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**Effectiveness of an Inquiry-based Learning using Interactive Simulations for  
Enhancing Students' Conceptual Understanding in Physics**

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## **Abstract**

Two mixed-methods studies (a pilot study and a main study) were carried out to investigate the effectiveness of a novel inquiry-based learning method (named the Inquiry-based learning with Interactive Simulation - ILIS approach). The studies focused on 10<sup>th</sup> grade students' conceptual understandings about force and motion in physics. In each of the studies, an explanatory mixed methods design was adapted to combine a quantitative phase with a qualitative phase. The initial quantitative phase employed a quasi-experimental method. Participants were randomly assigned to the ILIS approach (experimental group) and conventional instruction (control group) as learning methods. All participants were asked to respond to a test (modified Force Concept Inventory) and surveys (confidence in learning and inquiry process skills of hypothesising, operation, communication, and evaluation). The quantitative phase addresses the first research question: What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning? The subsequent qualitative phase of each study involving interviewing participants to explore the way in which the students and teachers understood the conceptual learning in relation to potential performance achieved with the ILIS approach. The results showed significant gains in conceptual understanding about forces and motion and inquiry process skills by the experimental groups in comparison to the control groups. The students' inquiry process skills showed the same trend as conceptual learning. Confidence in learning also correlated with students' conceptual understanding. In contrast, the results showed that the conventional instruction has the same positive effect on improving students' confidence in learning as the ILIS approach. Qualitative findings induced that students in the experimental group reported individual perceptions and viewpoints. The qualitative phase involved interviews with three teachers and six students. It revealed that the ILIS approach offers meaningful benefits for students' conceptual understanding, which complements the findings from the quantitative phase. The findings suggested that the ILIS approach may have implications as a practical and effective teaching and learning method in enhancing students to develop their conceptual understanding in physics.

## **Declaration by author**

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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## **Publications during candidature**

### ***Peer-reviewed papers:***

- Fan, X., & Geelan, D. (2013) Enhancing students' scientific literacy in science education using interactive simulations: A critical literature review. *Journal of Computers in Mathematics and Science Teaching*, 32:2.
- Fan, X. (2013) Effectiveness of the washback of tests on teachers instruction and professional development [in Chinese]. *Teacher's Journal*, 11, 57-60.
- Fan, X. (2013) Study on the washback of national matriculation English listening test: Based on the survey in shanxi province [in Chinese]. *Teacher's Journal*, 17, 46-49.
- Fan, X., Geelan, D., & Gillies, R. (under review). Evaluating ILIS, a novel instructional sequence for conceptual change in physics using interactive simulations. *Research in Science Education*.
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Inquiry-based learning, conceptual understanding/change, interactive simulations, Physics

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# Chapter 1 Introduction

This introductory chapter examines conceptual learning through different instructional approaches and focuses on inquiry-based learning with interactive simulations. Inquiry-based learning and interactive simulations-scaffolded learning are presented as strategies to assist conceptual learning. In this chapter, section 1.1 presents the problem statement. Section 1.2 provides context and explains why it is important to address this problem. Section 1.3 identifies the purpose and research questions of the study. Section 1.4 introduces two instructional approaches, used in the experimental groups and conventional groups respectively. Section 1.5 presents the definition of key terms. Section 1.7 outlines the significance of the study. And finally, section 1.8 describes the structure of this thesis.

## 1.1 Problem statement

Over the past three decades, the physics education community has aimed to describe and theorise students' learning of physics concepts, and to analyse problems related to the acquisition of conceptual knowledge. One of the biggest challenges identified by this research is the notion of alternative conception in physics. Numerous studies have found that students typically come to the science classroom with a number of alternative conceptual frameworks that are inconsistent with scientific concepts, but provide students with usable explanations for their life experiences. These alternative conceptual frameworks are commonly called alternative conceptions that inhibit conceptual understanding to make sense of new information (Driver et al., 1978; Driver et al., 1983; McCloskey, 1983). Further, students tend to share a set of well-documented alternative conceptions (Bryce et al., 2005; Colburn, 2000; Falconer et al., 2001; Geddis, 1991; Hake, 1998; Kloos et al., 2010; Knight, 2004; Mazur, 1997; McDermott, 1984; Redish, 1999, 2000; Redish et al., 2000; Redish et al., 1999; Zavala et al., 2007) after taking courses in physics (Bryce et al., 2005; Clement, 1982; Geddis, 1991; Halloun et al., 1985; McDermott, 1984).

There is growing evidence that inquiry-based learning can provide a constructivist environment where students can engage in an active process of knowledge construction (Bransford, 2000; Driver et al., 1994; NRC, 2000; Posner et al., 1982). Inquiry-based learning, if well supported, can be more effective than conventional instruction in its potential to switch students' allegiance from their alternative conceptions to the canonical conceptions (Furtak, Seidel, et al., 2012; Vreman-de Olde et al., 2013). For example, studies have found that in simulation-scaffolded environments, inquiry-based learning provided students more effective learning opportunities, and student achievement outperformed conventional instruction (Chen, 2010; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Vreman-de Olde et al., 2013).

Finkelstein et al. (2004) argued that PhET simulations can replace real laboratory equipment in physics courses. Sokolowski and Rackley (2011) also praised the use of PhET simulations in science education. They explained that utilising simulations enhanced the teaching of limits, and helped students to immerse in the virtual physical world model and the inquiry processes. Additionally, Easy Java Simulation (EJS) also provided evidence of enhancing students' physics concepts learning. Kepler's System Model, Geostationary Satellite around Earth Model, and One Dimensional Gravitational Model have all been used in the physics inquiry classroom (Goh et al., 2013; L. K. Wee et al., 2013; L. K. Wee et al., 2012) and have aimed to improve concept learning that the traditional pen-and-paper instructional approach cannot do. In addition, Bakirci et al. (2011) found that the simulation-supported 5E worksheet positively scaffolds students' hypothetical, correlation and combinational thinking skills in the simulation-supported environment.

Yet despite previous research studies' efforts, the results of inquiry-based learning in the interactive-simulation setting have not amounted to what educators had hoped for, and it was examined in only a very small number of empirical research studies. Some studies argued that students have been shown to continue to demonstrate inadequate conceptual understanding (Meir et al., 2005; Trundle et al., 2010). As such, there is a need to investigate how inquiry-based learning with interactive simulations experiences can enhance students' conceptual understanding, so as to inform contemporary efforts to design effective instructional approaches in the context of China.

## **1.2 Background of the study**

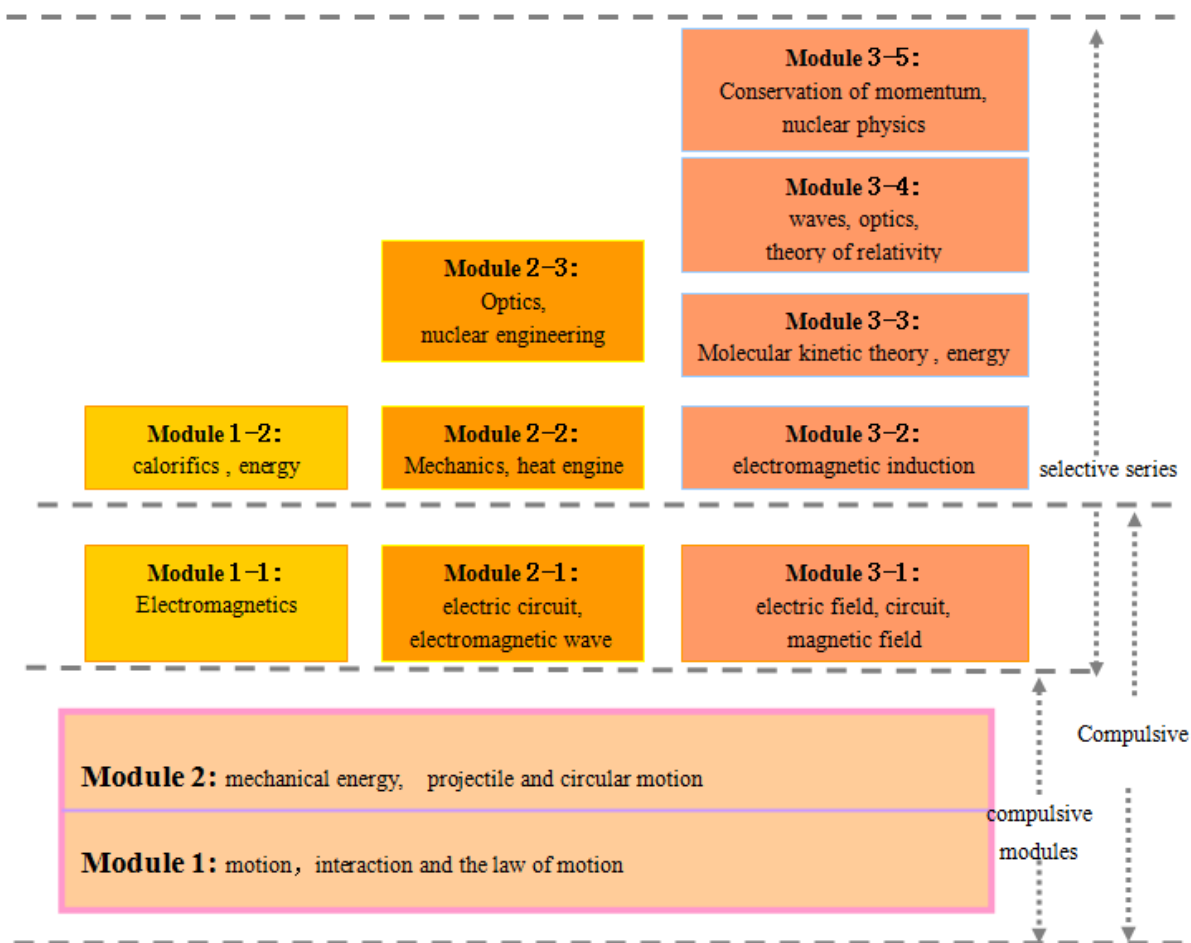
### **1.2.1 Physics curriculum standards reform in senior high schools**

Ongoing educational curriculum reform is a critical topic in the context of China, which has been undertaking a series of educational curriculum reforms since the early 1950s. Major milestones include the following: in 1999, the nationwide reform where the State Council issued the Decision on Promoting Quality-Education in an All-Round Way; in 2001, the Ministry of Education (ME) issued the outline of basic education curriculum reform (trial version) and the curriculum standards of 18 compulsory subjects (trial versions); in 2003, the ME launched the senior high school curriculum reform, and the national curriculum standards of senior high physics and another 14 subjects; and in 2012, under the direction of China's New Curriculum Reform (CNCR), the physics curriculum standards of senior high school were extended nationwide to all senior high schools.

According to the national curriculum standards of senior high physics, there are two compulsory modules and three elective series over three years of senior high school. All students are required to take module 1 and module 2, which are considered compulsory instructional content in grade 10. Then there are three elective series for grade 11 and grade 12. For instance, series 2 comprises three modules that focus on application of physics in technology. Series 3 comprises five



modules for students who pursue understanding of physics in science, technology, engineering and mathematics (STEM) and who plan to take science as a major in higher education. The physics standards state that students are required to take at least 3 modules and gain a minimum of 158 credit hours in order to graduate.



**Figure 1-1 Structure of the physics curriculum standards for senior high school (Guo et al., 2012)**

Three dimensions stipulate the implementation of the standards' content:

- 1) Knowledge and Skill, which requires students to learn basic physics knowledge and history, develop basic skills for conducting experiments through experimental instruments, and understand the application of physics in economy, society and science technology.
- 2) Learning Processes and Methods, which emphasises scientific inquiry including its processes, significance and application. Students are expected to understand research methods through learning physics concepts and laws. Students are also expected to be qualified in questioning, data-collection, data-treating, communication and cooperation to address problems by themselves. This helps students to develop the ability of self-learning, by planning and monitoring their own learning.
- 3) Emotions, Attitudes and Values, which fosters students' curiosity and motivation. It encourages students to put what they have learned into practice. It also stipulates that students should be provided with the opportunity to explore scientific questions independently and

cooperatively. Finally, students are expected to develop scientific attitudes and take responsibility for serving their country.

It is worth noting the dimension of Learning Processes and Methods. It requests that teachers use ‘scientific inquiry’ as their teaching method, and also asks students to acquire ‘scientific inquiry’ abilities. According to the standards, scientific inquiry includes seven main aspects: questioning, hypothesis, planning experiments, conducting experiments and data collection, data analysis and argumentation, evaluation, and cooperation and communication. This is the first time scientific inquiry has been included in national curriculum standards, and the first time scientific inquiry has been referred to as a teaching object and teaching content.

### **1.2.2 The teaching practices of inquiry-based learning**

In China, the new physics curriculum promoted the integration of scientific inquiry into teaching practice. A search conducted in May 2014 of the “China Academic Journals Web Publishing Inventory” (the first national digital journal database of education and social science manuscripts in China), using the keyword “inquiry-based learning for senior high school”, found 1154 papers published since 2004. Research of scientific inquiry has increased in China since the curriculum specified the use of inquiry learning including standards (SCC, 2001; Xu, 2001). Inquiry-based instruction is still a relatively novel pedagogy.

Some studies noted that the tradition of examination-orientation greatly influenced the instructional application of scientific inquiry in China. The implementation of the new curriculum actually didn’t change the old conventional instruction. Teaching, learning and school activities are still oriented towards exam preparation. Guo et al. (2012) found that Chinese students were well-prepared for the examinations, but with low experimental inquiry value (14.4%) in the investigated four provinces. Scientific inquiry is not paid enough attention in the practical classroom.

Some studies found that teachers were vocal in their appeals to promote scientific inquiry instruction. But most teachers do not know how to conduct a practical inquiry instruction. Relevant issues such as inquiry process, inquiry structure, and organisation of required curriculum content are not included in the new physics curriculum standards. Researchers cannot help but doubt whether or not the new physics curriculum standards can be implemented effectively in practice (Luo et al., 2005).

Li, who participated in an international research project said:

A new inquiry system to support the teachers to implement the new curriculum was needed. There was also a lack of appropriate support from academic researchers due to the fact that they were inexperienced and disconnected from classroom practice. The university academics were not welcomed by school teachers due to their big gap with practice. The model of

collaboration among teachers, curriculum facilitators and university colleagues was very superficial and ineffective.

There is a proverb in Chinese that says it is better to teach a hungry person to fish than to give him some fish. However, good examples of how to conduct inquiry-based instruction are badly needed (D. Zhang et al., 2005). Dai et al. (2011) found that Chinese teachers were receptive to inquiry-based instruction, but most of them did not know how to effectively conduct it in their classroom. It is necessary and effective to introduce relatively practical inquiry-based instruction models at the beginning of the curriculum reform. Presenting educational inquiry-based models can support teachers to understand the new curriculum reform and also the nature of scientific inquiry. After that, it makes sense to ask teachers to design their own inquiry-based instruction, or conduct it creatively.

Still, it is widely accepted that school-based inquiry instruction is cognitively and epistemologically different to authentic scientific inquiry. But few teachers have had even their own personal experience with conducting an inquiry. Additionally, most teachers considered inquiry instruction difficult to implement (B. Wee et al., 2007; Windschitl, 2004) and too advanced for their students (Bybee, 2000). Lack of knowledge and experience with inquiry is thought to act as a barrier for teaching science in this way (Blanchard et al., 2009). Undoubtedly, teachers prefer using easily operationalised conventional teaching methods, also known as teacher-centered lectures, experimental demonstration lesson, rote memorisation of discrete science facts, ‘cookbook’ laboratory activities and summative tests. This is regardless of the findings that indicate the conventional science classroom has less than the desired effectiveness for supporting students’ conceptual change (Bryce et al., 2005; Gillies et al., 2010; Zavala et al., 2007) and can, ironically, serve to destroy students’ innate curiosity about the world of science (Honey et al., 2011).

Thus, this study has designed a down-to-earth instructional approach in the context of China, named ‘inquiry-based learning with interactive simulation’ (ILIS) approach. This study developed the ILIS approach for scaffolding learning activities that support students’ conceptual understanding. The ILIS approach was easily blended into conventional instruction. For example, teachers used Confucius heuristic-teaching strategies to help students elucidate their findings. And, the ILIS approach met the national physics curriculum standards for senior high physics in China. These two features ensured the sound implementation of the ILIS approach in physics classrooms in the context of Chinese curriculum reform.

### **1.3 Purpose of the study**

This study was aimed to investigate the effectiveness of the ILIS approach versus conventional instruction in improving conceptual learning. Five specific purposes are shown below:

- 1) To develop a teaching method for supporting conceptual learning;
- 2) To investigate the effects of two instructional approaches to conceptual learning;
- 3) To examine the effects of gender on two instructional approaches to conceptual learning;
- 4) To explore the impacts of inquiry process skills and students' confidence in answers during the two instructional approaches;
- 5) To explain why and demonstrate how participants understand the conceptual learning in relation to (potential) performance achieved with the ILIS approach.

To achieve its purposes, this study used a mixed method approach. In the initial quantitative phase, this study adopted a quasi-experimental research design. This took place in schools within the classes of participating teachers. The classes were randomly assigned as experimental groups or control groups. The topics of Newton's laws were taught to the grade 10 students in the experimental groups using the ILIS approach, and in the control groups using conventional instruction. Conceptual understanding tests, surveys, classroom observation protocols and semi-structured-interview protocols were used for data collection. Data Analysis of Variance (ANOVA), Analysis of Covariance (ANCOVA), Multivariate Analysis of Variance (MANOVA), Pearson correlation and multiple regression analysis were adapted to address the research questions.

#### **1.4 Treatments**

This study compared the ILIS approach to classroom courses with conventional lecture-oriented experimental demonstration instruction as a quasi-experiment to investigate the effectiveness of different instructional approaches on conceptual learning. The participating classes were randomly assigned to an experimental or control group. The experimental groups were taught using the ILIS approach. The control groups were taught using conventional instruction.

The ILIS approach is underpinned by Posner's conceptual change theory and Vygotsky's zone of proximal development theory (often abbreviated as ZPD). Posner et al.'s four important conditions that can realize learning outcomes were adopted in the ILIS approach. The procedure of instructional activities is based on 1) there must be dissatisfaction with existing conceptions; 2) a new conception must be intelligible; 3) a new conception must appear initially plausible; and 4) a new conception should suggest the possibility of fruitful research. Meanwhile, students have scaffolds when they are engaged in each instructional activity from the ILIS approach.

The ILIS approach has been outlined in *Science Teachers' Use of Visual Representations* (Geelan et al., 2014). It involves five steps: 1) elicitation and clarification of existing conceptions and the 'target' scientific conception; 2) outlining the predictions and implications of students' existing conceptions and the scientific conception; 3) testing predictions of competing conceptions using interactive simulations; 4) elucidation of findings and linking results to the scientific

conception; 5) metacognitive evaluation and further testing to develop and deepen understanding of the scientific conception.

Teachers have considerable freedom to rearrange these steps to fit the constraints of the timetable, although these five steps are listed in instructional order, because it is necessary to choose a means of presenting them. However, if necessary, it is fine to switch the second and third activities. Additionally, rather than a linear progression with a beginning, middle and end, sometimes a learning sequence will involve cycling through the middle steps multiple times to ensure deeper understanding. More details of the ILIS instructional method will be introduced later in this paper.

Furthermore, it should be noted that there is a zeroth step before these five steps. This study would always suggest that, if at all possible, students should gain experience of the physical phenomena being studied. This is not always possible—one of the affordances of interactive simulations is to allow students to gain access to phenomena that are too large, small, slow or fast to be directly observed in the classroom, and also to concepts that are not directly visible in the physical world (such as magnetic field lines). But wherever it is possible for students to lift something, look at it, make measurements, collect data, mix solutions and so on, this study would suggest that this is essential. After all, scientific ideas are meant to explain our experience of the world around us, so as far as possible giving students access to direct experience (and asking them to carefully attend to its features) is valuable. In some cases the phenomena might also be too dangerous to work with in the classroom, or inaccessible because of distance or other factors. In these cases, video or other media may also be helpful in giving students experiences to use in testing theoretical perspectives. These media are less effective than direct experience, but more effective than no experience. It is therefore preferable to offer direct experience whenever possible, rather than default to the easier alternative of finding a piece of video on the web. And this paper argues that the interactive simulations always function to complement students' experience rather than to replace it.

This study contrasted the ILIS approach to what the researcher has termed “conventional” instruction. Conventional instruction is a more dependent, teacher-oriented teaching method. It is represented as a relatively more direct transmission of information, with more whole-class activities, lecture time, textbooks and seatwork. Hand, Sanderson, and O'Neil referred to this instructional approach as “reproductive conception of learning or the rote learning of the texts” (Hand et al., 1996).

The conventional instruction used in this study is popular in the Chinese classroom, namely teacher-demonstrated experiment lesson. The teacher demonstrates experiments, or ‘cookbook’ experiments, in front of the class. Meanwhile, students are requested to observe the teacher’s

experiments. Before each experiment course, the students are requested to read the lectures and textbooks. After the demonstrated experiment, the teacher provides a relevant lecture with an explanation of the experiment in order to support students' conceptual understanding. The course is usually ended with some summative evaluation such as exercises, seatwork or a quick quiz. This strategy is prominent in the physics classroom because of easy-organisation and time-saving (Li, 2010; Y. Lin et al., 2008; Wang, 2010).

To summarise, the ILIS approach was used as treatment in the experimental groups, and conventional instruction was employed as treatment in the control groups.

## 1.5 Definition of terms

**Conceptual understanding:** Conceptual understanding refers to achieve higher grades, or from initial conceptions to revised conceptions. It happens during the learning process, which involves not the enrichment of prior knowledge but the substantial reorganisation of existing knowledge. Conceptual understanding includes the process of conceptual change, but also the outcomes of conceptual change. Conceptual understanding is a gradual, on-going intellectual process and also a slow re-organisation of existing knowledge, rather than the sudden shift proposed by the classical conceptual change (Vosniadou et al., 1998).

**Conceptions about force and motion:** Conceptions include alternative conceptions and canonical conceptions. The alternative conceptions, also called misconceptions, preconceptions, alternative frameworks, naïve conceptions or sometimes children's science, are inconsistent with the canonical conceptions. This study explores what kind of teaching methods could help students construct the canonical conception about forces and motion, and therefore successfully achieve conceptual change from the alternative conceptions to the canonical Newtonian conceptions.

**ILIS approach:** This study developed a teaching and learning method: inquiry-based learning with interactive simulation (ILIS) approach. It involves five steps to realise conceptual understanding about forces and motion. The five steps include, 1) elicitation and clarification; 2) prediction and implication; 3) testing with interactive simulations; 4) elucidation and linking; and 5) metacognitive evaluation and further testing. This is a guided inquiry-based sequence with scaffolds such as teachers, peers, worksheets and others in an interactive simulation-based learning setting.

**Interactive simulations** as 'exploratory' applications is one type of external visualisation representation of dynamic systems of scientific phenomena (Kozma et al., 1997, 2005). Interactive simulations will be applied as the instructional scaffolding in this study. In this study, PhET simulations were used.

