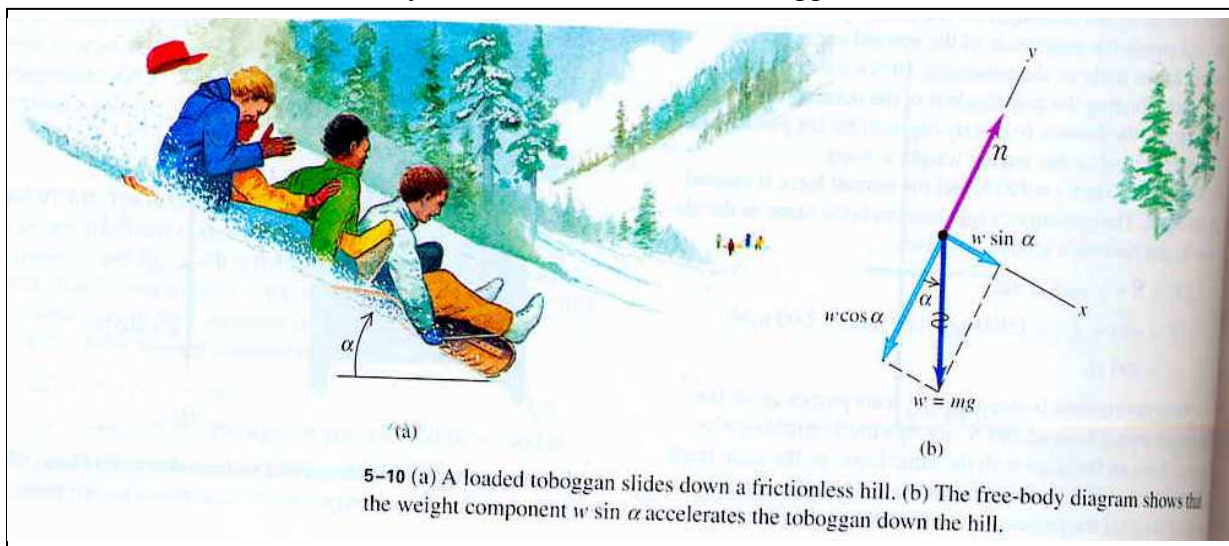
In Fig. 2-14, a block has been placed on an inclined plane and the slope angle  $\theta$  of the plane has been adjusted until the block slides down the plane at constant speed, once in has been set in motion. Find the angle  $\theta$ .



2-14 Forces on a block sliding down an inclined plane (with friction) at constant speed.

Example 2

Acceleration down a hill. A toboggan loaded with vacationing students (total weight  $w$ ) slides down a long, snow-covered slope. The hill slopes at a constant angle  $\alpha$ , and the toboggan is so well waxed that there is virtually no friction. What is the toboggan’s acceleration?



5-10 (a) A loaded toboggan slides down a frictionless hill. (b) The free-body diagram shows that the weight component  $w \sin \alpha$  accelerates the toboggan down the hill.

B. 3. What do you think about these two qualitative questions: (*shown*)

Question I. Sliding across the seat of an automobile can generate potentials of several thousand volts. Why isn't the sliding person electrocuted?

Question II. From a student's paper: "The relationship  $R = V/i$  tells us that the resistance of a conductor is directly proportional to the potential difference applied to it." What do you think of this proposition?

B. 4. What do you think about these two quantitative problems: (*shown*)

Problem I. A conical pendulum is formed by attaching a 50-g mass to a 1.2-m string. The mass swings around a horizontal circle of radius 25 cm. What is the speed of the mass?

Problem II. A car weighing 10.7 kN and traveling at 13.4 m/s attempts to round an unbanked curve with a radius of 61.0 m. If the coefficient of static friction between the tires and road is 0.35, is the attempt at taking the curve successful?

B. 5. When you study physics in the first year, have your lecturers:

- often given real-life phenomena as examples to clarify a concept?
- done demonstrations to illustrate concepts?
- asked you to perform some experiments outside the lab?
- done other things to connect physics with real-life phenomena?

*C. The help of real-life materials in student learning*

C. 1. What are the impacts of each of the above activities upon you?

C. 2. If you could give advice to improve physics teaching, what are your suggestions?

Notes: the sources of the physics problems in this questionnaire are the following:

Example I: Sears, Zemansky, & Young (1982), pp. 32-33

Example II: Young & Freedman (1996), p. 128

Question I: Halliday & Resnick (1988), p. 657, Question 28.10

Question II: Halliday & Resnick (1988), p. 657, Question 28.18

Problem I: Halliday & Resnick (1993), p. 155, Problem 6.54

Problem II: Halliday & Resnick (1993), p. 155, Problem 6.50

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