**Constructivist epistemology:** Constructivism is a theory about how people learn (Geelan, 1997). It considers learning as an active, constructive process. Students learn through interacting

with their prior knowledge and new information while selecting information, developing prediction, testing hypotheses, analysing data and making conclusions based on different situations.

*Inquiry process skills* demonstrate knowledge of the nature of science as well as the processes of scientific inquiry, such as developing predictions, testing hypotheses, making communication, and argumentation skills, collaboration-learning ability, metacognition awareness, critical thinking and reasoning abilities.

*Confidence in learning* in this study means to what extent students believe in what they have learned when they engaged in using the ILIS approach and in conventional instruction, as indicated in a self-survey of their learning experience.

## **1.6 Significance of the study**

The specific impetus for this study was prompted by theoretical, methodological and practical issues.

Theoretically, the significant contribution of this study is the combination of cognitive constructivist theories and social constructivist theories to illuminate possibilities for conceptual learning in science education. Posner et al.'s (1982) conceptual change, Vygotsky's social constructivist ZPD theory (1978), Sweller's cognitive load theory (1998) and Gobert's scaffolding theory (2005) underpin the theoretical framework of the inquiry-based learning with interactive simulations approach.

This study's methodological focus involves a mixed method (Creswell, 2012a; Teddlie et al., 2003) design. In the past, quantitative survey designs and qualitative interview designs were often separately carried out in most empirical studies on conceptual understanding. Since there are advantages and disadvantages in either quantitative or qualitative research, both of them will be employed in this study in order to more richly and fully understand the findings.

The practical impetus for this study is articulated by three aspects. First, the need for studies on senior middle school physics students. Alternative conceptions inhibit students' conceptual understanding and impact on their scientific literacy as future citizens. This study developed an instructional approach in order to support students to overcome alternative conceptions regarding forces and motion. Second, this study will assist physics teachers and instructors, especially those who are seeking meaningful instructional approaches in science education. Inquiry-based instruction should be strongly considered by physics teachers (Cox et al., 2002; Elby, 2001; Knight, 2004; Leonard et al., 1999; Redish et al., 1999). Due to a variety of constraints, however, it is often difficult for teachers to implement inquiry-based learning in the physics classroom. This study provided a positive example of how to implement inquiry-based learning in a technology environment. Third, the significance at school and state levels is to catalyse the development of

curriculum and the improvement of instructional approaches in physics. Understanding of conceptual change, relevant instructional approaches and the use of technological tools are important for effective pedagogy and curriculum reform. The results of relevant research studies will provide empirical evidence in order to serve the state and the Ministry of Education's decision.

In addition, this study is innovative in that it integrated inquiry-based learning with interactive simulations in the context of mainland China. Studies show that most teachers do not know how to conduct a practical inquiry instruction during their daily teaching (Guo et al., 2012). And studies have found that some teachers doubted its efficacy (Wei, 2005). This study argues for the integration of interactive simulations with inquiry-based learning. Not only can students engage in active construction of knowledge, but also, the use of interactive simulations allows teachers to conduct physics experiments easily. What is important is that the implementation of experiments is the center of the inquiry-based teaching method in physics classes.

To summarise, this study illuminates how thoughtfully designed instructional interventions can advance conceptual learning. It also contributes to filling the gap of inquiry-based learning in technology environments in China, and in the international science education research base.

## **1.7 Organisation**

Chapter One presents the problem statement, provides the context of the problem and identifies the purpose of the study. Treatments, definitions of key terms and research assumptions are provided. Chapter One also discusses the significance of the study in terms of its potential to fill theoretical, methodological and practical gaps in the physics education field.

Chapter Two provides a comprehensive review of relevant literature and identifies the research gap in the existing literature. Based on the literature review, the ILIS instructional approach was developed. A theoretical framework is stated at the end of Chapter Two.

Chapter Three presents a description of the method design and procedure of the educational experiments. The rationale of using a mixed-method approach is discussed. Furthermore, the rationale of participant selection and sampling strategies is explained in the quantitative phase and qualitative phase. Also discussed are instrument-design, what data were gathered, and how data were analysed. Additionally, the triangulation of data collection and analysis from the two phases are scrutinised. Finally, ethical consideration is addressed in this chapter.

Chapter Four shows the results of data analysis from the pilot study, while Chapter Five reports the findings of the data analysis from the main study.

Chapter Six presents the discussion, draws conclusions and highlights future directions of research. The limitations of the study are also addressed in this chapter by providing an overall picture of the research.





## Chapter 2 Literature Review

This study was developed to address two research questions:

RQ1. What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning?

RQ2. How do students and teachers understand conceptual change in relation to their performance through the ILIS approach?

With respect to these questions, the literature review straddles different bodies of scholarship on the achievement of conceptual learning and the design of inquiry-based learning with interactive simulations. Section 2.1 reviews the notion of conceptual learning from a cognitive perspective and a social-constructivist perspective. Section 2.2 and section 2.3 review the inquiry-based instructional approach and interactive simulation, with particular regard to the context of the physics classroom. Section 2 reviews the previous studies that focus on the use of inquiry-based learning with interactive simulations to support students' conceptual learning. After it summarises the literature review, this section identifies the gaps and establishes a proposal for this study which will be depicted in section 2.5. Section 2.6 develops constructivist perspectives of conceptual understanding and extends them with the combination of cognitive and social constructivist perspectives. This section then presents a complete theoretical framework by linking conceptual understanding, inquiry-based instruction and interactive simulations as a theoretical lens on the research questions. This chapter concludes with a brief summary in section 2.7.

### 2.1 Conceptual learning

Studies on conceptual learning have been explored over a period of 60 years. Among the different fundamental approaches, perspectives on conceptual learning in science have been heavily influenced by the work of Jean Piaget and Lev Vygotsky. Piaget and his followers focused on personal constructivism to construct conceptual knowledge. This involved processes of assimilation and accommodation (Piaget et al., 1952), the existing knowledge (Ausubel, 1968), and conditions of being intelligible, plausible and fruitful (Posner et al., 1982). Alternatively, Vygotsky emphasised conceptual learning in terms of social context (Vygotsky, 1978). This provided a way to understand learning from a social perspective. Thus it was considered as social constructivist theory and used in conceptual learning (Driver et al., 1994; Hodson et al., 1998).

In this paper, the key focus is on combining cognitive constructivist perspectives and social constructivist perspectives to support conceptual learning. This builds up a foundation for exploring mechanisms of the process of conceptual learning. The following sections will review the commitment to conceptual learning from a cognitive perspective and a social-constructivist perspective.

### **2.1.1 Commitment to conceptual learning: A cognitive constructivist perspective**

Cognitive approaches to conceptual change seek to explain how cognitive balance influences individual conceptual learning. The pioneering studies in science were conducted by Piaget et al. (1952), Ausubel (1968), and Posner et al. (1982).

According to Piaget's notions, a primary tenet was the idea that human beings possessed "schemas". These schemas referred to "integrated networks of knowledge that were stored in long-term memory and allow us to recall" (Pritchard et al., 2010, pp. 10-11). All schemas represented the functions of classification, analysis and evaluation to adapt new knowledge (Pelech, 2010). The adaption of schemas can help humans to understand how to construct new knowledge. For example, when a person already knows the object, such as an apple, his cognitive balance is in a state of equilibration. However, one day, he finds an object that has all the characteristics of apples that he already knows, but this apple is green. At this time, his cognitive balance is not in a state of equilibration, which Piaget calls "disequilibration" (Piaget et al., 1952). Based on his cognitive stage, this person may put this new type of apple into his existing schemas, or he may not. Piaget explains that this person will experience one of two processes to turn his disequilibration into equilibration: "assimilation" or "accommodation". Assimilation refers to integrating the new knowledge with the existing knowledge. Accommodation happens when the new idea does not fit into the existing ones, so a new schema is formed or revised to create cognitive construction balance.

With Piagetian notions of accommodation and assimilation and studies from the philosophy of science (Kuhn, 1970), Ausubel (1968) proposed that the existing conceptual knowledge significantly influenced conceptual understanding. Conceptual learning, particularly conceptual change from misconceptions that were rooted in preconceptions (Novak, 1977) to scientific concepts, is dependent on the pool of prior knowledge, rather than taking place in an "empty container". This insight provides a method to construct new knowledge or change alternative conceptions through integrating the existing knowledge framework during the learning process (Bransford et al., 1999; She, 2004). Empirical studies proved that the existing conceptual knowledge showed strong commonalities internationally (Driver, 1989). Take the alternative conceptions as examples. Common examples of alternative conceptions in physics are presented in the current research, as follows:

- 1) Heavier objects fall faster than slow objects (Halloun et al., 1985).
- 2) Larger or more active objects exert greater force than lighter objects when they interact (Maloney, 1984). Actually, this is in contrast to the Newtonian view that the forces are equal in magnitude and opposite in direction.

- 3) Force is considered to be a property of moving objects, in the sense that the force of the hand acting on a coin tossed in the air is seen to continue and gradually abate.
- 4) Force and velocity are linearly related (Eryilmaz, 2002; Hammer, 1996). According to Newton's second law, it is not force and velocity that are linearly related, but force and acceleration.
- 5) Velocity, or its scalar magnitude speed, has associations with other misconceptions, one of which is that if two objects have the same position then they have the same velocity (Eryilmaz, 2002; Rosenquist et al., 1987).
- 6) The velocity and acceleration may be of two different objects or it may be of a single object (Eryilmaz, 2002; Rosenquist et al., 1987).
- 7) Rooted in the misconception of velocity and acceleration is the misconception of the motion of an object moving freely in relation to trajectory in a gravitational field. That is, a force on or in an object in the direction of the object's motion (Clement, 1982; Sjoberg et al., 1981; Viennot, 1979) when in fact the force must be in the direction of the object's acceleration.
- 8) Friction depends on the area in contact, as a round ball is easy to move from one place to another as compared to a rectangular sheet (Singh, 2007).
- 9) A static object such as a table cannot exert a force upward on an object resting on it (Minstrell, 1982), in contrast to the Newtonian view which asserts that there must be a force from the table to balance the force of gravity.

Students have developed their own personal conception models before they receive formal education (i.e., mass, velocities, acceleration, force, and others physics concepts) or knowledge of fundamental laws (i.e., Newtonian mechanics laws, Laws of thermodynamics, Laws of relativity, and Laws of quantum mechanics).

In order to realise the commitment to conceptual understanding, Posner et al. (1982) identified four conditions for conceptual change: 1) The learner must be dissatisfied with their existing concept, i.e., the existing concept cannot solve this problem; 2) the learner must be provided a new alternative concept that is intelligible, i.e., the new alternative concept can be understood; 3) the new alternative concept must be plausible, i.e., it can be used to deal with the current cognitive conflict; and 4) the new alternative concept must be fruitful, i.e., it can be applied to different situations.

And Posner et al.'s ideas implied different instructional strategies to address students' cognitive conflict. Some studies found that the use of contrasting cases (Schwartz et al., 1998), the learning cycle of Inverting to Prepare for Learning (Schwartz et al., 2004), and design for knowledge evolution (Schwartz et al., 2005) were effective strategies to achieve conceptual change.

Further, some studies explored the idea that students could be explicitly exposed to new knowledge that is related to the existing misconceptions, in order to cause cognitive conflict. McKittrick et al. (1999) designed the conceptual understanding program that encourages students to challenge other students' existing conceptions, and modify their misconception in mechanics with cooperative learning. They found that using misconceptions in introductory mechanics improved students' understanding of basic concepts. Students are aware of what they are learning, and take more responsibility for their learning. Tekkaya's studies found that this strategy is much more effective to develop K-12 student's conceptual understanding (Dogru-Atay et al., 2008; Yenilmez et al., 2006; Yilmaz et al., 2011).

The above research prove that strategies consistent with Posner et al.'s (1982) theory of conceptual change are promising instructional strategies. However, successfully creating a state of dissatisfaction toward the existing concepts, and encouraging students to seek a state of satisfaction with their cognitive balance, doesn't always occur.

Dreyfus et al. (1990) explored how grade10 students addressed their misconceptions in biology. In this study, students were asked to think about two different conceptions, one of which was a misconception. Then the teacher employed discussions to address students' misconception and encourage them to accept the scientific conceptions. This study found that the students could recognise the existence of misconceptions by their inappropriate explanation. However, most students did not provide the appropriate explanation during discussion. And most students exhibit a regression to their previous inappropriate explanations several weeks later.

Similarly, in the study of Trundle et al. (2007), they also used a teaching model with cognitive conflict strategy. They found that 33.3% of students returned to their previous misconception of the moon phase six months later. The remaining eight out of twelve students still retained the scientific concept. The relevant studies conclude that the teaching model of cognitive conflict strategies may not always lead to successful performance in conceptual change, such as the regression to the pre-existing concepts in the delayed tests (Trundle et al., 2007), and the co-existence of scientific and non-scientific conceptions in the different context (Tao et al., 1999).

To explore why there were controversial findings regarding the efficacy of cognitive conflict on conceptual understanding, answers were also sought in Posner's conceptual change theory. First, the learners did not feel dissatisfied with their existing concept when the teacher presented them with contradictory information, and some students did not even realise there was a cognitive conflict (Kang et al., 2004). Second, the new knowledge was not intelligible, plausible and fruitful enough. Gatt (1999) found that it took time to guarantee the outcomes of new knowledge. For example, teachers needed time to make new knowledge understandable and applicable in different contexts. And students needed sufficient time to practice what they had learned and make sure their

new knowledge could solve different problems, which promoted students' conceptual change (Ketamo et al., 2010). In addition, the motivation of and belief in cognitive change were also needed during the period of conceptual change. Lee et al. concluded that the lower the degree of motivation to address their misconceptions, the more likely students would refute the conceptual change. Stathopoulou et al. (2007) argued that students' beliefs about knowledge and knowing may hinder or support students' learning of new knowledge. Stathopoulou et al. also found that there was a significant correlation between students' beliefs about how to learn, their performance and conceptual change. The reason students withdraw from their cognitive change is because they are not aware of the need to change the nature of their beliefs (Vosniadou, 2012).

In summary, Piagetian insights implied to educators that teaching and learning should be constructed rather than transferred. And existing knowledge should be highlighted in the building-up of new knowledge. In practice, however, there may be no simple instructional strategies for conceptual learning, as the cognitive perspective has proposed. Posner and Strike's (1982) equilibration model met challenges. For example, students did not feel dissatisfied with their misconceptions (Vosniadou, 1994); and the realisation of cognitive conflict alone cannot guarantee conceptual change (Limón, 2001), and the new canonical conceptions and the misconceptions can coexist in students' heads (Tao et al., 1999). The unanswered questions cannot let us discard Piagetian insights, but they lead us to search for answers in the social constructivist perspective as well as the individual cognitive perspective.

### **2.1.2 Commitment to conceptual learning: A social constructivist perspective**

During the age of Piaget, a fundamental theoretical framework of social constructivist perspectives regarding epistemological proposals was provided by Lev Semenovitch Vygotsky (1987/1934). Similar to Piaget's philosophy, Vygotsky regarded the construction of knowledge by people, and the new construction was based on prior knowledge possessed by people. Vygotsky's central insights were about the social property of knowledge. They argued that knowledge possesses a social component, and learning knowledge involved a journey from social plane to individual plane. For example, learning involved learning social language (Leach et al., 2003), discourse with others (Pritchard et al., 2010) and personal sense-making of talking and thinking in the context of society (Leontiev, 1981).

An important concept of Vygotsky's theory was his zone of proximal development (ZPD). The ZPD was "the distance between the actual developmental levels as determined by independent problem solving, and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). The ZPD stated that students working in a group can accomplish at a higher level compared with

working alone, and furthermore, that it is in that zone that learning occurs with supports, such as a more capable person or a range of modes of communication tools (reading, writing, talking, gesture, visual images, technologies, actions etc.). Things the student can already do alone have been learned, so further learning does not occur while alone. Things the student cannot do, even with scaffolding and support, are beyond her/his current capacity. Thus, in order to learn new knowledge, learners should be supported by knowledgeable persons in the zone of development in the social context. The process of supporting the learner to move out of the zone was considered “scaffolding”, and the supports that help learners move out of the zone was regarded as the “scaffold”. The scaffolding with various scaffolds could be “the elements of task that are initially beyond the learner’s capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence” (Wood et al., 1976), or “measured and appropriate intervention, ...the provision of materials, or the opportunity to interact with peers or even a computer program” (Pritchard et al., 2010). The achievement of ZPD works with the assistance of scaffolding and scaffolds when the learner moves into the zone. It provides the possibility of learning new knowledge.

As well as drawing attention to the conception of ZPD on the social plane, Vygotsky also proposed the view of individual sense-making during the process of learning, through the internalisation from inter-psychological level to intra-psychological level. According to the explanation of Pritchard et al. (2010), the inter-psychological level refers to the social plane in which development (e.g., observation, imitation, talk etc.) can take place within the interaction between people. The intra-psychological level means the internal plane in which the learner internalises the development in the context of intra-psychology, and the development makes the learner become competent.

Vygotskian theory directly influenced a number of researchers in science education. According to Vygotsky’s view, the high mental function of individual learning is derived from the social plane (Vygotsky, 1978). Language and other semiotic mechanisms are regarded as means for internalising scientific concepts in the social context. Driver et al. (1994) argue that there is a technical language for teachers to practice in science classrooms. The technical language is different from daily language, and even different among scientific communities. Driver et al. (1994, p. 4) stated that learning is the “co-construction of scientific knowledge by teachers and students” and teachers should help students understand the “symbolic world”. This suggests that science learning involves how individuals understand the technical language regarding particular concepts, and also involves how teachers provide scaffolds to explain the scientific concepts in that context. When applied to pedagogy, this interaction between teacher and students could be realised during inquiry-based courses. Hodson et al. (1998) re-applied the “Vygotskian notion of enculturation” (p. 33) in

teaching and learning science. They state that the understanding of building scientific concepts is the same as the way students understand how the world was built up. Similarly, Vosniadou et al. (1998, p. 1218) also state that '[i]nitial conceptual structures can change as a result of children's enriched observations in the cultural context'.

Thus, this study proposes that conceptual learning should take place in the process of reorganising individual conceptual models as well as in consideration of the social plane.

## **2.2 Inquiry-based instructional approach**

Inquiry-based learning is one instructional approach to help students construct knowledge through a discovery process that supports continuous learning. Theoretically, inquiry-based learning represents constructive perspectives. It can engage students in individual and social activities such as experiments, discussions, and argumentation. Driver et al. (1994) state that meaningful activities can support students to make sense of scientific conceptions and the processes of scientific methods.

In this study, the design of inquiry-based learning is based on the statement of Leach and Scott (2003) that brought the personal cognitive perspective and social constructivist perspective together to support conceptual learning. They said:

Bringing them [personal cognitive perspective and social constructivist perspective] together has important consequences for pedagogical practices and opens up a range of possibilities for science education research. Primarily, it opens up the possibility of relating findings about students' learning to insights about teaching, as well as explaining why internalisation is not a simple matter of transfer (p. 104).

This means that the inquiry-based learning used in this study not only emphasised individual thinking, but also focused on how students explain their thoughts and how teachers explain scientific conceptions. These were both used to support student understanding through inquiry-based learning.

The following sections will introduce the definition of inquiry, the history of inquiry, the practice of inquiry, and conclude by examining research.

### **2.2.1 History of inquiry-based learning in science education**

Inquiry-based learning emerged from science education reform (Buck et al., 2007; Haefner et al., 2004; Newman et al., 2004). As early as 1892 at a National Education Association (NEA) meeting, the Committee of Ten aimed to standardise the secondary school curriculum and make the different levels of education, from elementary to college, compatible. The teaching of science was regarded as a key topic to examine in the report of the Committee of Ten.



In the Report of the Committee of Ten, section six mentions Physics, Astronomy and Chemistry and states “the subject should be taught by means of experiments and by practice in the use of simple instruments for making physical experiments.” They offer relevant laboratory exercises within the appendix of the report. They also propose “a portion of Saturday morning should be regularly used for laboratory work in the scientific subjects” (Committee of Ten Report, 1892). With other proposals such as the amount of time on natural history in primary school, the amount of time for the school day, and the amount of time on science, the key point should be noted that the Committee calls for knowing science through doing science.

By the early 1900’s, John Dewey stressed that there was too much emphasis on facts and not enough emphasis on science for thinking and as an attitude of mind. Dewey (1910) proclaimed that children should experience science and not be the passive recipients of ready-made knowledge. He contended “knowledge is not information, but a mode of intelligent practice and habitual disposition of mind” (p.125). Learning, for Dewey, came out of authentic laboratory experience such as observing phenomena, and investigating and solving problems etc. Dewey encouraged students ‘doing’ science as opposed to students ‘knowing’ science, in a supportive environment where students would become engaged in constructing their own knowledge (Dewey, 1910, 1938).

From the 1950s to 1960s, Joseph Schwab finished a series of books that provided the foundation for inquiry as a relevant theme in science curriculum reform during the two decades (Schwab, 1958, 1962, 1966). He supported Dewey’s sentiments on the importance of inquiry-based instruction in school settings. Inquiry-based practices have been described as essential to students’ development of what Dewey (1910) calls “habits of mind,” a way of thinking that promotes scientific reasoning skills. Consistent with Dewey’s thoughts, Schwab encouraged science-teaching that paralleled the way modern science operates. In his book titled *The teaching of science as enquiry* (this paper will use ‘inquiry’ over ‘enquiry’ for consistency), Schwab (1962) emphasised that authentic science comes from abilities of doing inquiry rather than thinking without doing.

Schwab also pays attention to the inherence in the process of doing science. He stated that the laboratory is the place where students can address scientific questions and keep the inherent understanding of science. And this is the place where students use both minds and hands together to solve problems.

In addition, Schwab emphasised the importance of getting students actively involved in the learning process through means of investigation and not just teaching the content facts of science (1966). He encouraged science teachers to use the laboratory to assist students in their study of science concepts. This facet is exemplified in the *Biology Teachers’ Handbook* (BSCS, 1987) in which Schwab called for the use of “Invitations to Enquiry.” Using this strategy, teachers utilise sixteen activities, providing students with research readings that come from articles, reports, or

books. The teacher and students are then encouraged to engage in dialogue regarding the problems, data, analyses, and conclusions derived by the investigators. Schwab advocated the idea that students should read about alternative viewpoints and explanations of scientific inquiry. He recommended inquiry-based instruction as the preferred format for teaching science concepts so that students could be active in the learning process.

The launching of Sputnik I in 1957 caused the United States to question the quality of its science teachers, science curriculum, and the methods of science instruction used in schools; and sparked the most innovative and spectacular changes in the philosophy of science education ever seen in American schools (Collette et al., 1994). Later, the results of Project Synthesis (Harms et al., 1981) and National Assessment of Educational Progress (NAEP) showed that projects like the PSSC Physics, CHEM Study, and BSCS did not get the results that educators expected, even though the results of the Biological Sciences Curriculum Study (BSCS) were fascinating. Thus, the projects regarding the inquiry-based instructional approach were terminated. But the influence of inquiry had deep roots, and there still were a large number of research studies investigating the inquiry-based instructional approach and further examining its efficacy in science education.

### **2.2.2 Definition of inquiry-based learning**

The National Science Education Standards (NSES) defined the ‘inquiry’ of inquiry-based learning as instructional activities as well as an instructional strategy. It determined that students can learn science and understand the nature of science through engaging in a discovery process that includes meaningful inquiry-based activities.

Inquiry used as instructional method encouraged students to engage in activities that developed their understanding of the natural world and physical concepts in science education. The NSES states, “Inquiry refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (NRC, 1996, p. 23).”

Later, the NSES provided a clear definition of K-12 classroom inquiry. There were eight aspects in its definition, including the following (NRC, 2000, p. 19):

- 1) identify questions that can be answered through scientific investigations (students formulate a testable hypothesis and an appropriate design to be used);
- 2) design and conduct scientific investigations (using major concepts, proper equipment, safety precautions, use of technologies, etc., where students must use evidence, apply logic, and construct an argument for their proposed explanations);
- 3) use appropriate tools and techniques to gather, analyse, and interpret data,

- 4) develop descriptions, explanations, predictions, and models using evidence where the students' inquiry should result in an explanation or a model;
- 5) think critically and logically to make the relationships between evidence and explanations;
- 6) recognise and analyse alternative explanations and predictions;
- 7) communicate scientific procedures and explanations; and
- 8) use mathematics in all aspects of scientific inquiry.

The NSES (2000) expected students in grade 12 to be competent enough to 1) identify questions they want to explore; 2) complete the investigation by designing, conducting and data-treating with various reasons and ways; 3) use technology and mathematics that are essential in scientific inquiry; 4) analyse the data and formulate their explanations by logic and scientific evidence; 5) realise the alternative explanation; and 6) communicate their scientific findings with scientific language.

The key point was that the classroom inquiry emphasises not only “the process skills of doing tasks and solving problems, but also the cognitive abilities of critical thinking and reasoning” (Bybee, 2000, p. 29). For example, 5E inquiry cycle (Bybee, 2000) employs inquiry-based activities to implement in the class. A range of investigative activities could be involved in each ‘E’, including Engagement, Exploration, Explanation, Elaboration and Evaluation. Further, the process of 5E could also be regarded as instructional strategy when teachers implement instruction.

This view is similar to the statement by the Framework for K-12 Science Education (NRC, 2012). This emphasises that “engaging in scientific investigation requires not only skill but also knowledge” (p. 30). It proposes placing the term “inquiry” under the umbrella term “practices”. The practices are further explained by the Next Generation Science Standards (Achieve, 2013) with the following aspects: (1) asking questions and defining the problem; (2) developing and using models; (3) planning and carrying out investigations; (4) analysing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations and designing solutions; (7) engaging in argument from evidence; (8) obtaining, evaluating, and communicating information. All eight aspects will not necessarily be used in each inquiry-based activity, but these eight are the valuable rules that support the practices of inquiry in classrooms. Furthermore, it is argued that these are important for students to understand inquiry and develop the abilities of critical thinking.

Inquiry as instructional strategy was derived from the assumption that “what students learn is greatly influenced by how they are taught” (NRC, 2000, p. 28). The assumption indicates the importance the way in which teachers taught inquiry-based curriculum. Thus, the NSES published guidelines of teaching standards in order to guide teachers' instructional design. The guidelines

request that teachers understand how scientists use scientific inquiry, and that this should be modified and adapted before teachers use inquiry-based instruction in classrooms.

Further, it is recommended that teachers use various instructional strategies to support learning (Bybee, 2000; NRC, 1996, 2000). As the NSES (NRC, 1996) notes, “Although the Standards emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching (p.23)”. Teachers were encouraged to use different instructional strategies to develop knowledge and abilities, such as, questioning strategies, heuristic strategies, cooperative learning, group discussion, public presentations and so on.

Based on the definitions of inquiry, a practical definition of inquiry was also provided to benefit teachers’ understanding and application. The NSES issued the practical definition of classroom inquiry with five essential features, as noted below:

**Table 2-1 Essential features of classroom inquiry and their variations**

1	2	3	4	5
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use to sharpen communication	Learner given steps and procedures for communication

Note. From *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (p. 29), by National Research Council, 2000, Washington, DC: National Academy Press.

The NSES commented that it was not necessary to include all components presented in Table 2-1. The more coaching and scaffoldings the teacher provided to facilitate students’ learning, the less student-oriented inquiry was conducted in the classroom, where students can experience

student-oriented open inquiry, student-oriented guided inquiry and teacher-oriented guided inquiry. And it did not mean that teachers must use either the student-oriented open inquiry or the teacher-oriented guided to facilitate students' learning. Sometimes, compared with the teacher-oriented inquiry, students who engaged in the student-oriented open inquiry often could not perform better. It was advisable for teachers to understand different types of inquiry-based approaches and know when they should use which one, or a mix of approaches.

To summarise, this study defines inquiry-based learning as a type of instructional approach with three aspects. First, it is an instructional strategy that focuses on a learning process. Second, it includes different instructional activities that can engage students in the learning process. Third, it has different types of combinations that are flexible for teachers to use in different learning situations. It aims to develop students' understanding of the nature of science and scientific conceptions, the process skills of solving problems, and cognitive abilities of critical and logical thinking through a discovery process that supports continuous learning (Windschitl, 2004).

### **2.2.3 The effectiveness of inquiry-based learning**

A significant number of research studies have proved that inquiry-based learning has a positive effect on students' learning in science education, especially when compared with traditional laboratory instruction that seems minimally effective in meeting educational goals (Bybee, 2004; Duschl et al., 2007; C. B. Russell et al., 2011). "In general, research shows that inquiry teaching produces positive results" (R. D. Anderson, 2002, p. 4); and "there is substantial empirical and theoretical evidence that inquiry-based instruction is a starting point for personal construction of meaning and can lead to higher achievement of all students" (Von Secker, 2002, p. 151).

In order to investigate the effectiveness of inquiry-based learning, Shymansky (1983) conducted a large-scale analysis of existing research studies. Shymansky systematically analysed 105 experimental studies within 27 inquiry-based curricula, and found that students with inquiry-based instruction had higher achievement test scores compared with the students taught with traditional instruction. Analysis of the 1990 National Education Longitudinal Study data showed that 7642 grade 10 students who used inquiry-based instructional activities performed better than those without the same activities (Von Secker et al., 1999). Similarly, the study of Brunkhorst (1992) found that the mean score of 280 students who participated in inquiry-based curricula outperformed 87% of the scores in the national sample.

Further, Mattheis et al. (1988) found that inquiry-based science instruction supported students' performance in graphing and data-interpretation skills. Von Secker (2002) found a significant positive effect on students' conceptual understanding when students who had inquiry-based instruction were measured by achievement tests in science. And Gerber et al. (2001) found that

inquiry-based instruction also effectively improved students' reasoning ability. The use of inquiry-based instruction is striking in that the grade 9s gained more than the grade 10s on the same NCLB science test, because the grade 9s engaged in inquiry-based activities, while the grade 10 students did not participate in the activities (K. Kelly et al., 2006; Rickles et al., 2005).

Despite the general assumption that inquiry-based learning leads to effective conceptual understanding, its effects are challenged by practical implementation. The TIMSS 1999 Video Study (NCES, 2006) reported that less than 15 hours out of 88 were used for grade 8 science lessons with inquiry-based teaching. Almost 60 hours were spent developing instructional content, such as students' learning about facts, the definition of physical concepts through memorising, and repeating procedural experiments. The same situation was also reported by the National Research Council, which stated that the inquiry-based instruction in science laboratories in the US was conducted without clear learning goals: "teachers and laboratory manuals often emphasize the procedures to be followed, leaving students uncertain about what they are supposed to learn" (Singer et al., 2005, p. 133).

Why is inquiry-based instruction strongly advocated but seldom taking place in real-life classrooms? Studies have identified some problems that teachers encounter in practicing inquiry-based instruction (Jones et al., 2007; Roehrig et al., 2004), such as lack of knowledge of the scientific inquiry, incompetent instructional management, inexperienced pedagogical content, teachers' uncertain beliefs, lack of time and professional supports, risky experiments, inability to track the inquiry process, expensive experimental equipment, and so on.

Additionally, studies comparing the effects of inquiry-based learning to more traditional instructions found unstable evidences in its favour. As Metz (2004) explains, "simply engaging students in 'inquiry' is insufficient to bring about these desired changes" (p. 220). Furtak, Shavelson, et al. (2012) argue the inconsistent performances were because of disagreements among researchers about the features of inquiry-based instruction. And more studies noted that inquiry-based learning, when it has appropriate scaffolds, can help student learn concepts (Kirschner et al., 2006; Mayer, 2004).

As educational technology was developing, visualisation representations became increasingly popular and powerful in science education. This paper recommends the integration of interactive simulations into inquiry-based learning. Further discussion of this will follow in subsequent sections.

### **2.3 Interactive simulation**

Over the past three decades, a growing body of research has begun to explore how people learn science and how best to advance that learning (Duschl et al., 2007; National Research Council,

2005). Interactive simulations are considered by many scientists and science education researchers to be promising technological tools for science instruction (Clark et al., 2009). In this section, section 2.3.1 is drawn from the researcher's published paper, titled "Enhancing students' scientific literacy using interactive simulations: A critical literature review" (Fan et al., 2013). It introduces interactive simulations from theoretical perspective. Section 2.3.2 and section 2.3.3 were drawn from the researcher's other publication, titled "Teachers using interactive simulations to scaffold inquiry instruction in physical science education" (Geelan et al., 2014). They present the definition of interactive simulations and state the functions of interactive simulations to meet the goals of science education. At the end of section 2.3., the effectiveness of simulation-based learning is also critically reviewed.

### **2.3.1 Theoretical perspectives on interactive simulations**

Various theoretical perspectives have been used to explore and explain the educational effectiveness (or otherwise) of interactive simulations. Integrating previous studies, this discussion outlines three relevant bodies of theory—constructivism and cognitive theory—as theoretical foundations for the development and use of interactive simulations in science education. These theories provide theoretical 'lenses' as well as some design principles to support the development and educational application of interactive simulations.

#### ***Constructivism***

Constructivism is a theory about how people learn (Geelan, 1997). It considers learning as an active, constructive process. Students learn through interacting with their prior knowledge and new information while selecting information, formulating questions, testing hypotheses, analysing data and making conclusions based on their experiences. This section synthesises six principles of constructivist learning as follows:

- a) learning is active, and needs students to engage in the whole construction process (Dewey, 1916);
- b) learning involves the mind, which engages in significant mental interactions (Dewey called this 'reflective activity') as well as hands-on experiences (Henriques, 1990);
- c) learning involves language – discourses, arguments, terms – which intertwine with the underlying learning (Vygotsky, 1978);
- d) learning involves social activity and context: we learn from other human beings, and our life experience (Driver et al., 1994);
- e) learning is built on the foundations of prior knowledge, which supports learners to assimilate new knowledge. The more we know, the more we can learn. Any learning starts from learners' past knowledge and their state of learning (Ausubel, 1968).

According to constructivist learning theory, learning with interactive simulations occurs effectively when students tie together their prior knowledge and experiences with new classroom material to develop or deduce their own explanations or principles (Collins et al., 1993; Perkins, 1991; Piaget et al., 1967).

Constructivists contend that engagement is a prerequisite for successful knowledge acquisition (D. Jonassen, H et al., 1999; Mayer et al., 1996; Phillips, 1997). Engagement implies extended focus and thought on a topic. Engagement, as defined by increased motivation and a deeper level of cognitive activity, should therefore result in the enhanced construction of mental models. Maximal learning gains will be realised when students actively participate in experimental practices: the grounds for considering interactive simulations to have educational potential is that they are seen as affording learning opportunities of this kind. During such experiences, students explore their own answers, encode cues for memory, and construct new systems of knowledge based on their own interests and prior knowledge.

Studies by Graf et al. (1978) and Hirshman et al. (1988) suggest that the high level of interactivity offered by experiments is promising for the development of deep understanding of information. Some authors claim that learning through active engagement with experiments and visualisation tools must entirely replace didactic or Socratic methods that can lead to poor engagement and inert knowledge (e.g. Brown et al., 1989). We would argue, however, that these tools are more effective as complements to other modes, rather than as replacements. Enhancing teaching is about extending the repertoire of available activities from which teachers can choose, rather than 'converting' from one approach to another.

Interactive simulations provide opportunities for students to learn science through engaging experimental practices, individual prior knowledge, and new technology tools. Rapp (2005) described three interactive factors influencing learning: cognitive engagement, interactivity and multimedia learning. He argues that the use of multiple media with which students can interact (rather than passively consume) can enhance cognitive engagement. Evidence for the success of instructional techniques is often attributed to the degree to which students can interactively direct the lesson (Ferguson et al., 1995; Wagner, 1997). Current views of education place an emphasis on the interactive components of lessons (Rogers et al., 1996). If the students have control over the presentation of information, this may result in increased learning. Interactive instructional technologies make it more likely that students will become actively involved in the learning situation.

Stieff et al. (2005) proposed two pedagogical approaches based on constructivist theory to support the use of visualisation tools. The first pedagogical approach is guided inquiry, which means inquiry environments play a critical role in the science classroom by supporting students to



behave like research scientists (Edelson, 2001). The other approach emphasises the interactive procedures of learning science. The use of visualisation tools supports students to build up individual models of scientific phenomena and to develop deep understanding and improve their problem-solving skills.

Involving students in more interactive activities, rather than simply using visualisation tools as aids in traditional modes of representing the world, can maximise students' learning benefits. The key theoretical features arising from a constructivist framework are the emphasis on students' active construction of knowledge, the conception of knowledge as a rich network of related concepts, and the emphasis on building new knowledge on the foundations of students' existing knowledge.

### ***Cognitive theory***

Cognitive theorists advocate the notion that there is a link between external representations of information and internal representations: mental models. A mental model is like an internal simulation (selecting data, hypothesising, conducting, making conclusions) of the external world, which is constructed by a person's intuitive perceptions, analogies or acts of imagination.

Buffler et al. (2008), drawing on work from Johnson-Laird (1983), suggest that there are three main types of mental constructs in the mind: propositional thoughts, mental images and mental models. Buffler suggests that mental models offer a site for mediation between mental images and propositional representations of knowledge. In science education, high-level theories and invisible objects are not described directly by instructors. Mediation is needed to match the mental model to the canonical scientific concepts, and support students in learning such high-level theories in relation to real-world phenomena.

In comparison with traditional instructional approaches such as text-based materials, interactive simulations are used to provide sites for the kind of mental mediation and manipulation of students' internal models of phenomena and concepts that Johnson-laird (1983) describes. When students' mental models agree with the model of the real world implied by the interactive simulation, students obtain opportunities to foster the development of their meta-visual capacity, which is one important means of distinguishing between expert scientists and novice scientists (Buffler et al., 2008). Characteristics of interactive simulations such as their focus on causal relations, more active learning, and mutual student support, mean that they offer very effective ways to improve meta-visual capacity and to build deeper comprehension.

One of the most influential cognitive theories related to interactive simulations is Sweller's cognitive load theory (Sweller et al., 1998). Cognitive load theory emphasises human cognitive architecture and assumes that a limited 'buffer' of short-term memory (also called working memory) interacts with the effectively unlimited long-term memory (Cook, 2006).

Cognitive load theory asserts that learning will be impaired by the presentation of overwhelming levels of novel information that must be processed in working memory (de Jong, 2010; Sweller et al., 1998). Working memory is limited in capacity and persistence over time, limiting its ability to further process novel information and retrieve prior knowledge. Working memory typically stores seven to eight elements but manipulates only two to four elements through sensory memory. Within about 20 seconds, novel information will be lost if people don't process it more deeply through rehearsal (van Merriënboer et al., 2005). However, retrieval from long-term memory doesn't have these limitations (Ericsson et al., 1995; Paas et al., 2004; Sweller, 2003).

Developing a schema that 'chunks' a number of pieces of knowledge or skills can reduce the demands on working memory. Cognitive schemata are processed through working memory and stored in long-term memory. The degrees of complexity and automation are the indicators of expertise and non-expertise: that is to say, experts are experts because they have built up powerful schemata. Research on cognitive load theory has focused on identifying ways to support the development of schemata as knowledge is processed and built up into long-term memory, reducing demands on working memory.

Analysis of learning tasks using the cognitive load theory approach (Sweller et al., 1998) has shown that the cognitive load required to actually learn a topic (intrinsic cognitive load) cannot readily be reduced without vitiating the learning. What can be addressed, however, are the other loads placed on students by the processes of schooling and the ways in which information is presented (extrinsic cognitive load). Instructional approaches advocated within this framework focus on reducing extraneous cognitive load in order to allow students to take full advantage of their cognitive resources for learning.

Cognitive load theory has supported the application of new visualisation technologies in science education (Mayer et al., 2002, 2003). Presentations combining visual and verbal information (e.g. as graphs, animations, simulations et al.) have been widely used for supplementing (Cook, 2006) or even replacing traditional instructional materials. Cognitive load theory is no longer limited to traditional classrooms but has turned to the design of multimedia representations (Mayer et al., 2002, 2003) as well as active learning environments for computer-based collaborative learning (van Bruggen et al., 2002). Instructional design principles (e.g. multiple representations, dual-mode presentations, narration, split-attention material, redundant material, animation, material with interacting elements, and instructional guidance) based on cognitive load theory have been supporting students' learning (Cook, 2006).

Dual coding theory, another important cognitive approach, was proposed by Paivio (1986) and Sadoski et al. (2001). This theory suggests that there are two processing systems in the human cognitive system: a cognitive-verbal system and a non-verbal system. The former emphasises

learning through language-like processing such as words in spoken or printed text; the latter includes emotions and visual representations such as pictures, visual simulations and other visualisation tools. Rieber (2002) claimed that visual stimuli, such as pictures, offer greater support than verbal stimuli, such as words, for encoding and retrieval of information.

Based on dual coding theory, cognitive load theory and constructivist learning theory, Mayer et al. (1992) presented three basic assumptions to explain how people learn concepts and principles in multimedia situations: dual channel, limited capacity, and active processing.

Mayer et al. (1992) dual channel assumption is similar to Paivio (1986) dual coding theory. It assumes that knowledge is processed through auditory-verbal and visual-pictorial channels which are separated into two parts in the human mind (Baddeley, 1999; Paivio, 1986). Their limited capacity assumption is that the brain's working memory is relatively limited and can be overloaded when it is processing and manipulating information from both or each of the two channels. Mayer's and Anderson's third assumption, called active processing, suggests that due to the limits of working memory, effective learning occurs when students actively select, organise, and integrate auditory-verbal (words) and visual-pictorial (pictures) information with prior knowledge. "The effectiveness of multimedia instruction increases when words are presented contiguously (rather than isolated from one another) in time or space," (Mayer et al., 1992). This means working memory will be most effectively employed when processing corresponding auditory-verbal and/or visual-pictorial channels at the same time.

Later, Mayer (2001) proposed eight principles of multimedia learning derived from numerous research findings and intended to address and support the learning of difficult concepts and principles: 1) multimedia principle; 2) contiguity principle; 3) coherence principle; 4) modality principle; 5) redundancy principle; 6) interactive principle; 7) signalling principle; and 8) personalisation principle. The cognitive theory-based design principles proposed by Mayer (2001, 2002, 2003) suggest that students are more likely to learn difficult concepts and principles when interacting with inputs presented in the form of both words and pictures. Moreover, information will stay longer in memory and be more practical when learned using combined presentations, than if the information is represented by words or pictures separately.

### **2.3.2 Defining interactive simulations**

Interactive simulations are considered by many scientists and science education researchers to be promising technological tools for science instruction (Clark et al., 2009). Interactive simulations include external (as opposed to mental) visualisations that are usually computer-based, such as graphics, diagrams, models and animations (Frederiksen et al., 1988), with which students can interact: for example, by entering data, changing settings and observing the results. Interactive

simulations can be described as computer-based ‘exploratory’ applications and considered as representations simulating dynamic systems of scientific phenomena in ‘virtual laboratories’ (Gilbert et al., 1998).

Although interactive simulations have been described as ‘computer-based’, the rise of tablets and smartphones, and the increasing incidence of computing capabilities in a wide range of everyday objects, means that it might be better to talk about these tools being ‘device-based’. Simulations are as likely—perhaps more so—to be run on iPads and other tablets, students’ smartphones, interactive whiteboards and other devices as they are on desktop or laptop computers. This notion links with the ‘BYOD’ (bring your own device) movement (Raths, 2012) in educational technology more broadly.

Interactive simulations visually offer hypothetical, natural, engineered or invented scientific phenomena to students (Committee on Modeling, 2010). They also support students to observe invisible phenomena beyond the range of the naked eye, such as atomic and molecular scale processes, as well as allowing visual representation of non-physical concepts such as magnetic field lines (Botzer et al., 2005; Gobert, 2000).

Interactive simulations provide opportunities for students to learn science through bringing their individual prior knowledge and engaging in experimental practices using new technology tools. Rapp (2005) describes three interactive factors influencing learning: cognitive engagement, interactivity and multimedia learning.

He argues that the use of multiple media with which students can interact (rather than passively consume) can enhance cognitive engagement.

Issues related to the use of interactive simulations for supporting teaching and learning have been explored in research for over four decades (Smetana et al., 2011). Interactive simulations typically allow users to interact with visual representations by manipulating or altering experimental data sets and exploring the implications of modifying parameters (Clark et al. 2009).

Six features of interactive simulations have been identified in the literature:

1. High involvement and interaction with users are the primary educational affordances of interactive simulations. They can better support students’ learning compared to passive visualisation tools and also can ignite and maintain students’ interest and motivation.

2. Offering students opportunities to make mistakes and test hypotheses through changing parameters is a process that has the potential to create robust learning.

3. Interactive simulations can convey information in plausible, economically viable ways. Students can experience situations and phenomena that are impossible to observe in traditional classrooms or real time. What is more, this approach aligns with the nature of mental representations and supports the construction of mental models (Brunye, 2004).

4. Interactive simulations, as visual representations, enable students to construct individual explanations from their own investigations instead of learning through direct instruction. This allows them to concretise their own images for their own understanding. Interactive simulations provide opportunities for students to reflect on their learning while they are constructing new concepts.

5. Instant visual feedback is available. This allows students to discuss the results and concepts with their peers and instructors, to learn more about concepts according to their own results. Furthermore, this is an effective way for instructors to monitor students' progress and provide support and guidance in a timely manner.

6. Interactive simulations can scaffold students' learning, supporting them to develop concepts, particularly in situations where their prior conceptual knowledge is lacking.

Each of these features is important for fostering students' scientific literacy, and together these things are often (to some extent) missing in current school science education (Clement et al., 1989; Gobert et al., 1999; Lowe, 1993). Given these affordances, it seems plausible that interactive simulations would be highly effective for fostering science learning and enhancing students' scientific literacy.

### **2.3.3 The previous studies of interactive simulations for addressing four goals of science education**

Synthesising the study of Hodson (1990) and the NRC's (2005) learning goals for secondary school science classrooms, we have developed (Fan et al., 2013) a framework of four dimensions for use in categorising and considering the impacts of interactive simulations in secondary school science education. Among the four dimensions, this study further investigated dimension 2 – developing conceptual understanding and dimension 3 – promoting science process skills and understanding of the nature of science. Therefore, relevant research regarding these two dimensions are briefly summarised below.

#### ***Developing conceptual understanding***

As early as the 1970s, studies (e.g. Boblick, 1972a; Boblick, 1972b) demonstrated that interactive simulations are at least as effective as traditional instructional approaches, such as hands-on lab, for the conceptual understanding of high school students. Zietsman et al. (1986) found the same conceptual understanding effectiveness with motion simulation as with science remedial instruction, and Choi et al. (1987) found that the volume displacement simulation in Earth science had the same effect as hands-on labs, including no difference in results between girls and boys.

J. W. Russell et al. (1994) investigated an interactive simulation in which students could change chemical variables and examine the feedback of these changes. They found that this significantly increased students' understanding of concepts, and reduced the number of related

misconceptions. In studying students' use of interactive simulations in science classes, research indicates that learning through simulations or simulation-based technology can enhance students' deep understanding of scientific concepts (Quellmalz et al., 2009; van Joolingen et al., 2009). Interactive simulations are most effective when placed within a broader curriculum unit and supported by scaffolding and teacher support.

### ***Promoting science process skills and understanding of the nature of science***

One of the challenges in science education is to engage students in inquiry and scientific investigative process skills in the classroom. Interactive simulations offer new affordances for enhancing students' science inquiry (Jacobson, 2004). Early studies on science process skills found that interactive simulations can capture such phenomena more effectively than traditional approaches, and have the potential to spark a desire in students to learn scientific concepts and understand the investigative process. Interactive simulations can also expand and improve classroom inquiry work (Geban et al., 1992; Kinzie et al., 1993; Rivers et al., 1987). Making sense of science as a way of knowing and learning about phenomena is described as understanding the 'nature of science', which includes learning science process skills such as observation, questioning, hypothesis formation, exploration, manipulation, analysis and reaching conclusions (Honey et al., 2010; Krajcik et al., 1998). In the interactive simulation environment, deeper understanding of scientific concepts occurs as students engage in intensive interactive investigation. Buckley (2006) reports the relationship between the development of science process skills and understanding of concepts in a simulation-based classroom. Students used a software system linking simulations to a genetics unit in text, and wrote logs when they interacted with the instructional system to solve science process tasks. In analysis of students' pre- and post-tests, researchers argued that developing understanding of science processes helped students' conceptual understanding.

These findings are summarised briefly here but presented in more detail in Fan and Geelan (2013), with references to many more relevant studies.

In summary, over the past four decades, the use of interactive simulations has been increasing in elementary, secondary, and undergraduate science classrooms (Scalise et al., 2009). However, while these tools provided opportunities for teachers to individualise students' learning and to contextualise learning within virtual environments (regardless of whether instructors teach in urban, suburban or rural schools), challenges are still taking place in implementation that guarantees the effectiveness of interactive simulations for students' learning. Studies found that interactive simulation-based learning did involve students in active learning, but did not improve their learning outcomes consistently (de Jong et al., 1998; Lee, 1999). In order to promote effective interactive simulation-based learning, a number of studies have been conducted to help students with particular

approaches, by linking them with well-structured inquiry-based learning. This will be discussed in the next section.

## **2.4 Linking together: Conceptual learning, inquiry-based learning and interactive simulations**

Contemporary studies emphasise that inquiry-based learning with interactive simulations can provide students more opportunities to actively construct conceptual knowledge. Studies have found that students taught through inquiry-based learning with simulation outperformed those using conventional instruction (Y. Chen et al., 2010; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Vreman-de Olde et al., 2013). Cox et al. (2003) investigated simulations focused on interactive Physlet-based curricular materials. The simulations allowed students to manipulate the experiment and generate data. Researchers claimed that it was difficult and time-consuming for traditional instruction to facilitate the development of students' conceptual understanding, let alone engage students in the investigative processes of science inquiry: the essence of science. This process of simulation-based inquiry inspired students' innate curiosity about the natural world and developed deep understandings about various physics concepts.

Schwarz et al. (2005) designed a six-step scientific inquiry cycle in a technology-based environment, where students were requested to build up knowledge of meta-modelling. They found the nature of the inquiry learning supported the physics knowledge and inquiry skills. And inquiry learning transferred to the understanding of science content. In addition, the inquiry steps provided opportunities to discuss students' own theories of force and motion and evaluate their inquiry models. These regulatory discourse activities were critical to a successful teaching method.

Buckley (2006) report the relationship between the development of science process skills and understanding of concepts in simulation-based classrooms. Students used a software system linking simulations to a genetics unit presented in text, and wrote logs when they interacted with the instructional system to solve science process tasks. Based on their analysis of students' pre- and post-tests, the researchers argued that developing understanding of science processes helped students' conceptual understanding.

The simulation-based 'Model-Enhanced ThinkerTools' (METT) environment developed by Schwarz et al. (2005) was embedded in a 7th grade science curriculum unit for 45 minutes every school day. The goals of the METT curriculum unit were to create, evaluate, and discuss understanding of concepts in science. The background of these four experimental classes was varied. Mixed cultures and different class levels are the main features of this study. Researchers administered three pre- and post-tests that included a modelling assessment, an inquiry test and a conceptual test over 10.5 weeks. Comparing METT students and ThinkerTools students, there was

no significant difference between them. METT Students, however, gained higher scores on 'proposing conclusions'. Based on the analysis of METT students' results, Schwarz and White concluded that students' acquisition of science process skills (inquiry skills) and their understanding of models (the nature of science) supported their understanding of concepts relating to motion and force.

Sahin et al. (2009) used the 5E model with simulations to remediate students' misconceptions. Their results showed that the integration of simulations into the 5E learning model can produce significant conceptual change in students with alternative conceptions. Limson et al. (2007) promote the use of web-based simulations for inquiry instruction. They created virtual courseware websites for the life science and Earth science fields of learning. Results indicate that students and teachers in schools ranging from junior to senior high, as well as in the college classroom, benefit from the course. The study said, "Students were excited and motivated to think and discover", particularly about basic concepts and the inquiry principles.

Study findings (Sokolowski, Yalvac, et al., 2011) highly praise the application of the PhET simulations. They propose that utilising simulations enhances the teaching of limits and helps students immerse in the virtual physical world model and the inquiry processes. Researchers also argue that PhET simulations can replace real laboratory equipment in physics courses (Finkelstein et al., 2004; Vreman-de Olde et al., 2013).

However, not all inquiry-based learning with simulations leads to positive conceptual learning outcomes. Tao et al. (1999) adapted POE (predict-observe-explain) tasks to engage students' in learning force and motion with simulations. They found students' performances were different between one context and another after the students participated in the intervention. Similar results were also shown in the study of Hsu et al. (2002). They compared three groups, including a control group, a group using simulation, and a group using simulation and using a recording log. They found there was no statistically significant difference between the three groups.

In order to promote effective inquiry-based learning with interactive simulations, a number of studies have been conducted to help students' learning. Some studies suggested developing a structured inquiry-based learning (Reid et al., 2003; Nico Rutten et al., 2012). The inquiry-based learning is a typical scaffold to support learning based on inquiry activities. As an authentic inquiry-based learning, it is considered integral to the physics course to help students build models to investigate questions (Schwarz et al., 1999). Students can monitor their understanding by learning through the inquiry-based learning, and check their conceptual change from initial concepts to the modified concepts.

Seven main interlocked aspects were included in the inquiry-based sequence with interactive simulations (MoE, 2003; NRC, 2000):



1. Problem proposal that heavily relies on existing knowledge;
2. Hypothesis generation that leads to follow-up activities;
3. Hypothesis testing that will generate appropriate understanding;
4. Treating data that will make the initial understanding intelligible;
5. Communicating findings that will make the understanding plausible;
6. Evaluating findings that will make the initial understanding fruitful;
7. Metacognition learning, meaning self-monitoring of the inquiry process and integration of the inquiry principles, which will make the learning continuous.

Based on an inquiry-based sequence with interactive simulations, students were expected to “go beyond what they have learned and to use knowledge in creative ways in solving novel problems and building new understanding for themselves, and by themselves” (Hodson, 1999, p. 248). In educational practice, however, the inquiry-based sequence with interactive simulations was often challenged by understanding of the inquiry-based sequence with interactive simulations itself. The affordances of the designed instructional activities “may be wasted” if the meaningful scaffolds are not provided, because “students become either confused or overwhelmed trying to figure out what is being depicted in the visualisation or students may not engage in any deep processing of the visualisation” (Gobert, 2005, p. 4). For example, studies have found that some interactive simulations made students confused (Clark et al., 2009; de Jong et al., 1998; Xie et al., 2006). There are four categories of confusion that students may encounter during an inquiry-based learning with simulations: 1) difficulties in generating and adapting hypotheses; 2) poorly designed experiments; 3) difficulties in data interpretation; and 4) problems regarding the regulation of discovery learning (de Jong et al., 1998).

Taking these difficulties into account, some studies argue that when inquiry-based learning with interactive simulations is conducted with proper scaffolds, students can access knowledge construction and achieve efficient knowledge gains (Jari et al., 2014)(Jari Ensio et al., 2014). Effective scaffolds come in many forms. Examples include 1) educational interactive simulations; 2) knowledgeable teachers; 3) capable peers; 4) mandatory worksheets, and so on.

Recently, some educational simulations have been proved effective in facilitating conceptual learning. For example, Easy Java Simulation (EJS), including Kepler’s System Model, Geostationary Satellite around Earth Model, and One Dimensional Gravitational Model, were used in the physics inquiry classroom (Goh et al., 2013; L. K. Wee et al., 2013; L. K. Wee et al., 2012). These researchers found that the use of EJS in physics inquiry instruction can achieve higher concept learning than traditional pen-and-paper instruction. Besides simulations, Bakirci et al. (2011) found that the simulation-supported 5E worksheet positively scaffolded students’

hypothetical, correlation and combinational thinking skills in the simulation-supported environment.

How the interactive simulations were used in the inquiry-based learning played an important role in its effectiveness. In particular, the scaffold provided by the teachers was the critical factor (Akaygun et al., 2013; Nico Rutten et al., 2012). For example, Jari et al. (2014) explained that teachers provided the opportunities of discussion and elaboration when students studied about the greenhouse effect. Students' plans, ideas and explanations must be made explicit and understandable (Kyza, 2009). K. E. Chang et al. (2008) pointed out that learners need help in proposing hypotheses, conducting experiments and in interpreting data when exploring simulation-based inquiry instruction. They also found that the better the background of understanding, the more students benefit from simulations and gain in learning outcomes. It is vital for teachers to provide background information before task practice, but the best time for providing procedural information is while conducting the experiments (Nico Rutten et al., 2012).

Reid et al. (2003) have suggested that it is necessary for teachers to apply three types of scaffolds in order to increase the efficacy of inquiry-based learning in simulation environments: (1) interpretative support helps learners to activate their previous knowledge and relate this to different applications in the virtual environment, in order to generate hypotheses and construct coherent understanding. Studies suggested that teachers should provide students a comprehensive background of the concepts. The better the background knowledge, the better students can perform in comprehension (Park et al., 2009). Reid et al. (2003) demonstrated that interpretative support had significant influence in scientific processes and application of new knowledge; (2) Experimental support consists of guiding students in designing a systematic and logical experiment or drawing conclusions from the results. Teachers were important to help students to make and modify their hypothesis (Fugelsang et al., 2004). Students also needed support in interpreting data that were collected through interactive simulations. In the inquiry-based learning with interactive simulations classroom, teachers should facilitate students to create their communal database. Students were encouraged to use evidences collected to build their ideas, or comment on others' findings; (3) Reflective support increases learners' awareness of their own learning processes, and prompts the reflective abstraction and integration of their inquiry.

Further, the scaffold offered by students' peers was also meaningful. Studies found that students gained understanding when they were actively involved in the teaching experience (Biswas et al., 2005; Roscoe et al., 2007; Vreman-de Olde et al., 2013). Students were highly motivated when they taught others, which in turn supported better learning (Chase et al., 2009). And in the study of Matsuda et al. (2010), they found that teaching other students was motivating for students

themselves. Students using SimStudents gained noticeable achievements, in particular, when feedback of their actions was obtained.

In addition, a mandatory scaffold was needed in the context of simulation-based inquiry learning. While there was no study that explored metacognitive guidance in simulation-based inquiry learning, studies regarding the role of metacognitive function could provide relevant implications. Metacognitive thinking can actively monitor and regulate students' learning process (Flavell, 1976). It is often described as "thinking about one's own thinking". Meta-cognitive thinking was found to be effective in students' performances (Boulware-Gooden et al., 2007). And it can monitor students' conceptual understanding and thinking process (Yuruk et al., 2009). In practice, the mandatory scaffold can also make tasks more tractable and productive for learners (Quintana et al., 2004). Therefore, the use of mandatory scaffolds was a reasonable way to metacognitive scaffold students' inquiries in the interactive simulation settings.

Summarising the results of previous studies suggests that there is a need for further research to explore the use of inquiry instruction, in order to dispel students' alternative conceptions and help their authentic understandings of concepts in the interactive simulations environment. This study believes that inquiry-based learning with interactive simulations can provide a proximal learning environment, if well supported with structured and meaningful scaffolds. In this study, the implications of previous studies will be catalogued into two main aspects (i.e., scaffolding with scaffolds) in order to support the theory on positive effects of inquiry-based learning with interactive simulations on conceptual learning regarding forces and motion:

- 1) Scaffolding means the inquiry-based sequence of inquiry-based learning
- 2) Scaffolds include interactive simulations, knowledgeable teachers, capable peers, and mandatory worksheets.

Based on previous studies, this study believes that inquiry-based learning with interactive simulations holds the promise of supporting students' conceptual learning in physics, even though there is evidence that results have not always met researchers' expectations. This study designed the ILIS approach that was introduced in Chapter One, and theoretically and empirically explored the effectiveness and efficacy of conceptual learning through inquiry-based learning with interactive simulations to fill the gaps in the literature.

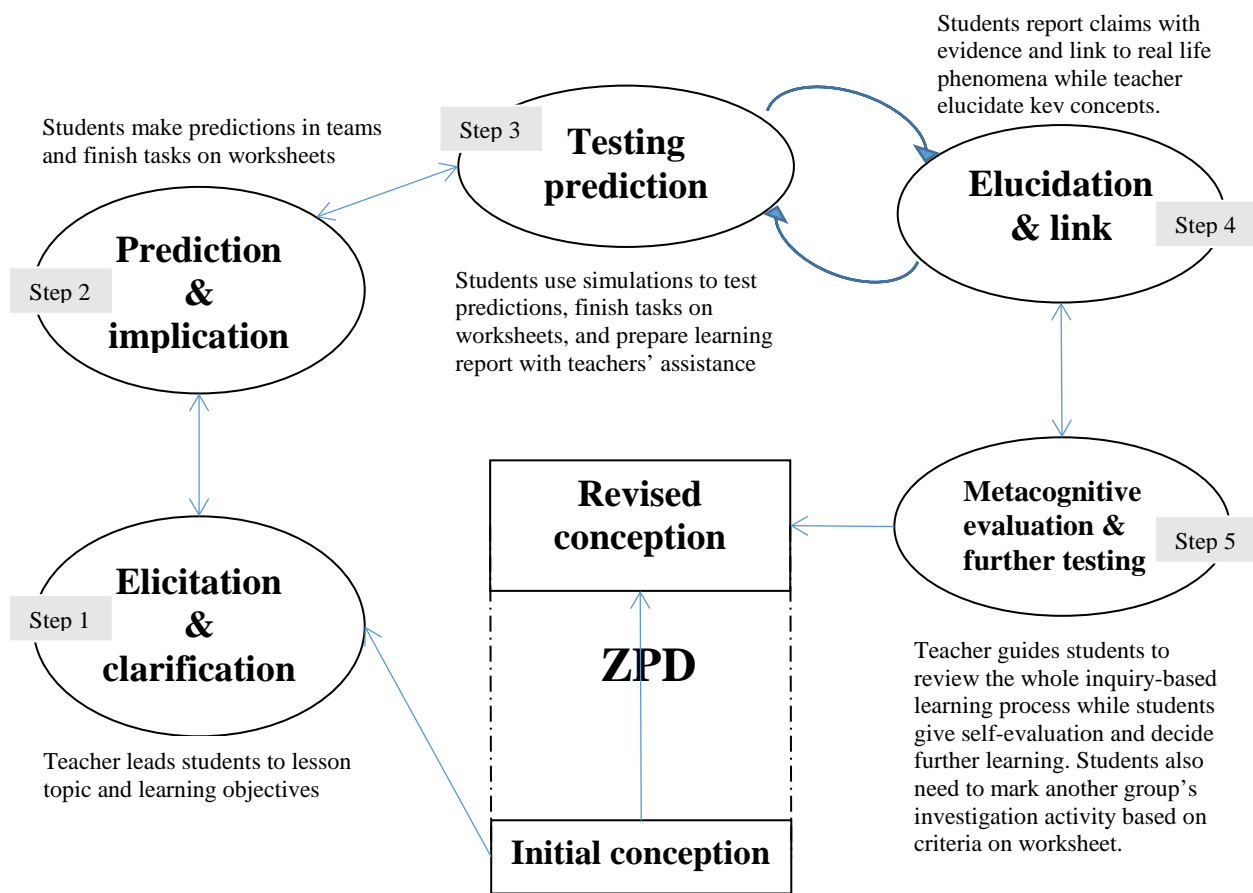
## **2.5 Theoretical framework**

The current study draws on constructivist perspectives to build a framework that underpins the investigation of the research problems. The current study is based upon the literature of the conceptual change theory (Hewson et al., 1992; Posner et al., 1982; Scott et al., 1992; Vosniadou, 1994) and more on literature about the ZPD in the practice of conceptual understanding (Quintana

et al., 2004; Wood et al., 1976). The following perspectives, which contribute to the current study, are articulated to underpin understanding of the inquiry learning with interactive simulation (ILIS) for students' conceptual learning.

- a) Learning is constructed, rather than received; but commonalities exist between individuals (Driver et al., 1994; Posner et al., 1982);
- b) Personal and social planes are equally important to the process of learning (Vygotsky, 1978);
- c) Existing ideas greatly influence students' subsequent learning (Posner et al., 1982; Vosniadou, 1994);
- d) Conceptual change may take considerable time and have frequent reversals, involving experiencing formalised instruction and informal daily activities (Vosniadou, 1994);
- e) Conceptual change may take place through exchanging, modifying, and enriching the other concepts (Scott et al., 1992; Scott et al., 2007).
- f) In the scaffolding of ZPD, assistances or scaffolds from knowledgeable figures, language, technology tools, cognitive tools and activities are influential to support conceptual change (Quintana et al., 2004; Vygotsky, 1978; Wood et al., 1976).

In light of the constructivist perspectives and previous studies, a theoretical framework is presented in Figure 2-1.



**Figure 2-1 Theoretical framework of the ILIS approach and its procedure**

This framework guides conceptual learning from initial conceptions to revised conceptions. The realisation of the conceptual learning is supported by an inquiry-based learning that is regarded as the learning scaffolding, as well as various scaffolds during the learning through an inquiry-based learning, such as teachers, interactive simulations, peers, and worksheets.

The theoretical framework underpins the investigation of the research questions, as follows: RQ1. What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning? RQ2. How do students and teachers understand conceptual change in relation to their performance through the ILIS approach?

## 2.6 Summary

The commitments to conceptual learning have been understood differently from the cognitive constructivist perspective and the social constructivist perspective. The cognitive constructivist camp used individual's cognitive balance to explain learners' conceptual learning, whereas the social constructivist camp considers learners' conceptual learning influenced by social plane and individual plane. To a certain extent, these two perspectives are similar in terms of their understanding of how learners learn knowledge. It is believed that knowledge is constructed rather

than transferred. Thus, this study adapted the combination of two constructivist perspectives to investigate a practical method for conceptual learning.

In practice, the combination underpins the implementation of conceptual learning. The ILIS approach is regarded as learning scaffolding that will support students to arrive in the zone of proximal development. Specifically, there are five steps, which include eliciting existing knowledge, proposing a hypothesis, conducting experiments, collecting and analysing data, and then communicating findings and making metacognitive evaluations. During the five steps, students will be facilitated with different scaffolds. For example, teachers inspire students to recall what they have already understood of the concepts; students participate in conducting experiments through interactive simulations; teachers encourage students to present their findings, meanwhile teachers help students develop the use of scientific discourse; and teachers also assist students to foster the habit of monitoring their learning process during the ILIS approach. Therefore, students' conceptual learning will be gradually developed and actively constructed, rather than passively transferred.

In the context of China, many educators recalled the adaption of inquiry-based instructional approaches. But few empirical studies were conducted to investigate their implementation, let alone the integration of interactive simulations. Therefore, there is a paucity of research regarding the effectiveness of inquiry-based learning with interactive simulations on conceptual learning. The findings of this study will illuminate this field in the context of China. The next chapter will explicate the method of research design and its implementation.

## Chapter 3 Methodology

This chapter provides an overview of the research methodology. Section 3.1 re-states the research questions and accordingly presents the research design. This section also explains the rationale for conducting a mixed methods design in this study. Sections 3.2 and 3.3 separately introduce the research procedure and teacher training. Section 3.4 presents the quantitative phase. The quasi-experimental research design, research questions, population and sample, instruments, data analysis, are described in detail in this phase. Section 3.5 delineates the qualitative phase. The focus questions of the qualitative phase, sampling, instruments, and data analysis and data report are described in detail in this phase. Then, ethical consideration is addressed in section 3.6. The chapter concludes with a brief summary, Section 3.7. In all, this chapter provides a holistic research design to explore the research problem.

### 3.1 Research questions and research design

This study aims to explore the effectiveness and efficacy of two instructional approaches on student conceptual learning in physics. Accordingly, research questions as shown below were addressed in this current study:

RQ1. What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning?

RQ2. How do students and teachers understand conceptual change in relation to their performance through the ILIS approach?

In order to address these two research questions, a mixed-method research design was used. Creswell (2012b, p. 535) attempts to define a mixed-method design as “a procedure for collecting, analyzing, and mixing both quantitative and qualitative research and methods in a single study to understand a research problem”. Although there are contrasting views about mixed methods research (see Bednarz, 1985; Silverman, 2010), the proponents of the mixed methods argue, “They view no problem, however, if methods are not contradictory to the ontological standpoint. But what if two competing methods are used in the same study if they enhance understanding of the phenomenon?” (Muhammad, 2013, p. 19). In line with these conflicting arguments, this study supports the view that the issue is not the use of mixed methods, but how we use the mixed methods in a study. In practice, it is believed that quantitative and qualitative methods could be complementary.

Specifically, this current study employs an explanatory mixed methods design to compare, corroborate, and cross-validate findings (Creswell, 2012b, p. 541). The design includes first producing quantitative data to test and explain the theoretical framework. Then it is followed with qualitative data that complement, refine and enrich the quantitative results. The explanatory mixed

methods design more importantly provides interpretation in the qualitative phase in case unexpected findings emerged from the initial quantitative phase. This design ensures the trustworthiness, credibility, and reliability of the research findings, as well as producing more complete knowledge to inform theory and practice.

This study employs a mixed-method research design governed by several reasons.

Firstly, the research questions need the use of quantitative and qualitative research methods. In this current study, RQ1 makes predictions of the relationship between instructional approaches and conceptual learning and seeks their general relationships, while RQ2 asks about individual perceptions and meaning for each participant, specifically how they understand their conceptual learning in relation to performance achieved by the instructional approaches. The mixed methods design could provide a whole picture of this educational issue and better facilitate the investigation of this complex social phenomenon, when compared with the use of a single research method (Mertens, 2005). Therefore, the mixed methods research design is a key element in exploring the issues in educational and social science (Creswell et al., 2003; Gorard et al., 2004; Thomas, 2003).

Secondly, an integration of quantitative and qualitative research design provides a practical enhancement to the depth and scope of the investigation. Words and narrative can be used to add meaning to numbers, and the numbers in turn can add precision to words and narrative.

In addition, methodological pluralism involving the use of both quantitative and qualitative methods in the same research endeavour is a growing research paradigm in educational and social research. In order to find out the truths and reality about educational phenomena, quantitative research seeks the general cause-and-effect relationships, makes quantitative predictions, and generalizes research findings. And qualitative research seeks to understand individual perceptions in depth, provides individual meanings in rich detail, and vividly interprets how each participant constructs their meanings and why. Mixed-method research design is emerging as an educational and social research method that can gather a better and more complete picture (Moran-Ellis et al., 2006; Muhammad, 2013). This study, specifically, believes that the nature of reality is objective, the social reality is independent of human beings, but human beings socially construct knowledge and in turn impact on the reality. In this sense, people describe the reality in the position that inevitably involves both the objective external world and human beings' paradigmatic lenses (Creswell et al., 2011). Accordingly, the standpoint of methodological pluralism could be used to better understand and to get a thick description of the current research topic.

In the current study, the appropriate application of the mixed research methods not only overcomes these complex challenges but also provides stronger evidence for the research conclusion than when only a single method is used. The mixed methods design could also make good use of the quantitative or qualitative research to overcome the weakness in using the single



method and minimise the weaknesses by using both in a research study. Thus, the mixed methods design in the current study could provide a more complete portrait of conceptual understanding, in relation to how teachers and students use the inquiry-based learning with interactive simulations to develop conceptual understanding in the physics classroom.

### **3.2 Research procedure**

The research procedure included a pilot study and main study. The pilot study plays an important role in social science research. The implementation of the pilot study is often conducted with a small sample to undertake a preliminary check of the research design and ensure the quality and efficiency of the main study (Haralambos et al., 2004).

Specifically, there were three steps in both the pilot study and the main study including before-, during- and after- experimental intervention. Before the experimental intervention was conducted, participating teachers were invited to participate in teacher training. Students and their parents read letter to parent and students and signed consent forms (see Appendix E and Appendix F) and formally agreed to participate in this study. Then pre-tests were administered to all participating students. During the experimental intervention, the teachers and students were involved in eight weeks' learning using the ILIS approach in the experimental group and conventional instruction in the control group. Two researchers (Ms Fan and Professor Liang) observed the implementation of both experimental groups and the control groups. After the experimental intervention, all participating students undertook the post-test. The teachers and selected students were invited to participate in the interview phase. Accordingly, teacher training, quantitative phase and qualitative phase will be introduced in the following sections.

### **3.3 Teacher training**

In the pilot study, there was no teacher training because of the time limitation. The researcher conducted the ILIS approach in the experimental group of the pilot study. One participating teacher conducted the conventional instruction in the control group. And the participating teacher was also involved as a teaching assistant.

In the main study, two teachers participated in the teacher training. The teacher training introduced the way of conducting the ILIS approach and the concept of inquiry-based learning with technology. Three other physics teachers engaged in the teacher training. These three physics teachers aimed to support the two acting teachers. The five teachers formed a teacher group and had a weekly research meeting in order to ensure the successful implementation of the current study.

The teachers attended a two-day workshop. Topics were as shown below:

- 1) PhET simulation introduction;

- 2) Playing with PhET simulations;
- 3) Discussion about how teachers could use the simulations to facilitate students' learning;
- 4) Introducing physics conceptual understanding or change and discussing students' alternative conceptions;
- 5) Introducing the force concept inventory test that is to assess students' conceptual understanding of force and motion;
- 6) Inquiry skills survey introduction and discussion;
- 7) Inquiry-based instructions introduction;
- 8) Guidelines for conceptual understanding instructional method;
- 9) Discussion the details of lesson plan and students' worksheets;
- 10) A summary table of the educational experiment's schedule

On the first day, the teachers firstly had the opportunity, for two hours, to play with all PhET stimulations. They were then organized to discuss ways of integrating the simulations into their classroom. Secondly, the teachers went through the force concept inventory test and inquiry skills survey, and the researcher introduced the theory of conceptual change. Then, the researcher guided the teachers to discuss misconceptions their students were holding, especially regarding the misconceptions of forces and motion. Finally, the first day's workshop ended with discussion about ways of improving conceptual understanding and overcoming students' misconceptions.

On the second day, the researcher firstly introduced inquiry-based instructional approaches to all teachers. After that, teachers learnt the inquiry-based learning with interactive simulations (ILIS) approach (see Appendix G) based on the ILIS guidelines. Next, the teachers individually modified lesson plans and students' worksheets. And then, the teachers went to classrooms with computers to conduct the ILIS approach in practice. After 60 minutes, all teachers went back to the meeting room and discussed their experience of conducting ILIS approach. Based on their experiences, the lesson plans and students' worksheets were modified one more time. The final 30 minutes were spent in discussing the educational research design and the implementation of the experimental intervention.

To sum up, the two days' teacher training workshop helped teachers understand the current research study and ensured the implementation of experimental intervention as it was planned. Meanwhile, the participating schools were benefiting from the two days' teacher training workshop. It provided the teachers and schools free professional development training, instructional materials, teaching method, computer-based technology toolkits and academic support.

### 3.4 Quantitative phase

#### 3.4.1 Quasi-experimental research design

The quantitative phase from the pilot study and main study adopted a quasi-experimental research design. This research design is often used in the context of authentic and complex social studies. It offered a method for gathering information from “something other than a random sample of the relevant population with random assignment to experimental and control groups” (Achen, 1986). The current study took place in schools where the intact classes of acting teachers were invited. And the classes were randomly assigned into the experimental group or the control group. Table 3-1 shows the information of the quasi-experimental research design. There were two classes from one school involving in the pilot study. There were four classes from school B and another class from school C participating in the main study (all names were pseudonyms chosen by participating teachers). The experimental groups used the ILIS approach, but the control groups used conventional instruction. The detailed treatments had been introduced in Chapter One.

**Table 3-1 The quasi-experimental research design in quantitative phase**

Study phase	Schools	Teachers	Classes	Experimental group	Control group
Pilot study	A	Researcher + Wang	1	Yes	No
					Yes
Main study	B	Wang	2	No	
		Zhang	3	Yes	No
			4	No	Yes
		Han	5	Yes	No
			6	No	Yes
			7	No	Yes
	C	Fang			

#### 3.4.2 Research questions

In order to explore the effectiveness of ILIS approach and conventional instruction on student conceptual learning, several sub-questions below were examined in the quantitative phase.

RQ1<sub>1</sub>. What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning?

RQ1<sub>1.1</sub>. Which instructional approaches provide better conceptual learning during the ILIS approach and conventional instruction?

RQ1<sub>1.2</sub>. And what effects does gender have on participants' conceptual learning during the ILIS approach and conventional instruction?

RQ1<sub>2</sub>. What is the relationship between conceptual learning and confidence during the ILIS approach and conventional instruction?

RQ1<sub>2.1</sub>. Which instructional approaches provided better confidence during the ILIS approach and conventional instruction?

RQ1<sub>2.2</sub>. And does confidence influence participants' conceptual learning during the ILIS approach and conventional instruction?

RQ1<sub>3</sub>. What is the relationship between conceptual learning and inquiry process skills during the ILIS approach and conventional instruction?

RQ1<sub>3-1</sub>. Which instructional approaches provide better inquiry process skills during the ILIS approach and conventional instruction?

RQ1<sub>3-2</sub>. And do the inquiry process skills influence participants' conceptual learning during the ILIS approach and conventional instruction?

### 3.4.3 Population and participants

#### *Population*

The target population consisted of all senior school students enrolled in physics in China. The accessible population is senior school students enrolled in physics in Shun Yi district, Beijing, China. Shun Yi is one of the 18 districts in Beijing, with a population of about 594,000 residents in 2013. The number of senior students in Shun Yi was around 3310, with 1840 exemplary public school students, 1320 ordinary public school students, 150 private school students, and 350 vocational school students.

#### *Participants*

The study sample in this current study was chosen from the accessible population based on the principle of convenience. It included the ordinary public schools from Hai Dian district and Shun Yi district with students and teachers who volunteered to participate in this study. Finally, three out of five ordinary public senior secondary schools were selected to participate in the current study. As shown in the Table 3-2, there were 38 students participating in the pilot study. There were 142 students involving in the main study.

**Table 3-2 The general information of participants in pilot study and main study**

Study phase	Schools	Teachers	Classes	Number of students	Experimental group	Control group
Pilot study	A	Researcher + Mrs Wang	1	22	Yes	No
		Mrs Wang	2	16	No	Yes
Main study	B	Mr Zhang	3	26	Yes	No
			4	30	No	Yes
		Mrs Han	5	29	Yes	No
			6	32	No	Yes
			7	25	No	Yes
	C	Mr Fang				

The reasons for choosing the three public schools were to ensure that schools, teachers and students were comparable. Three of the chosen ordinary public schools were medium-sized schools with around 1500 senior secondary students. The student to regular classroom teacher ratio is about 35 to 1. About 70% of students annually pass the national college entrance examination and enter universities. In these schools, classes were equipped with computers and multi-media screen. A good number of science and computer labs were well provided in these schools. All the acting teachers in the current study had more than 5 years teaching experience in physics. The average age

of the participating students was 16 years old, which excluded the difference in the students' age in experimental and control groups.

### **3.4.4 Materials**

#### ***PhET interactive simulation***

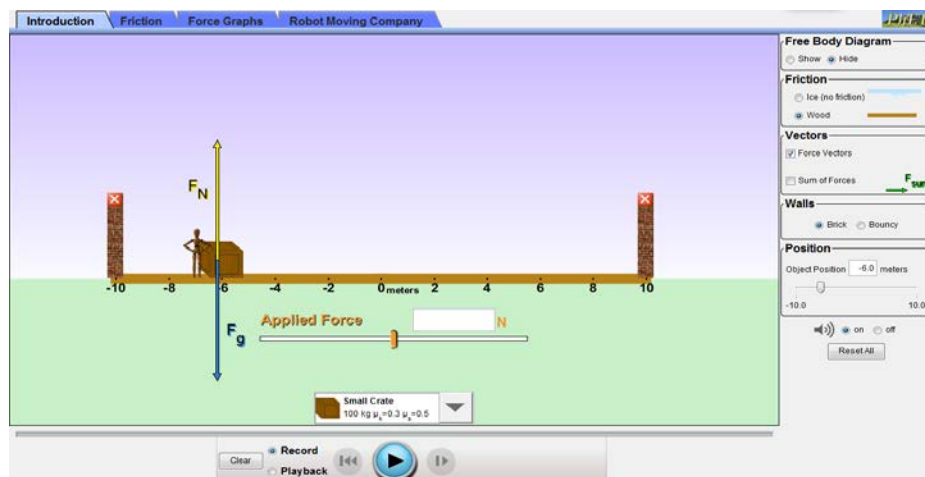
The students in experimental groups used computer-based interactive simulations to explore the topics of force and motion. The two interactive simulations developed by the physics education technology (PhET) project group were employed in the current study. This project is a library of free online applications designed by the Interactive Simulations Project at Colorado University. There is a growing list of over 110 million of physics simulations and other subjects like biology, chemistry, earth science and math. The central characteristic of PhET simulations is to support the implementation of inquiry learning. The design principles are based on research on how students learn (Bransford, 2000). PhET simulations have been used in a series of studies (Adams et al., 2008). Chinese translated versions of the physics simulations were used in this current study.

Studies have shown that PhET simulations can challenge, improve, correct and reinforce conceptual understanding through self-driven exploration (Wieman et al., 2010; Wieman et al., 2008). Students gained more knowledge when using the PhET simulation than when learning through the real laboratory equipment (Finkelstein et al., 2004).

For example, findings in chemistry (Moore et al., 2013) showed that PhET simulations were chosen by teachers teaching in large classrooms because of their implicitly scaffolded quality. Moore, Herzog and Perkins found that students engaged in discussions about experimental content when they were supported by the implicitly scaffolded simulation. In physics, PhET quantum simulations addressed many student difficulties in quantum mechanics. The researchers concluded that the features of PhET were effective for helping students understand the abstract concepts of quantum mechanics. Sokolowski and Rackley (2011) also praised the application of the PhET simulations. They found that utilizing simulations enhanced the teaching of limits and helped students become immersed in the virtual physical world model and the inquiry processes. Sokolowski et al. (2010) showed more gains on mathematics district and state standardised test items when students learned with simulations.

Furthermore, PhET interactive simulations represent the features of well-designed educational technology tools (Adams et al., 2008) such as scaffolding the implementation of exploring scientific cause-effect relations, providing a variety of visual representations, offering interactive learning, allowing students to conduct virtual experiments, etc.

Take the interactive simulation used in the current study as an example. The use of force and motion simulation (see Figure 3-1: A screenshot of the Force and Motion simulation interface) includes an introduction interface, a graph interface and game interface. The graph interface of the Force and Motion, once launched, provides three kinds of visual representations. At the centre, there is an image of a man in a moving position going from the left side of the screen to the right side of the screen. Furthermore, there are several kinds of graphs representing the second kind of visual displays. The graphics in the central part show the man's motion. Under the moving man, there is motion graph depicting the man's position, velocity, and acceleration through the whole time. At bottom of the screen, there are some numerical input boxes. They are the third kind of virtual display to assign a value to the man's parameters of motion like position, velocity, and acceleration. They are also used for students to replay and examine any part of a motion through Playback, Pause, and Rewind buttons by playing with mouse and keyboard.



**Figure 3-1 Force and Motion simulation interface**

The Force and Motion interactive simulation allows students to conduct virtual experiments. The students can 1) choose frictionless and frictional surfaces that are impossible or difficult to create in the classroom; 2) assign the value of different properties as mass, applied force, position, friction with extreme conditions; 3) see the results in tables that provide students with accurate information about position, time, velocities, acceleration, vectors and different forces; 4) provide an animation that vividly shows whether the man may or may not move an object, which depends on the amount of force; 5) it is also possible to experience unlimited experiments though recording and playing back their experiments.

Additionally, the PhET website provides additional teaching resources for each simulation such as main topics, sample learning goals, tips for teachers, and teaching ideas. It also provides a valuable opportunity to submit and share teaching ideas, materials and designed activities with

those who are also interested in teaching through interactive simulations. More information is available on their website <http://phet.colorado.edu/>.

### ***Learning activities***

Both experimental groups and control groups studied a module on ‘Newton’s Laws of Motion’ which is a compulsory topic in the new physics curriculum standards for senior secondary school. Students in the experimental group had a 60-minute inquiry instruction lesson once per week for eight weeks while students in the control group had a teaching sequence using the teachers’ usual approach to teaching this topic – which we describe as ‘traditional’ instruction – on the same topic once per week for eight weeks. Classes for the experimental groups and control groups were in Chinese.

### ***Treatment***

#### ***ILIS approach***

The ILIS approach was used in the experimental group. It aimed to facilitate teachers to develop students’ conceptual understanding. There are five steps in the ILIS approach. They are 1) elicitation and clarification, 2) prediction and implication, 3) testing through IS, 4) elucidation and linking, and 5) metacognitive and further testing (see Figure 2-1). These five steps integrated different inquiry practices such as proposing experimental design, testing hypotheses observing experiments, discussing findings, critiquing others’ investigations, and self-evaluation. There is detailed information of the ILIS approach outlined in *Science Teachers’ Use of Visual Representations* (Geelan et al., 2014).

Before each lesson, all participating teachers were requested to complete an ILIS lesson plan form (See Appendix J). The teachers needed to integrate each topic and content into the ILIS approach. The lesson plan stated the five ILIS approach steps. It asked the teachers to fill in teaching objectives, student activities, and teacher’s role. There was also a blank left named practice reflection. The acting teachers were requested to complete it after each lesson. For example, Table 3-3 showed the example of a lesson plan of Newton’s first law.

**Table 3-3 A completed ILIS lesson plan form**

Teaching Date: 16/05/2013		Class Number: Class 3			
Teacher's name: Mr. Zhang		Lesson topic: Newton's second law			
Time	Teaching steps	Teaching objectives	Student activities	Teacher role:	Practice reflection
First lesson					
10-15mins	Step 1: Elicitation and clarification	To elicit students' existing concepts and clarify the 'target' scientific conception.	Teacher's introduction started with providing the lesson objectives and the roadmap of the content of the lesson. Then Teacher asked three questions related to Newton's first law. And asked students to write down their initial ideas.	Facilitate students' to elicit their misconceptions through their teacher and peers	
15-20mins	Step 2: Prediction and implication	To outline the predictions and engage students in the implications of their prior conceptions on certain topics.	Teacher described the situations again in order to prompt more discussions with students. Following that, he introduced the class sequence and interactive simulation that would be used in the current lesson. After that, teacher asked students to finish a task in pairs, which was showed in student's worksheet. Students in pairs gave their predictions and provided their explanations.	Lead students' to clarify their problem and propose predictions out of and in the worksheet	
20-25mins	Step 3: Testing prediction through interactive simulations	To test predictions of competing conceptions using interactive simulations.	Teacher led class discussion on how to make a plan to test their hypothesis. Students used "Move and Force" simulation and scaffolding forms and questions of student notes to explore their hypothesis. Most students appeared to be working collaboratively on their prediction problems; and some group finished quickly and started to play games attached with the simulation.	Facilitate students' to conduct their experiments through simulation, and solve the on-going problems through peers their teacher, and worksheet	
5-10mins	Close the first class				
Second lesson					
Teaching Date: 23/05/2013					



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10-15mins	Review			
35-40mins	Step 4: Elucidation and linking	To clarify the findings and link results to the scientific conception through students' presentation and teacher-student's discussion.	Students gave their presentation. Teacher said, "Feel free to make the presentation in your style or using the worksheet." But he also introduced four main aspects of the presentation. There were four groups presenting their exploration experiments with simulations. Teacher proposed several questions during or after each group's presentation. Teacher cared about the questioning techniques and questioning time.	Guide students to clarify and link their findings through simulation, peers and scientific discourse methods.
5-10mins	Step 5: Metacognitive evaluation and further testing	To evaluate the whole inquiry sequence in order to develop metacognitive inquiry thinking and deepen understanding of the scientific conception.	Teacher said to students, "I want you to mark your worksheet in group and then invite one other group to re-mark your worksheet. The five criteria have been listed in the worksheet."	Facilitate students' to complete self-evaluation and other-evaluation through in the worksheet.

Note: The teacher has considerable freedom to rearrange these steps fit the constraints of the timetable, although these five steps are listed in instructional order, because it's necessary to choose a means of presenting them. While (a) if it's necessary to, say, switch the second and third activities, that is fine and (b) rather than a linear progression with a beginning, middle and end, sometimes a learning sequence will involve cycling through the middle steps multiple times to ensure deeper understanding.

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The ILIS classroom was designed with almost forty computers in the centre of the classroom. At the front of the room were a demonstration table and a central computer behind which was a large blackboard and a multi-media screen. Students' seats were fixed. Computers with PhET interfaces were placed in the centre of the classroom. Demonstration equipment was on the demonstration table for teacher use. Students in pairs used one computer for conducting the experiments.

The two acting teachers conducted the ILIS approach based on the teacher training as well as the lesson plans. Table 3-4 contains notes from the observer's perspective. It depicted the details of how the acting teacher taught the lesson of Newton's first law using the ILIS approach in the experimental group. The class began with Mr. Zhang's greeting "class begins", all students stood up and said "Teacher, good afternoon".

**Table 3-4 The implementation of the ILIS approach observed by the researcher**

Teaching Date: 16/05/2013		Class Number: Class 3	Teacher's name: Mr. Zhang	Lesson topic: Newton's second law
Time (60mins)	Steps	Instructional activities		Observer's notes
6mins	Step 1: Elucidation & clarification	Zhang's introduction started with providing the lesson objectives and the roadmap of the contents of the lesson. Then Zhang said, "I want you to think about these questions that I have: 1) When you play football and kick the ball, does the ball move? 2) When you suddenly push a chair, does the chair move? 3) When you are on a moving bus and throw a coin straight up, does the coin move in a vertical direction? 4) A bowling ball accidentally falls out of the cargo bay of an aeroplane as it flies along in a horizontal direction. What path would the ball follow after leaving the aircraft? After that, Zhang asked students to write down their initial ideas.		Teachers used different situations and questions to stimulate students' potential ill-structured concepts on the Newton's first law. This study proposed teachers create mental disequilibrium in the engagement step. This leads to students into the central topic.
6mins	Step 2: Prediction & implication	Zhang described the situations again in order to prompt more discussions with students.		No answer for all questions.
6mins		Following that, he introduced the class sequence and interactive simulation that would be used in the current lesson. He also asked students to fill in the worksheet throughout the lesson. He said, "There are five parts in the worksheet which follows the sequence of the inquiry instruction and scaffolds the learning of the lesson. You must fill it in and hand in after finishing each class."		The University of Colorado PhET group designed the simulation software. It can be freely downloaded from <a href="http://phet.colorado.edu/">http://phet.colorado.edu/</a> .
12mins		After that, Mr. Zhang asked students to imagine playing games on an ice surface playground. At the same time students should answer the three "Force and Motion" questions on the student worksheet. In response to the questions, students gave their predictions in response to the given scenario and provided their explanations. The students spent several minutes discussing the scenarios with their partner. When Zhang listened to students' conversations and talked with some students sometimes, he repeated the question and invited students to present their answers. And then Zhang paraphrase the answers – "So, some students think your friend would be moving, because there is still a force. It goes that way. Some students are saying your friend would be at rest, because of no force on your friend. Some students think your friend would fall down, flying, oh wait just a guess". After that he informed that each group must propose a problem or hypothesis associated with the scenario on student note and fill in the blanks. Then Zhang led class discussion on how to make a plan to test their hypothesis.		The students obviously engaged in the questions and topic. They discussed with their partner actively.

15mins	Step 3: Testing prediction through interactive simulations	Zhang suggested students frame a hypothesis based on discussion. Students used “Move and Force” simulation and scaffolded forms and questions of student notes to explore their hypothesis. Zhang introduced students the procedure for conducting inquiry instruction using the computer-based interactive simulations. Students could adjust the variables as they observed the situation of motion with different force and mass as well as the direction of acting force. Students group scaffolded each other for learning accounted for most time. During this period, Zhang dutifully recorded students’ performance on the spot and supported students to solve their problems during the experiment step. Most students appeared to be working collaboratively on their prediction problems; and some group finished quickly and started to play games attached with the simulation.	The student argued about their prediction, the conceptions “force cause velocity” had been discussed in their conversation. There was no off-task behaviour.
10mins		Most students finished their experiments with computers. Some of groups did the following part and some of them talked with other group members. Then Zhang asked students to discuss with their partners on their whole experiments.	Students went to be socialized and Zhang also noticed that. Then he asked students to have a discussion about their experiments. Topics were on student’s worksheet.
5mins		Zhang closed the class by asking students to re-think about the main topic of “what forces are acting on your friend after you give your friend a push.” He gave students suggestions about how to do their presentation. He said, “you can tell us what you found from your data; what conclusion you made from your exploration, share your achievements using your exploration process, and also could tell us what you learned about today’s lesson”. And you are encouraged to use simulations to support your presentation.	The class is over, but there were students still staying at class. Several of them played with other simulations. One group was filling in the worksheet because they did not finish it at class. One group asked teacher Zhang for the presentation matter.

The second observation of Zhang’s class started with the ringing of the class bell.

Teaching Date: 23/05/2013		Class Number: Class 3	Teacher’s name: Mr. Zhang	Lesson topic: Newton’s second law
Time (60mins)	Teaching steps	Instructional activities		Notes
3mins	Engagement	Zhang said “We have tested our hypothesis using simulation software yesterday. Let’s have a quick review what we learned at the last lesson.” And Zhang summarized the important points when doing the lesson report. Zhang said, “Feel free to make the presentation in your own style or using the worksheet. But what you should report is required using simulation and including four main parts 1) What is your question you are going to explore? 2) Why do you want to investigate the question? 3) What is your answer to the question? 4) How do you get the answer? Then Zhang said, “Now it’s the presentation time. Which group wants to be the first one?”		Students seemed not confident to do the presentation. So the class kept quiet after teacher’s invitation. Mr. Zhang named one group to start.

7mins	Step 4: Elucidation & linking	The first group made their presentation according to their worksheet.	Mr. Zhang complemented Group 1's report detailing conducting the simulations.
15mins		After the first group presentation, Zhang asked them several questions. Their conversation was presented following this table.	
8mins		For Group 2, Zhang did not interrupt their presentation. He also asked them several questions after they finished their report. The questions and conversation were presented in the following part below.	During their conversation, class discussions also happened.
5mins		During Group 3's presentation, Zhang paraphrased students' presentation using more appropriate vocabulary so as to reinforce proper use of the new terminology. After Group 3's presentation, Zhang said, "Your presentation is excellent with a clear central topic. You answered the four main questions. Our presentations need to demonstrate that we can use scientific language to describe your case and report it."	Zhang directly corrected the third student's unauthentic expression.
5mins		Group 4 gave a presentation.	Zhang looked satisfied with their presentation.
12mins		Zhang said, "Let's go back to today's question: "How can forces affect the motion of an object?" In your pairs, come up with three ways forces can affect the motion of an object." After students answered, Zhang asked "Does any group have questions confused on today's topic?" – No voice "negative".	The students were engaged in the experimental presentation and video.
5mins		Then Zhang provided daily life activates to make sure of student understanding. He presented the experiment using a real car model, a wooden board and smooth rail. He also played a video about a bowling ball accidentally falling out of the cargo bay of an aeroplane as it flies along in a horizontal direction.	
5mins		Following that, Zhang asked students several test questions. Most students were quick to reply.	
5mins		Zhang organized students to answer the seven questions on the worksheet.	Zhang asked the students who did not present their report at class to answer these questions.
5mins	Step 5: Metacognitive evaluation & further testing	Zhang said to students, "I want you to mark your worksheet in group and then invite one other group to re-mark your worksheet. The five criteria have been listed in the worksheet." He also said, "If your conclusion is still different to ours, you can ask me or other group members for help. I am very glad to discuss with you about your results."	Most of students were actively engaged and looked happy when they left the class. There was one group left exploring their question and modifying their data.

The ILIS approach was designed for experimental groups for two teaching periods. Each teaching period has 60 minutes to finish the instruction task. The teachers were requested to fill in the lesson plan template before each lesson. There was a teacher professional development group and two researchers supporting the acting teachers. The completed lesson plan was used as a guideline during teaching. Finally, the ILIS teaching activities were finished according to the lesson plan.

### *The conventional instruction*

Students in the control group received conventional instruction. The conventional instruction used experimental demonstration teaching method that is popular in Chinese classes. Teachers demonstrate experiments or cookbook experiments in front of the classroom. Meanwhile, students are requested to observe the teacher's experiments. Before each experiment course, the students are requested to read the lectures and textbooks. After demonstrating the experiments, the teacher provided relevant lectures with explanation in order to support students' conceptual understanding. Courses were ended with summative evaluations such as exercises, seatwork and a quick quiz. The conventional instruction was relatively more direct transmission of information, more whole-class activities, and more lectures, textbooks and seatwork. This way is prominent in physics classrooms because of easy-organization and time-saving (Li, 2010; Y. Lin et al., 2008; Wang, 2010).

There was a lesson plan for each conventional instruction course. It stated instructional objectives, levels of knowledge difficulty, and instructional design. There were examples of lesson plans in teacher's instructional books. However, all teachers were allowed to design their own individual plan based on their understanding of the teaching method, and the learning situation of their students.

Based on the lesson plan used in conventional instruction, Table 3-5 recorded instructional process and instructional activities in Mr Zhang's classroom. It depicted the details of how the participating teacher implemented conventional instruction for the Newton's first law topic in the control group. The class began with Mr. Zhang's greeting "class begins", all students stood up and said "Teacher, good afternoon".

**Table 3-5 A implementation of the conventional instruction observed by the researcher**

Time	Steps	Instructional activities
Teaching Date: 25/04/2013 Teacher's name: Mrs. Han Class Number: Class 5 Lesson topic: Newton's first law		
15mins	Introduction	Teacher presented two pictures on the multi-media screen. According to the two pictures, Mrs. Han asked 1) Why does the driver wear his seat belt? 2) Why did the man dare to drive the car cross the Yellow River?
30mins	Elucidation	Elucidation of the topic through lecture and discussion Mrs. Han introduced Aristotle, Galileo, Descartes, and Newton. These scientists were related to today's topic and the proposed questions. Then the teacher led students to review the scientists' viewpoints that were presented in their textbook, and spend several minutes discussing the relevant viewpoint. Mrs Han provided the students with ongoing learning from one scientist's viewpoint to another by using an animation and texts that demonstrated why and how the different viewpoints challenge, enrich and confirm others. The animation was about Galileo's ramp experiment in the ideal condition. At the phase, students could understand what the Newton's first law is and how it comes. Thus, Mrs. Han presented the scientific expression of the law on screen: an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force. She introduced inertia as the name of this kind of force. Then Mrs. Han further proposed the questions: 1) what factors could impact an object's inertia property; 2) Does the water or gas have inertia? She organized the students to discuss in groups.
Teaching Date: 09/05/2013 Teacher's name: Mrs. Han Class Number: Class 5 Lesson topic: Newton's first law		
20mins	Application	The application of the topic via assessment and discussion. Mrs. Han played two videos and organized students to discuss these two videos in pairs. The videos included the sand and the shovel, the ball on a moving car, why people have to fasten a seat belt. Then, Mrs. Han re-showed the Newton's first law on the screen, and finished with a few 'yes-or-no' question tests and a multiple-choice question test.
15mins	Review	At end, Mrs. Han guided the students to review what they had learned during the two lessons. Then introduced the significance of Newton's first law and the importance of the scientific inquiry process of the law.
10mins	Exercise	Mrs. Han asked the students to finish the questions in their exercise books. Before the bell rang, Mrs. Han wrote after-school assignments on the blackboard.

The conventional classroom was designed with a demonstration table and a multi-media computer in the front of the classroom. Behind them were a raised platform and a fixed blackboard and a multi-media screen. Individual student desks were fixed in six rows in the centre of the classroom. There were seven narrow aisle ways. Class periods in this school met for 45 minutes five days per week. Thus, class periods in the current study had 45 minutes one day per week.

### **3.4.5 Instruments**

There were four instruments in the study: a force concept achievement test with three tiers, an inquiry-process-skills survey, students' work sheets, and classroom observation checklists.

#### ***Force concept achievement test***

The Force concept achievement test was adopted from Hestenes, Wells and Swackhamer's (1992) Force Concept Inventory (FCI). It was used as an indicator of students' conceptual understanding in physics. The FCI includes 30 multiple-choice questions, with one answer representing the Newtonian canonical scientific answer, and the remainder representing common student alternative conceptions. It is considered as a common test instrument for assessing students' conceptual understanding of force and motion, with high reliability and validity in the world.

Specifically, the FCI (Halloun et al., 1995; Hestenes et al., 1992) had its origins in investigating students' alternative conceptions at the dawning of physics education research. "The Initial Knowledge State of College Physics Students" (Halloun et al., 1995) has been attempting to identify, quantify, and assess student alternative conceptions in Newtonian mechanics. It also served to inform instructional approaches in light of the chronically abysmal performance of students in introductory-level physics courses. These investigations included countless hours of one-on-one and focus group conversations with physics students at all levels—high school to graduate school—from which were constructed carefully crafted conceptually-oriented multiple-choice questions to probe students' understanding. The key feature of these questions was the incorporation of powerful "common sense" distracters extracted from the painstaking research described above. The questions went through many iterations of piloting, refinement and retesting, eventually evolving into the FCI. The FCI itself was initially administered to over 1500 students in high school physics classes, including those of Malcolm Wells in Arizona and Greg Swackhamer in Illinois, and Harvard University. Student scores on the FCI also were positively correlated with student performance on tests of quantitative ability. The FCI has been administered to over 200,000 students in many countries and in at least 12 languages. It has been the subject of much scrutiny in the physics education community (Henderson, 2002) and there were some minor revisions in 1995, but it remains the gold standard for assessing student learning gains in elementary Newtonian mechanics.



In the current study, the FCI was modified from one-tier multiple choice to a three-tier one. The new FCI was named the modified force concept inventory (MFCI), which is included as Appendix L. First, the researcher and one senior physics teacher carefully read the original FCI test and checked whether any of the questions could be difficult for students. They then decided to use eighteen questions in regards to Newton's first, second and third laws. The researcher selected eighteen questions from the thirty in the FCI test, based on the analysis results of the pilot study. The discarded items were because their item difficulty is less than 0.1 or greater than 0.9, and discriminating power is less than 0.2. After that, the eighteen questions were included in the main study with 142 senior secondary students.

Second, the second tier was added into the eighteen multiple questions. It requested an explanation of why the particular option was chosen. The explanation tier can help the students check whether the chosen answer was the one they intended to choose. And the explanation tier reflected students' deeper understanding of physics concepts.

Accordingly, there were seven levels for each MFCI question (see Table 3-6). The student conceptual learning was scored on a 7-point scale ranging from 0 (F-N answer) to 6 (T-T answer) for their overall quality. For example, students whose two tiers of a question are correctly answered were given six points. The possible score of each question could range from 0 to 6. Possible test scores of the MFCI could range from 0 to 180. The higher scores showed greater conceptual understanding of force and motion.

**Table 3-6 Scoring rules for MFCI test**

	Tier		Score
First tier	-	Second tier	
True response	-	True response (T-T)	6
True response	-	False response (T-F)	5
True response	-	No response (T-N)	4
False response	-	True response (F-T)	3
False response	-	False response (F-F)	2
False response	-	No response (F-N)	1
No response			0

In addition, the third tier was a 5-point Likert scale. It measured the students' confidence in the answer they selected. The response scale ranged from (a) quite sure, (b) sure, (c) no opinion, (d) uncertain, to (e) quite uncertain. Each response was given a score from 0 to 4. The higher score, the more confident students were about the answer. In a word, each question can measure two aspects – conceptual understanding and confidence in learning in the MFCI test. An example of the question was shown below:

A ball is fired by cannon from the top of a cliff as shown as Figure 3-2 below. Which of the paths would the cannonball most closely follow?

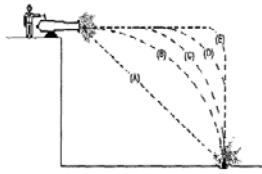


Figure 3-2 The question of conceptual understanding test

☺: Please write down the reasons why you chose this answer in your own words.

☺: Are you sure about your answer selected?

A. Quite sure; B. Sure; C. No opinion; D. Uncertain; E. Quite uncertain

To ensure the consistency and accuracy of the MFCI test and confidence-in-learning survey (Conf), this study explored its validity and reliability. The content of MFCI test was checked by a physics professor and two high school physics senior teachers. It was administered to 38 senior students in the pilot study. Internal reliability was calculated by using Cronbach's alpha coefficient (Ho, 2006). The MFCI test values obtained were .81 for the pre-test and .83 for the post-test. The Conf survey values obtained were .94 for the pre-survey and .94 for the pre-survey.

### ***Inquiry process skills survey***

To measure students' inquiry process skills, the researcher developed a survey based on White and Frederiksen's study (1998). The inquiry-process-skills survey (InqS) aimed to measure student's inquiry process skills (see Appendix I). There were four inquiry process skills including hypothesis skill, practice skill, communication skill, and evaluation skill. The contents of the InqS survey were checked by one physicist, three physics teachers from senior secondary schools and all participating physics teachers. And it was administrated to 38 senior students in the pilot study. After that, it was conducted in the main study with 142 senior students. Internal reliability was calculated by using Cronbach's alpha coefficient (Ho, 2006). The values obtained were .87 for the pre-survey and .91 for the post-survey.

The items of the InqS were measured through a 5-point Likert scale. The five response options ranged from (a) strongly agree, (b) agree, (c) no opinion, (d) disagree, to (e) strongly disagree. Each response was given a score from 0 to 4. The score of 4 reflected highly positive perceptions toward inquiry process skills. An example of survey items was presented below:

I understand the physical problems that I am exploring, but there are still some people who do not understand what I said or wrote.

5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

In the current study, scoring was done by the participating teachers after pre- and post-tests. In order to avoid the possibility of bias, teachers did not know the name and classes of the students. In

addition, the researchers reviewed all scores after teachers finished scoring. Any score disagreement was discussed again in order to guarantee the reliability of the scores. Students who had not completed the pre- and post-MFCI tests and the inquiry skills survey were removed from the current study. Non-completion of the tests and surveys included excessive absences, same answers to most of the questions, and missed the whole paper.

In summary, the validity evidence and reliability estimates for these instruments implied that scores obtained on the MFCI test, the confidence-in-learning survey and inquiry-process-skills survey were reliable and valid indicators for measuring conceptual understanding, confidence in learning and inquiry process skills.

### ***Classroom observation instruments***

There were two different classroom observation instruments in the current study. The first classroom observation instrument was a classroom observation checklist. It was adapted from the “lesson observation rubric”. It was used to measure teachers’ instructional practices. There were thirteen aspects that were measured such as instructional objectives, instructional contents, instructional assessment, instructional materials and technologies, teacher instructions, student engagement, and others (see Appendix L). The second classroom observation instruments were classroom observation form 1 used in the experimental group and classroom observation form 2 used in the control group. They recorded classroom activities for treatment verification (see Appendix M).

### ***Students’ worksheets***

Four students’ worksheets (see Appendix K) were developed for experimental group students. The students’ worksheets aimed to support students’ inquiry-based procedure when they engaged in ILIS approach learning. The topic of these four worksheets included buoyancy, Newton’s first law, Newton’s second law and Newton’s third law. The structure of the students’ worksheets was similar, based on the five steps of the ILIS approach. However, the content of worksheets was different regarding the four lesson topics. The students’ worksheets provided inquiry activities and some discussion questions, but did not involve any interpretation or explanation about these questions. And, in order to ensure students’ were prepared, the first page of the worksheet was handed out to the students before the lesson started. The first page noted information regarding the learning topic and experimental questions. All of the students’ worksheets were checked and evaluated by the two researchers after the experimental interventions were completely implemented.

### **3.4.6 Analysing**

The instruments discussed above measured students outcomes in learning. The responses to the MFCI test, Conf survey and Inq survey provided by the participants were transferred into SPSS,

which produced a raw data set. The raw data were checked by the researcher and her colleague in case there was any entry error. The data set was finally formed with the row regarding all variables about each participant and the lines regarding each variable across all participants. Finally, analysis of variance (ANOVA), analysis of covariance (ANCOVA), multivariate analysis of variance (MANOVA) and multiple linear regression were conducted to analyze the data in the main study. However, the small sample size limited the investigation of the pilot study. The current pilot study preliminarily explored the relationship among conceptual understanding, confidence in learning and inquiry process skills when using the ILIS approach and conventional instruction. The relationships among the three variables were investigated using Pearson correlation coefficient instead of multiple linear regression. Table 3-7 presented data analysis according to research questions and data sources.

**Table 3-7 Data analysis summary**

Research question 1:			
Sub-research questions	Operational research questions	Data sources	Data analysis
RQ1 <sub>1</sub> . What effects do make on participants conceptual learning during ILIS approach and conventional instruction?	Which instructional approaches provided better conceptual learning, during ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test	Repeated-measures analysis of variance (ANOVA)
	And what gender effects do make on participants conceptual learning during ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test	2 by 2 between-groups analysis of covariance (ANCOVA)
RQ1 <sub>2</sub> . What is the relationship between conceptual learning and confidence during ILIS approach and conventional instruction?	Which instructional approaches provided better confidence, during ILIS approach and conventional instruction?	Scores on Conf pre-test and post-test; Score on Conf pre-test	Repeated-measures analysis of variance (ANOVA)
	And does confidence influence participants' conceptual learning during ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test; Score on inquiry process skills pre-test and post-test	Multiple linear regression
RQ1 <sub>3</sub> . What is the relationship between conceptual learning and inquiry process skills during ILIS approach and conventional instruction?	Which instructional approaches provided better inquiry process skills, during ILIS approach and conventional instruction?	Scores on Inq pre-test and post-test; Score on Inq pre-test and post-test	Repeated-measures multivariate analysis of variance (MANOVA) with follow-up ANOVA
	And do the inquiry process skills influence participants' conceptual learning during ILIS approach and conventional instruction?		Multiple linear regression

### **3.5 Qualitative phase**

The initial quantitative phase provided general explanations and relations of the research topic. However, it cannot provide in-depth and holistic meanings of the research questions. In order to make up for the weakness of the quantitative research, the subsequent qualitative phase was employed to complement the initial quantitative phase in this study. The qualitative phase sought to explore the research topic in the perspective of individual's experiences (Creswell, 2012b).

The qualitative phase of this study adopted an interview approach to explore what learning experiences meant to the participants. Interview protocols were designed and used to interview six selected students and two participating teachers. They were engaged in a face-face-interview which took around 60 minutes. In this section, the qualitative phase is discussed in detail with focus questions, sampling, instruments, data analysis and data report, as well as with 'reliability' and 'validity' of the data in the qualitative phase.

#### **3.5.1 Sampling**

There is no definitive number of participants in a qualitative study (Mertens, 2005). In social and educational research, quantitative research supports that the larger the samples involved, the broader understanding the study could define. The proponents of qualitative study argue that the small sample of participants can also provide a detail account of their experience about the phenomenon (Ryan et al., 2009), which can answer the research questions with the core elements. In the qualitative research study, thus, it is not the question of how many participants are involved, rather how to sample the participants.

The current study adopted extreme sampling. Extreme sampling is often used in the qualitative phase of social and educational studies. The selected participants in extreme sampling are the extreme cases that are defined as unusual or special candidatures. These extreme cases can provide more insight than average cases in a study (Danermark, 2002; Patton, 1990). In the qualitative phase from this current study, the extreme cases were a number of outliers that were identified through statistical analysis in the quantitative phase. The perceptions and viewpoints through interviewing these outliers could confirm, enrich or challenge the findings in the quantitative phase.

Further, the selection of the interviewees was also based on the maximum-variation sampling principle (Patton, 1990). It was valuable to provide an insight understanding of the phenomenon from the special cases across different academic levels. Thus, the interviewees were selected from high, middle, and low three levels that were evaluated through statistical analysis in the initial

quantitative phase. This study eventually invited six students and two acting teachers to participate in the qualitative phase.

### **3.5.2 Instruments**

Data sources in the qualitative phase come from one-to-one interviews that involve asking questions and recording answers from one participant at a time (Creswell, 2008). The use of interview can “yield in-depth responses about people’s experiences, perceptions, opinions, feelings, and knowledge” (Patton et al., 2002), when the participants feel safe and comfortable to share their ideas (Creswell, 2008).

This study adopted semi-structured one-to-one interviewing. According to Tod (2006), semi-structured interviewing was defined as an interview protocol with prepared open-ended questions or probes. It not only provided a planned protocol with themes and a sequence for further probes, but also offered a flexible space to allow the interviewers to explore unexpected issues which emerged from their conversations. The semi-structured interviewing was described as a valuable way that can produce richer information from the discourse perspective than the use of formally structured interviewing.

Specifically, there were four themes with potential questions interviewed during the qualitative phase from this current study. The potential questions were regarded as leading questions that provided an answer (Patton, 1990). Leading questions could represent the information expected by the researcher rather than reflecting the participants’ thoughts. In order to take full advantages of the leading questions, this study further focused on whether the leading questions lead the participants into important direction that elicited interviewees new and valuable opinions (Kvale, 1996).

Further, the reliability and validity of the interview was considered in this study. According to Patton’s (1990) suggestions, research questions should consider the participants’ background, opinions, perceptions, perspectives, values, knowledge, and experience. And, the interview protocol had mixed questioning types instead of only ‘yes or no’ questions or multiple-choice questions. The answer of ‘yes or no’ questions was too short to provide sufficient details for further explanation. The multiple questions had the potential to attract the interviewees’ attention to multiple answers that this study could not focus on. The interview protocols used in this current study was shown in Appendix N and Appendix O.

Still, to ensure the interview questions were reasonable, all questions were included in the pilot study. The pilot study provided opportunities to reshape the questions. It was not only a good rehearsal to practice the original interview questions, but also to improve the interviewer’s

interviewing skills. Actually, there was no major modification between the original interview questions used in the pilot study and those used in the main study.

In addition, with the permission of the participants, audio-recordings were made of all interviews. Two voice recorders were used to capture all interviews. It was a good strategy to guarantee the quality of interviews (Cavana et al., 2001). And the field-notes were used when the interviewer needed to note key points and relevant reminders. Specifically, before the interview, appropriate interview places and times were found based on the participant's convenience. The researcher made an appointment with the participating interviewees, and then conducted the interviews in a booked staff meeting room at participating schools. At the very beginning of each interview, each participant was asked to confirm they or their parents had signed the interview consent (see Appendix F). The statements about this study including the aims and procedure, the time of this interview, the participant's pseudonym, the use of voice recorders were introduced to the interviewee. After the participating interviewees answered all questions, the interviewer gave participating interviewees a short block of quiet time to consider whether they would like to share more, or might have new insights through the conversations. Finally, the interviewer expressed gratitude and asked the interviewee to leave their contact details for future reference.

All interviews were conducted in Chinese with the assistance of audio-recorders and field-notes. Then the raw data were transcribed into Chinese words and a preliminary analysis was administered in Chinese, finally the data report was produced in English. More information about data analysis is presented in the next section.

### **3.5.3 Data analysis**

Qualitative data from the study was analysed by using themes (Kvale, 1996). The conceptual framework developed in this study was used to investigate three themes and conceptualise their relationships. Therefore, the qualitative phase further elaborated the conceptual framework through an overarching theme that explores how the students and teachers understood the conceptual understanding through performance made by the ILIS approach. Attuned to this theme, the qualitative phase explored the following research questions: 1) In what ways did the ILIS approach affect student conceptual understanding? 2) How students' confidence in learning influenced their conceptual understanding? 3) How students' inquiry process skills influenced their conceptual understanding? These questions aligned with the manner of data collection. In this study, the semi-structured interview was used to obtain the initial knowledge, perceptions, and viewpoints held by the participants. The information built up a base from which to provide a comprehensive and in-depth analysis to address the research questions from the participants' learning experience and perspective.

Despite in the context of the research questions above, the qualitative approach to data analysis was conducted through the following two steps.

The first step decided the use of intra-case analysis in analysing interviews (Patton et al., 2002). The intra-case analysis was administered across each interviewee who was regarded as a specific data collection session. The intra-case analysis required careful reading of all data and obtaining a general understanding of the data (Bogdan et al., 1998). Therefore, the researchers read all data chronologically. The interviews were digitally recorded in a computer in order to be transcribed verbatim. The researcher used a voice control program that allowed the voice speed to be reduced. And then, data were read again, and coded by segmenting and labelling the text. To ensure the reliability of transcriptions, the researcher listened to the interview audio recording several times. A Chinese colleague with a strong science education background was invited to achieve transcription reliability.

The second step required codes to develop themes by aggregating related codes together. Meanwhile, the research questions would be further explored by connecting and interrelating themes. Codes for the second interview and the other six interviews were conducted similarly. After eight participants' interviews were coded separately, cross-thematic analysis was used to explore the similarities and differences amongst the interviewees' insights. The Chinese colleagues also reviewed the process of coding in the current study.

It is worth noting that how the students and teachers understood the conceptual understanding in relation to (potential) performance made by the ILIS approach because the research questions in the initial quantitative phase figure out the relationship among conceptual understanding and other two impactors.

#### **3.5.4 Data report**

The data report was followed with data analysis for the presentation of the qualitative results. Kvale (1996) suggested that a qualitative study report focus on the trustworthiness of the results. The combination of quotations and interpretations was the strongest method to improve the credibility in reporting qualitative data. Therefore, this study reported the qualitative data from the interviewees' perspective by utilising the interview's quotations and interpretations. This way can construct interviewees' viewpoints, perceptions and values, but also enhance the trustworthiness.

Specifically, this current study adopted Kvale's (1996) quotation reporting strategies. Quotations were described in the context of each interviewee. And the quotations were interpreted under the specific statements of perspectives and viewpoints. Furthermore, this study emphasized interviewees' non-verbal actions like repetitions, facial expressions, pauses, and verbal transcripts



in the data report. This study also aimed noted to balance the percentage of quotations and interpretations. There were not as many quotations as interpretations, accounting for less than 50% of the text. Additionally, this study employed a theoretical frame to display how the researcher interprets those quotations for serving the study's focus questions.

### **3.6 Ethical considerations**

A key ethical consideration in social science research is potential distress or harm to participants (Liamputtong, 2009). This research conducted educational experiments with the Grade-10 students and their teachers in Beijing, Mainland China. To avoid inappropriate research behaviours, ethical clearance for this study was obtained at the forefront of the implementation in accordance with the National Statement on Ethical Conduct in Human Research and the ethics guidelines of the University of Queensland Human Ethics Committee. This current study has received approval (number 12-041A) from the University of Queensland Human Ethics Committee.

In order to pose an extremely low risk to all participants, the current study did not involve sensitive or intrusive actions. And all personal information of participants was protected and all documents were kept private. The researchers knew the identities of participants in the tests and interviews. However, student names were removed and replaced with a number (ID code) once the data collection was complete (i.e., pre- and post-test/survey scores of all participants were matched and stored in a data base). An ID code was used during the whole process and pseudonyms were used in the reports unless the participants requested disclosure of their genuine identity. Participants' identities were only known and available to the researchers. They were not disclosed. Identification was removed from the data. ID code and pseudonyms were stored separately from the data. Confidentiality and anonymity were guaranteed to schools and individuals.

Furthermore, participating schools, teachers, and students participated voluntarily and were well informed about the study. Schools and teachers were introduced to detailed information about the study and students with the general information about this study. All of them were invited to sign the relevant consent forms. And all of them were allowed to share their real thoughts.

In addition, during the process of fieldwork, all participants had the right to withdraw from the study before returning the tests or reporting the findings. Data collected from participants who withdraw were destroyed.

In short, the highest standard of ethical concern was considered in the current study.

### **3.7 Summary**

This chapter presented the path for the current study. The two main research questions required the use of a mixed-method design. And the selection of an explanatory mixed-method design was based on methodological considerations. In this current study, the combination of an initial quantitative phase and the subsequent qualitative phased established the basis for a holistic understanding of the research problem.

Section 3.4 firstly introduced a quasi-experiment research design that was used in the quantitative phase. And then sampling, materials, instruments, and data analysis were gradually discussed. The subsequent qualitative phase was introduced in section 3.5. Accordingly, the focus questions, sampling, instruments, data analysis and data report were described in this section. Section 3.6 addressed the ethical considerations.

Guided by the methodology chapter, the detailed quantitative and qualitative data analysis and findings from the pilot study and the main study will be presented in the following Chapters Four and Five.

## Chapter 4 Pilot Study

The pilot study was conducted in a school setting where the findings of laboratory-based research cannot be applied into authentic classrooms directly. The pilot study aimed to test the instructional intervention, instruments, and materials to identify any potential implementation problems. The implications from the pilot study were used to adjust and redesign the teaching and learning environment in the main study.

This chapter reports the data collection, data analysis and findings from the pilot study with respect to the two research questions shown below:

RQ1. What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning?

RQ2. How do students and teachers understand conceptual change in relation to their performance through the ILIS approach?

Section 4.1 introduces participants, material, instruments, and the procedure of the pilot study. Section 4.2 presents the quantitative data analysis and discusses quantitative findings. Section 4.3 presents the qualitative data analysis and interprets qualitative findings. Section 4.4 highlights the key findings from the quantitative phase and qualitative phase, and concludes with a brief summary. Moreover, it reports the limitations of the pilot study. The potential modification to the main study will be presented in the last section, 4.5.

### 4.1 Participants, materials, instruments, and procedure

One teacher, her thirty-eight grade 10 students from one public school, and the researcher participated in the pilot study (As shown in the Table 4-1). Twenty two students (12 males and 10 females) were engaged in the ILIS approach group and sixteen students (eight males and eight females) were engaged in the conventional instruction group. The educational trial started when the students had been enrolled in senior secondary school for three months. Both the students using conventional instruction and the students using ILIS approach had four weeks' learning materials. They had one class per week to explore Newton's first law. Data were collected after the four weeks' intervention.

**Table 4-1 Participants information about the classes and teachers from the pilot study**

Group	Teacher	Gender		Number
		Male	Female	
Experimental group	The researcher and Mrs Wang	12	10	22
Control group	Teacher Wang	8	8	16

Regarding materials, all participating students were introduced to the same instructional materials—Newton’s first law. However, the experimental group used the ILIS approach while the control group received conventional instruction. The ILIS approach is an inquiry-based learning approach that was designed by the researcher and other educators. Students engaging with this approach were engaged in a five-step inquiry-based learning with interactive simulations to construct new knowledge. The control group students were involved in the conventional instruction that is usually used in China’s physics classrooms. Both of these instructional approaches are discussed in the previous chapter.

Regarding instruments used in the pilot study, the quantitative phase used the MFCI test, the confidence in answer scale, and an inquiry-process skills survey to measure students’ performances. All instruments used in the quantitative phase were conducted with Cronbach’s alpha reliability testing. The alpha values above .7 ensured that the items of all instruments used in the pilot study were reliable and internally consistent (Ho, 2006). In the subsequent qualitative phase, semi-structured interview protocols were used to collect interview data. And the intra-case analysis was employed to analyse the interview data (Patton et al., 2002).

The procedure of the pilot study included three steps. The first step included students’ pre-test, four weeks’ intervention, and students’ post-tests. Those were conducted in the initial quantitative phase that addressed the first research questions. The second step was the subsequent qualitative phase where the researcher interviewed the participating teacher. This provided answers to the second research question. Lastly, the limitations that were found in the two phases were identified, and potential modifications were proposed to improve implementation of the main study.

## 4.2 Quantitative findings and discussions

The pilot study aimed to preliminarily examine the effectiveness of different instructional approaches on students’ conceptual understanding. Under the first main research questions, Table 4-2 presented four detailed research questions, data sources, and data analysis from the pilot study.

**Table 4-2 Pilot study data analysis framework**

Research question 1: What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning?		
Sub-research questions	Data sources	Data analysis
RQ1 <sub>1</sub> . Which instructional approaches provide better conceptual learning during the ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test	Repeated-measures analysis of variance (ANOVA)
And what effects does gender have on participants’ conceptual learning during the ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test	2-by-2 between-groups analysis of covariance (ANCOVA)
RQ1 <sub>2</sub> . What effects are made on participants’ confidence in learning during ILIS approach and conventional instruction?	Scores on Conf pre-test and post-test	Repeated-measures analysis of variance (ANOVA)
RQ1 <sub>3</sub> . What effects are made on participants’	Scores on Inq pre-test	Repeated-measures

inquiry process skills during the ILIS approach and conventional instruction?	and post-test	multivariate analysis of variance (MANOVA)
RQ1 <sub>4</sub> . What are the relationships among conceptual learning, confidence in learning, inquiry process skills, and treatment groups during the ILIS approach and conventional instruction?	Scores on MFCI post-test, Conf post-test, Inq post-test, and groups	Pearson correlation

### 4.2.1 Research question 1<sub>1</sub>

The research question aimed to answer whether or not there was a statistically significant difference between students' conceptual learning during the ILIS approach and the conventional instruction.

The current study expected that the conceptual learning of students using the ILIS approach would outperform those taught by conventional instruction, when measured through the MFCI test.

Although the results of the pilot study did not confirm the significantly positive effects of the ILIS approach, it is worth noting that students using the ILIS approach obtained higher scores than those with the conventional instruction. Findings are discussed below:

Hypothesis:

$H_0$  [conceptual learning]:  $\mu_I - \mu_C = 0$ . There is no statistically significant difference in the MFCI pre-test versus the MFCI post-test between students using the ILIS approach and those using the conventional instruction.

$H_0$  [gender, conceptual learning]:  $= 0$ ; no interaction gender effects exist. There is no statistically significant gender effect on the MFCI pre-test versus the MFCI post-test between students using the ILIS approach and those using the conventional instruction.

Finding 1:

Null Hypothesis 1 ( $H_0$  [conceptual learning]).

An ANOVA was used to analyse whether or not the two treatment groups had any statistically significant difference in the MFCI pre-test. The result showed there was no statistically significant difference between the two groups in the MFCI pre-test,  $F(1, 36) = .027, p = .871$ . Therefore, the two groups were comparably equal before the intervention.

Table 4-3 shows the pre-test and post-test performance of all participating students according to two treatments, as measured by their scores on conceptual learning of Newton's first law. Performance scores ranged from 0 to 42, with higher scores indicating better conceptual understanding.

**Table 4-3 MFCI test score means and standard deviation according to two treatments**

		Pre-test		Post-test	
Treatment	N	Mean	SD	Mean	SD
Experimental group	22	23.73	4.32	30.45	5.96
Control group	16	23.50	4.12	26.25	7.28

Note: N=number; SD=standard deviation.

As shown in Table 4-3, the two treatments' mean scores increased from pre-test to post-test. The greatest difference between the pre-test and post-test exists in the experimental group, with 6.72 points. It demonstrates that students using the ILIS approach obtained higher scores than those using the conventional instruction. It is noteworthy that the variability measured by standard deviation in the experimental group is less than that in the control group.

A repeated-measures ANOVA was conducted to statistically examine the treatment effects on the students' MFCI test from pre-test to post-test, with inputting treatment group as a between-subject and time as a within-subject factor. Results showed that there was a significant main-time effect, Wilk's  $\Lambda = .68$ ,  $F(1, 36) = 13.47$ ,  $p < .001$ , multivariate partial  $\eta^2 = .32$ . This indicates that students using the ILIS approach and the conventional instruction made statistically significant improvement from pre-test to post-test. However, there was no statistically significant main treatment effect,  $F(1, 36) = 2.53$ ,  $p = .12$ , partial  $\eta^2 = .07$ , nor significant Treatment x Time interaction effect, Wilk's  $\Lambda = .92$ ,  $F(1, 36) = 3.0$ ,  $p = .094$ , partial  $\eta^2 = .08$ . Therefore, null hypothesis ( $H_0$  [conceptual learning]) was retained, although students with the ILIS approach obtained higher MFCI post-test scores than those using the conventional instruction.

Regarding the effects of two instructional approaches on conceptual learning, the significant time effect on the students' conceptual understanding test indicates that both the ILIS approach and conventional instruction support students' conceptual learning. The pilot study found that the ILIS approach students did not outperform the conventional instruction students through the MFCI test. This result conflicts with the existing studies (Y. Chen et al., 2010; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Vreman-de Olde et al., 2013), which showed that students can achieve efficient knowledge gains when using inquiry-based instruction with proper supports (Jari et al., 2014). Researchers also showed that PhET simulations can provide effective scaffolds in physics learning, and can even replace the real laboratory equipment (Finkelstein et al., 2004; Sokolowski & Rackley, 2011; Vreman-de Olde et al., 2013).

#### Finding 2:

The current pilot study did not find gender effects on students' conceptual learning when using the ILIS approach or conventional instruction.

Table 4-4 shows the pre- and post-test performance of all participating students according to two treatments, as measured by their scores in conceptual learning. Performance scores ranged from 0 to 42, with higher scores indicating better conceptual understanding.

Table 4-4 shows that from pre-test to post-test the mean scores of male and female students in both groups increased. The greatest difference between pre-test and post-test lies in male students' scores in the experimental group, with 7.66 points. According to the table, both male and female students from the experimental group obtained higher scores than their peers in the control group.

**Table 4-4 MFCI test score means and standard deviation according to treatments and gender**

Treatment	Pre-test				Post-test			
	Male		Female		Male		Female	
Gender	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Experimental group	24.92	3.50	22.30	4.95	32.58	6.94	27.90	4.00
Control group	24.88	5.06	22.13	2.53	27.38	7.50	25.13	7.38

Note: SD=standard deviation.

To statistically investigate the gender effect on students' conceptual understanding during the ILIS approach and conventional instruction, a 2-by-2 between-groups analysis of covariance (ANCOVA) was used with students' outcomes (pre-test) as a covariate. The results reveal that after adjusting for scores at pre-test, there was no significant gender x groups interaction effect,  $F(1, 33) = .333, p = .568$ . There was no statistically significant main effect for groups,  $F(1, 33) = 3.48, p = .071$ . The main effect for gender,  $F(1, 33) = 1.74, p = .196$ , did not reach statistical significance.

Therefore, null hypothesis was retained. There is no statistically significant gender effect on MFCI pre-test versus MFCI post-test between students using the ILIS approach and those using the conventional instruction.

The result challenges the statement that sex-related differences are closely related to concepts in the science curriculum, favouring boys (Fogelman, 1970; Linn et al., 1983). Researchers have noted biological differences with respect to quantitative skills and spatial visualisation (Trankina, 1993), and suggested that girls are less confident than boys about their performance in male-type tasks (Kahle et al., 1994) such as physics. However, the results from the pilot study at least provide evidence that girls can do as well as boys in physics, which is typically considered to comprise 'boy tasks'.

#### 4.2.2 Research question 1<sub>2</sub>

RQ<sub>12</sub>. What is the relationship between conceptual learning and confidence in answers during the ILIS approach and conventional instruction?

This research question explored the relationship between conceptual learning and confidence in learning when using the ILIS approach and conventional instruction. The pilot study expected that the ILIS approach students could gain more confidence in learning than those who used the conventional instruction. However, the result did not find that the ILIS approach had a more positive effect on confidence than conventional instruction. Findings are discussed below:

Hypothesis:

$H_{0[\text{confidence}]}$ :  $\mu_I - \mu_C = 0$ . There is no statistically significant difference in student Conf pre-test and Conf post-test between the ILIS approach and conventional instruction.

Finding 3:

An ANOVA was used to analyse whether the two treatment groups had any statistically significant difference in the Conf survey. The result shows there was no statistically significant

difference between the two groups in the Conf pre-test,  $F(1, 36) = .024$ ,  $p = .877$  before they were engaged in the pilot study.

Table 4-5 shows the pre- and post-test performance of all participating students according to the two treatments, as measured by their scores on their confidence in learning. Performance scores ranged from 0 to 42, with higher scores indicating more confidence in learning/answers.

**Table 4-5 Confidence-in-learning survey means and standard deviation according to two treatments**

		Pre-test		Post-test	
Treatment	N	Mean	SD	Mean	SD
Experimental group	22	22.10	5.67	27.59	7.47
Control group	16	22.38	5.33	26.81	7.44

Note: N=number; SD=standard deviation.

Table 4-5 shows that the means of two treatments increased from pre-survey to post-survey. The means in both the experimental group and control group increased by around 5 points. The student mean in the experimental group post-test was 1.06 points higher than that of the conventional instruction group.

A repeated-measures ANOVA was conducted to statistically examine the treatment effects on the students' confidence-in-learning survey from pre-test to post-test. With inputting treatment group as a between-subject and time as a within-subject factor, the results showed that there was a significant main time effect, Wilk's  $\Lambda = .63$ ,  $F(1, 36) = 20.82$ ,  $p < .001$ , multivariate partial  $\eta^2 = .37$ . This indicates that students using the ILIS approach and the conventional instruction made statistically significant improvement between the pre-test and post-test. However, there was no statistically significant main treatment effect,  $F(1, 36) = .018$ ,  $p = .895$ , partial  $\eta^2 = .07$ , nor significant Treatment x Time interaction effect, Wilk's  $\Lambda = .99$ ,  $F(1, 36) = .23$ ,  $p = .629$ , partial  $\eta^2 = .007$ .

Therefore, null hypothesis ( $H_0$  [conceptual learning]) was retained, although students using the ILIS approach obtained 1.06 points higher than those using conventional instruction.

Regarding this topic in previous studies, while few studies have exclusively examined the effect of inquiry-based learning with interactive simulations on confidence, or the effect of conceptual learning on confidence in an inquiry-based learning with interactive simulations environment, many of studies nonetheless found that there was a close relationship between conceptual learning and confidence (Butler, 2011; Cordova et al., 2014; Maria, 1998; Pintrich et al., 1993; Sinatra, 2005; Sinatra et al., 2008; Windschitl, 2001). For example, Windschitl (2001) found students' assertiveness was related to conceptual change, and in turn their assertiveness affected the conceptual change as well. In this current study, there was also a statistically significant correlation revealed between conceptual learning and confidence in learning. This is discussed in the following finding.



### 4.2.3 Research question 1<sub>3</sub>

The research question 1<sub>3</sub> aimed to explore the relationship between conceptual learning and inquiry process skills during the ILIS approach and conventional instruction. This study expected that the ILIS approach would better develop students' inquiry process skills than conventional instruction would. The finding confirmed the positive effects of the ILIS approach in improving students' inquiry process skills on the Inq measures.

Hypothesis:

$H_0$  [inquiry process skills]:  $\mu_I - \mu_C = 0$ . There is no statistically significant difference between student Inq pre-survey and student Inq post-survey during the ILIS approach and conventional instruction.

Finding 5:

An ANOVA was used to analyse whether or not the two treatment groups had any statistically significant difference in the Inq survey. The result shows there was no statistically significant difference between the two groups in the Inq pre-survey,  $F(1, 36) = .211, p = .649$ .

A one-way MANOVA was performed to investigate group difference in four dimensions of the Inq pre-test. The four dimensions were hypothesis, operation, communication and evaluation. The independent variable was two treatment groups. There was no significant difference between the four dimensions in the two groups before they participated in this study, Wilk's  $\Lambda = .87, F(4, 33) = .42, p = .80$ , multivariate partial  $\eta^2 = .048$ . When the results for the four dependent variables were examined separately, analysis of variances (ANOVA) on each dimension showed that there was still no statistically significant difference, with Dimension 1 hypothesis,  $F(1, 36) = .274, p = .604$ , partial  $\eta^2 = .008$ ; Dimension 2 operation,  $F(1, 36) = .955, p = .335$ , partial  $\eta^2 = .026$ ; Dimension 3 communication  $F(1, 36) = .001, p = .973$ , partial  $\eta^2 = .000$ ; and Dimension 4 evaluation,  $F(1, 36) = .059, p = .809$ , partial  $\eta^2 = .002$ .

Table 4-6 demonstrates the pre- and post-test performance of all participating students according to the two treatments, as measured by the scores on their inquiry process skills. As discussed previously, performance scores could range from 0 to 44, with higher scores indicating better inquiry process skills.

**Table 4-6 Inquiry process skills and four dimensions score means and standard deviation according to two treatments**

Treatment	Experimental group		Control group	
	Pre-survey Mean(SD)	Post-survey Mean(SD)	Pre-survey Mean(SD)	Post-survey Mean(SD)
Inquiry process skills	36.59(4.84)	47.73(4.08)	35.88(4.60)	37.25(4.97)
Hypothesis	4.59(1.26)	7.41(.85)	4.81(1.33)	5.13(1.26)
Practice	9.14(2.10)	11.50(2.09)	8.44(2.28)	8.94(2.29)
Communication	8.09(2.33)	11.05(2.09)	8.06(2.74)	8.25(2.89)
Evaluation	14.77(2.74)	17.77(2.29)	14.56(2.45)	14.94(2.08)

As shown in Table 4-6, the two treatments facilitated an increase in the mean score of inquiry process skills from pre-test to post-test, and the four dimensions as well. Students in the experimental group obtained much higher scores than those in the conventional instruction group across inquiry process skills and its four dimensions. The means in the control group did not change.

To statistically examine the difference between the two groups, a repeated-measures ANOVA was conducted on the inquiry process skills from pre-test to post-test. With inputting treatment group as a between-subject and time as a within-subject factor, the results showed that there was a significant main time effect, Wilk's  $\Lambda = .39$ ,  $F(1, 36) = 56.72$ ,  $p < .001$ , multivariate partial  $\eta^2 = .61$ . There was also a statistically significant main treatment effect,  $F(1, 36) = 19.52$ ,  $p < .001$ , partial  $\eta^2 = .35$ , and a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .51$ ,  $F(1, 36) = .34.53$ ,  $p < .001$ , partial  $\eta^2 = .49$ . These statistics revealed that the ILIS approach significantly enhanced students' inquiry process skills, when compared with the effects of conventional instruction.

Furthermore, a repeated-measure MANOVA was conducted to test treatment effect on four dimensions of inquiry process skills between pre-test and post-test. Inputting the treatment group as a between-subject and time as a within-subject factor, the results showed there was a significant time effect on the four dimensions, Wilk's  $\Lambda = .11$ ,  $F(1, 33) = 64.59$ ,  $p < .001$ , multivariate partial  $\eta^2 = .887$ , and a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .18$ ,  $F(1, 33) = .37.92$ ,  $p < .001$ , partial  $\eta^2 = .821$ . The follow-up univariate tests indicate that three of the four dimensions reach a statistically significant difference between the experimental group and the control group, with Dimension 1 hypothesis,  $F(1, 36) = 8.30$ ,  $p = .007 < .01$ , partial  $\eta^2 = .187$ ; Dimension 2 operation,  $F(1, 36) = 7.90$ ,  $p = .008 < .01$ , partial  $\eta^2 = .180$ ; and Dimension 3 communication,  $F(1, 36) = 5.38$ ,  $p = .026 < .05$ , partial  $\eta^2 = .130$ . Regarding Dimension 4 evaluation, the follow-up univariate test showed a marginally significant treatment group effect,  $F(1, 36) = 3.86$ ,  $p = .057$ , partial  $\eta^2 = .963$ . But it is noteworthy that the treatment effect favoured the ILIS group: the mean (17.77) of Dimension 3 in the ILIS approach group was better than the mean (14.94) of those in the conventional instruction group.

Specifically, a repeated-measures ANOVA was conducted on dimension 1 hypothesis. It was found there was a significant main time effect, Wilk's  $\Lambda = .23$ ,  $F(1, 36) = 122.37$ ,  $p < .001$ , multivariate partial  $\eta^2 = .77$ . There was also a statistically significant main treatment effect,  $F(1, 36) = .8.30$ ,  $p = .007 < .001$ , partial  $\eta^2 = .187$ , and a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .32$ ,  $F(1, 36) = .78.39$ ,  $p < .001$ , partial  $\eta^2 = .69$ . These statistics indicate that the ILIS students' hypothesis skills significantly outperformed those of the students using conventional instruction.

A repeated-measure ANOVA was conducted on dimension 2 operation. It was found there was a significant main time effect, Wilk's  $\Lambda = .75$ ,  $F(1, 36) = 11.73$ ,  $p = .002 < .01$ , multivariate partial  $\eta^2 = .25$ . And, there was also a statistically significant main treatment effect,  $F(1, 36) = 7.90$ ,  $p = .008 < .01$ , partial  $\eta^2 = .18$ , also and a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .88$ ,  $F(1, 36) = 4.97$ ,  $p = .032 < .05$ , partial  $\eta^2 = .12$ . These statistical numbers revealed that the ILIS approach students' operation skills were significantly better than those of the students using the conventional instruction.

A repeated-measure ANOVA was conducted on dimension 3 communication. It was found there was a significant main time effect, Wilk's  $\Lambda = .81$ ,  $F(1, 36) = 8.41$ ,  $p = .006 < .01$ , multivariate partial  $\eta^2 = .19$ . There was also a statistically significant main treatment effect,  $F(1, 36) = 5.38$ ,  $p = .026 < .05$ , partial  $\eta^2 = .13$ , and a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .85$ ,  $F(1, 36) = 46.52$ ,  $p = .015 < .05$ , partial  $\eta^2 = .15$ . These numbers indicate that the ILIS approach students' communication skills were statistically significantly better than those of the students using conventional instruction.

Finally, a repeated-measure ANOVA was conducted on dimension 4 evaluation. It was found there was a significant main time effect, Wilk's  $\Lambda = .29$ ,  $F(1, 36) = 86.82$ ,  $p < .001$ , multivariate partial  $\eta^2 = .71$ . There was also a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .41$ ,  $F(1, 36) = 52.52$ ,  $p < .001$ , partial  $\eta^2 = .59$ . However, there was a marginally significant main treatment effect,  $F(1, 36) = 3.86$ ,  $p = .057$ , partial  $\eta^2 = .097$ . These numbers show that the ILIS approach students' evaluation skills were better developed than those of the students using conventional instruction.

Therefore, null hypothesis ( $H_0$  [inquiry process skills]) was rejected. With regard to the effects of the two instructional approaches on conceptual learning, the significant time and treatment effect on the students' conceptual learning indicated that the use of the ILIS approach was more capable of improving students' inquiry process skills than the use of conventional instruction.

#### **4.2.4 Research question 1<sub>4</sub>**

Multiple linear regression analysis should have been conducted to evaluate how accurately the confidence-in-learning factor predicts the student conceptual-learning factor. However, the small sample size limited the investigation of the pilot study. Thus, the current pilot study preliminarily explored the relationship among conceptual understanding, confidence in learning and inquiry process skills when using the ILIS approach and conventional instruction. The relationships among the three variables were investigated using Pearson correlation coefficient. The assumptions of normality, linearity and homoscedasticity were met.

As Table 4-7 shows, there was a strong, positive correlation between variable conceptual understanding and confidence in learning before the participating students were involved in the study. This indicated that students with a high level of conceptual understanding also had a higher level of confidence in learning. There was no statistically significant relationship between conceptual understanding and inquiry process skills.

However, the relationship among the three variables changed according to the post-test, measured by the same instruments as the pre-test. As shown in Table 4-8, in the experimental group there was a significant positive correlation between conceptual understanding and confidence in learning,  $r = .51, p < .05$ , suggesting a high level of conceptual understanding paired with a higher level of confidence in learning. And there was also a statistically significant positive correlation between conceptual understanding and inquiry process skills,  $r = .50, p < .05$ , revealing that a high level of conceptual understanding was paired with a higher level of inquiry process skills. However, the correlation between conceptual understanding and inquiry process skills was not significant, and even negative. The correlation between conceptual understanding and confidence in learning was still significantly positive, with  $r = .62, p < .05$ .

**Table 4-7 Pearson correlations between variables in the pre-test from the pilot study**

Variables	1	2	3
1 Conceptual understanding	1.00	.51**	.13
2 Confidence in learning		1.00	.42
3 Inquiry process skills			1.00

Note:\*  $p < .05$ ; \*\*  $p < .01$

**Table 4-8 Pearson correlations between variables in the post-test from the pilot study**

Group	Variables	1	2	3
Experimental group	1 Conceptual understanding	1.00	.51*	.50*
	2 Confidence in learning		1.00	.47*
	3 Inquiry process skills			1.00
Control group	1 Conceptual understanding	1	.62*	-.26
	2 Confidence in learning		1	-.11
	3 Inquiry process skills			1

Note:\*  $p < .05$ ; \*\*  $p < .01$

While few existing studies have investigated the relationship among conceptual learning, confidence in learning and inquiry process skills in a simulation-based inquiry learning environment, Schwarz et al (2005) found that students' outcomes came from both the understanding of science content and inquiry process skills. And the integration of simulations and inquiry learning showed the effectiveness on conceptual changes (Buckley, 2006; Gerber et al., 2001; Jacobson, 2004; Von Secker, 2002; Von Secker et al., 1999). Although the pilot study did not provide relevant evidence to support relevant previous studies, it at least found that there was a relationship among conceptual understanding, confidence in learning and inquiry process skills within the inquiry-based learning with interactive simulation environment.

### **4.2.5 Summary**

Section 4.2 presents a detailed report of the statistical analysis of the pilot study. Quantitative data were analysed through SPSS version 21 to perform ANOVA, ANCOVA, MANOVA, and correlation analysis.

The use of the ILIS approach to enhance students' conceptual learning and confidence in understanding was not supported in the pilot study. Accordingly, null hypotheses were retained as the results were not significant at the  $p < .05$  level. However, the use of the ILIS approach to improve students' inquiry process skills was confirmed in the pilot study, and null hypothesis was rejected as the result was significant at the  $p < .01$  level. Furthermore, the pilot study also found that there was a relationship between conceptual understanding, confidence in learning and inquiry process skills within the inquiry-based learning with interactive simulation environment.

## **4.3 Qualitative findings and discussion**

The findings from the qualitative phase were organised according to research questions. The participating teacher (Mrs Wang) was interviewed in the pilot study.

### **4.3.1 Who was the interview participant?**

Mrs Wang received her Bachelor of Science in physics at a public university in China. She had been teaching physics for 8 years, since her graduation in 2005. Since Mrs Wang became a physics teacher, she has received many teaching skill awards and has won funding for physics research.

When the researcher conducted the pilot study, Mrs Wang was teaching grade 10 students. She expressed great interest in the study and applied to participate in the pilot study. Mrs Wang said, "Inquiry-based teaching method is not a new term for me. But I am interested in teaching students through inquiry-based instruction with technology." She had already actively explored the inquiry-based instructional approach. Mrs Wang had joined a community that supports physics teachers in Beijing to practice inquiry-based teaching and learning. She was therefore invited to participate in the pilot study as a teaching assistant.

In the pilot study, both teacher training and classroom observation were held informally. The researcher introduced the ILIS approach to Mrs Wang, and discussed how the ILIS approach would be supported while the researcher was conducting it. Mrs Wang took responsibility in supporting the implementation of the ILIS activities. She was also requested to observe whether the ILIS activities were suitable for the students. As an outsider, she also needed to observe the implementation of the ILIS approach and record possible modifications if needed. Even though Mrs Wang independently conducted conventional instruction in the control group, the researcher was mainly in charge of conducting the ILIS approach. This is because there was not enough time for Mrs Wang to attend the whole teacher-training workshop. Also, this was the first time the ILIS

approach was used in a real situation, and it needed a physics teacher who had years of teaching experience to ‘criticise’ the implementation of the ILIS approach. Thus, the pilot study invited Mrs Wang to be the teaching assistant, while the researcher was the primary teacher.

### 4.3.2 What did the ILIS approach mean to Mrs Wang?

Mrs Wang was supportive of the use of the ILIS approach in the physics classroom. She first expressed that the implementation of the ILIS approach was consistent with the physics curriculum standards, and that it was easily integrated into senior secondary classes. The analysis of Mrs Wang’s interview showed three overarching themes: 1) the five-step learning sequence of the ILIS approach; 2) different scaffolds in the ILIS approach; 3) other contributors (see Table 4-9).

**Table 4-9 Interview data summary in the pilot study**

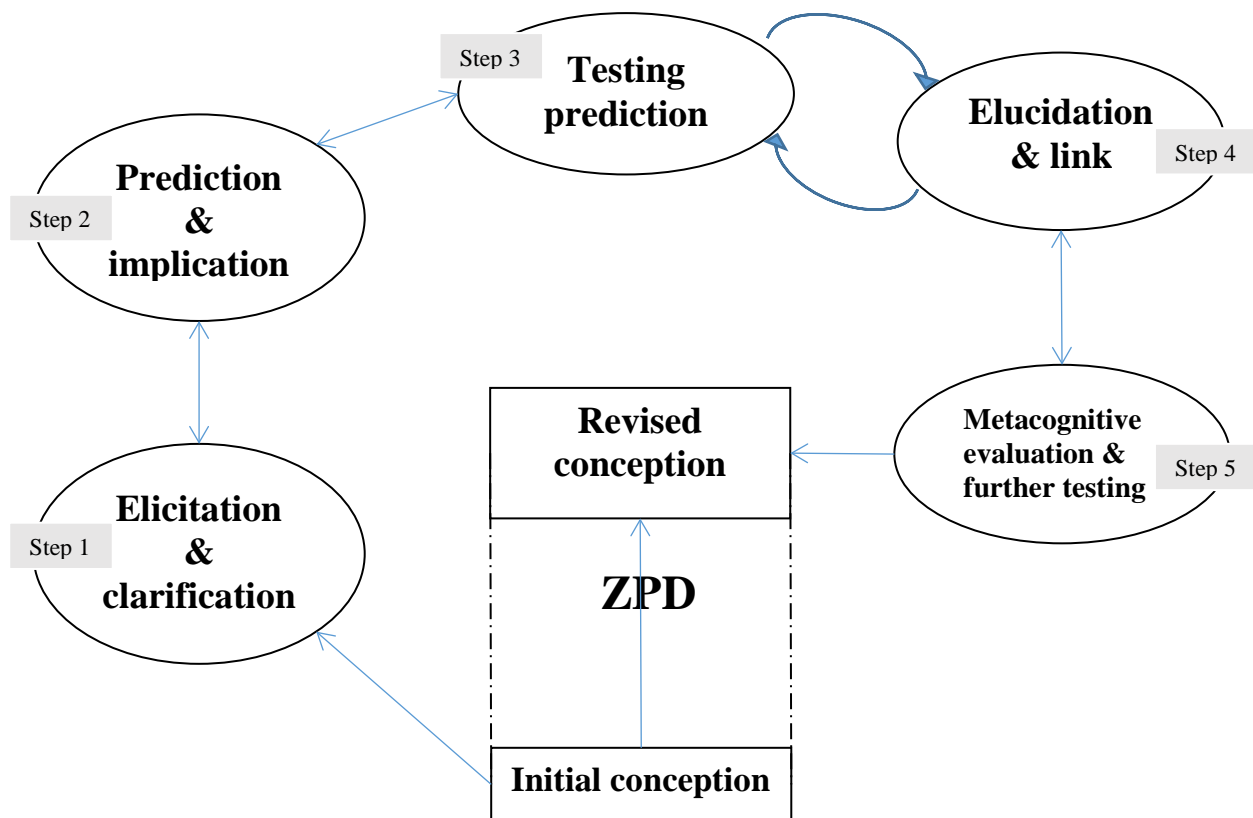
Overarching themes	Topics	Details
Function of the ILIS approach	Existing knowledge as prerequisite	Cognitive conflict
	Testing hypothesis	Scaffold from PhET simulations that effectively support experimental practices;
	A style of scientific discourse	Scaffold from scientific language that supports in-depth thinking;
	Notions of metacognitive knowledge	Superficial but suggested to be deleted or redesigned.
Function of other factors	Confidence in learning	Developed through using the ILIS approach and in turn could be predict students’ conceptual understanding.
	Inquiry process skills	

As shown in Table 4-9, Mrs Wang highlighted two functions of the ILIS approach. Regarding the first function, Mrs Wang specifically pointed out three aspects that can effectively support students’ conceptual learning. However, she noted that the metacognitive evaluation could be deleted or modified. Regarding the second function, Mrs Wang did not provide specific evidence, just her perceptions and viewpoint from the participating teacher’s perspective. The next sub-sections interpret the two overarching themes in detail.

#### ***Function of the ILIS approach on conceptual learning***

Mrs Wang said that the current physics curriculum standards for senior secondary schools requested physics teachers to use an inquiry-based approach in practice. However, there was no specific instruction about how to conduct an inquiry-based lesson. This made physics teachers such as her confused and disappointed. After Mrs Wang finished the pilot study, she quoted an old Chinese idiom, “雪中送炭”, to express her appreciation of the ILIS approach in the physics classroom. The translation of “雪中送炭” is “people offer fuel to others on a snowy day”, which in essence means “timely help”.

Mrs Wang’s transcripts revealed there was an intertwined relationship between the five steps. Each individual step and the interplay of relationships among different steps worked together to promote students’ understanding of physics concepts. As Figure 4-1 shows, this first step aimed to inspire students’ motivation for learning. It used alternative conceptions to attract students’ attention, and engaged the students by clarifying what they already knew and what the learning objectives were. After the students clarified their conceptual conflicts, they needed to make predictions based on their existing knowledge and conceptual conflicts.



**Figure 4-1 The procedure of the ILIS approach**

During step 3, students were provided opportunities with PhET simulations to test their predictions, and were encouraged to explore evidence for supporting the predictions. The investigative process, results and evidence were presented in step 4. This step aimed to support students to elucidate their finding and acquire the appropriate scientific discourse: that is, the ability to prove claims with evidence through discussion and argument. The last step facilitated the students to review the entire procedure of the ILIS approach and the cognitive change from the initial thinking to the revised understanding. It also developed the ILIS students’ metacognitive thinking through evaluating what they had done during each learning step. The evaluation step also provided the ILIS students information to decide where they should go next - either back to the current physics concept, or further to explore a new physics concept.

Specifically, a number of studies have argued that the role of existing knowledge can influence new knowledge learning (Ausubel, 1968; Piaget et al., 1952; Posner et al., 1982). Mrs Wang agreed with this notion, and expressed that the ILIS approach taught her to practice a new method of engagement: that “teachers should guide students to recall what kind of ideas they are holding, instead of using the previous lesson’s knowledge to attract students’ attention”. She provided an example to compare the ILIS approach and conventional instruction. Mrs Wang said she usually used a question to attract students’ attention, such as “we have learned the definition of force in the last lesson. Who knows what it is?” After Mrs Wang had received several students’ answers, she would say, “Ok, it seems you know the definition of force. Then let’s move to today’s lesson topic—Newton’s first law.”

Conversely: “When I teach Newton’s first law now, I think I will lead the students to review their ideas about force and the relationship between force and motion.” Mrs Wang commented that the strategy of using students’ existing knowledge could help the students become aware of what they already know about the specific physics concepts. And the awareness of the existing knowledge “can inspire students to test whether their ideas are right”. Teachers should take good advantage of students’ existing conceptions.

Second, Mrs Wang highlighted the integration of PhET simulations in the inquiry-based teaching. She said the PhET simulations provided students opportunities to test their existing ideas and hypothesis. And students can use the PhET simulations to collect evidence for supporting or refuting their claims. Mrs Wang added that she focused on the relationship between evidence and claims. She agreed that the hypothesis, tests and claims become scientific based on respective evidence. In the conventional instruction classroom, only evidence collected by scientists in the past is provided, but “the ILIS classroom encourage students to establish a relationship between student self-collected evidence and claims. Particularly, the PhET simulations provided good opportunities to support the students’ finding evidences. This is a great tool.” Mrs Wang also noted “the students in the ILIS approach group expressed more willingness to share their ideas during the presentation step, when compared to the students in the conventional instruction group.” She thought the willingness to communicate came from active thinking, when the ILIS students were engaged in testing their hypothesis and exploring the evidence.

Third, Mrs Wang understood the importance of sharing ideas in the physics classroom. As she explained, “I think sharing ideas could provide opportunities for developing discussion and argument.” However, she did not adopt it into her teaching practices, because “I tried before. It is very difficult to make students actively engaged in discussing with me.” In the context of the ILIS approach, she said:



It becomes easier. I think PhET gives my students' confidence to present their ideas. This provided me with a valuable opportunity to start discussion with my students. And then I provided students with scaffolded opportunities to discuss and argue with them. Take the law of inertia as an example. There was a group. They reported that the more friction, the more easily an object can stop. When I asked them how they could make the claim, they provided evidence to support the claim. Based on that claim, I guided students to review the views from scientists in the past (e.g. Aristotle, Galileo, Descartes). During another group presentation, we discussed the relationship between force and motion. I felt we (Mrs Wang and students) created a new learning environment, in which students engage in a process of discussion and argument from evidences. Finally, we concluded that a force is not needed to keep an object in motion, but to change an object in motion.

She noted that although sometimes her students' expressions were not specific, she was satisfied because "my students seemed willing to actively share their ideas. And when I asked them questions, some students were able to use evidence to support their claim."

This revealed that Mrs Wang engaged students in developing a style of scientific discourse through three ways: 1) students' presentation encourages sharing ideas in the classroom; 2) students' report establishes evidence-claim relationship in the physics classroom; 3) the use of specifically scientific and specific language is acquired during the process of discussion and argument.

Fourth, Mrs Wang expressed that the metacognitive evaluation did not help students understand physical concepts, because "it is a little bit superficial. Like the students in my class, they can fill in the evaluation forms, but they might not understand the reason of filling in them." She suggested that at the beginning of using the ILIS approach, teachers should guide students to complete the metacognitive evaluation tables. Mrs Wang elaborated:

"Most students subconsciously do not understand the function of meta-cognitive evaluation. The first few times, it is much better if teachers work with students to complete the metacognitive evaluation table. The teachers also should lead the students to review all the inquiry-based steps, and explain the significance of why they need to develop the metacognitive thinking."

### ***Scaffolds from important steps of the ILIS approach***

#### *PhET simulations*

As Benjamin Franklin said, "Tell me and I forget, teach me and I may remember, involve me and I learn." The idea is also supported by Confucianism: "不闻不若闻之，闻之不若见之，见到的不如了解到的，了解到的不如去实行，学问到了实行就达到了极点"（《孟子语·儒效》，*Mencius*). In the ILIS learning environment, students were supported by a variety of learning

scaffolds. “PhET simulation was the first one that should be mentioned”, Mrs Wang said. She highlighted functions of PhET simulations because “PhET simulations involve students in conducting experiments in an efficient way”, and “I can see the use of PhET simulation will provide the students more opportunities to test their hypothesis and communicate with each other”. PhET simulations are considered well-designed educational technology tools, and PhET simulations can help students effectively construct conceptual understanding in physics (Adams et al., 2008).

When asked to discuss advantages of PhET simulations for conceptual understanding, Mrs Wang said that the multi-representation on the PhET simulations interface was useful: “PhET simulations provided objects, images, words, sounds, tables, figures, and equations to present the relationship between vectors, force, velocity, acceleration and friction.” The multi-representations can lead to better understanding of the phenomenon (Tabak, 2004) and help students to higher levels of knowledge integration (H. Z. Zhang et al., 2008).

Mrs Wang also noted that PhET simulations allowed the students “unlimited tests and timely feedback”. She explained, “Unlimited tests could not happen in real labs, however, students need to do more than one experiment to test their thoughts.” PhET simulations made it practical for students to explore their hypothesis. Besides unlimited tests, PhET simulations also offered immediate feedback that “met the students’ tests, and provided lots of evidence to support students’ arguments, discussion, and communications.”

Furthermore, Mrs Wang expressed that the use of PhET simulations supported students’ discussion during student presentations. She reported that students in the ILIS classroom seemed happier to talk with her than those in the conventional instruction classrooms did. And the ILIS students’ arguments were apparently more scientific and logical. She explained, “The use of simulations for testing provided students evidences. Those evidences supported students to prove their claims when they needed to discuss with others during presentation.” As indicated in the study of K. E. Chang et al. (2008), students who used simulations were supported to gather scientific evidences.

In addition, regarding the influence of gender when using PhET simulations, Mrs Wang admitted that there were different impacts on male students and female students. She observed that the boys more involved in playing with the computer-based simulations than the girls were. She said, “Some boys I know who are naughty in my class could concentrate in that class. Some girls I felt expressed a little bit of nervousness when they conducted experiments with the computers.” When whether or not there was a gap between male students and female students when using the ILIS approach, Mrs Wang expressed a conflicted feeling, saying, “I am afraid that would happen in my class. But I can also see the potential of inquiry-based instruction with simulations, which could improve both male and female students’ learning.”

### *Roles of teachers and worksheets*

Noteworthy among these findings were Mrs Wang's interpretations of teachers' roles during the ILIS approach: 1) teachers needed to change their existing understanding about traditional teaching; 2) teachers needed to improve their professional instructional practices. She expressed that the ILIS approach clarified for her the teacher's role:

In my conventional instruction classroom, I thought I was the 'facilitator' to teach students, because I facilitated them to remember knowledge. However, the ILIS approach showed me I should facilitate students to develop a way of thinking to solve the current problems or the problems in the future, rather than feeding them through memorising physics concepts. This is much harder for teachers.

Mrs Wang highlighted her roles in the ILIS approach, especially at the experiment-conducting step. She regarded this step as similar to what they did in the physics labs. She noted that she had to monitor students' activities and remind students to clarify the purpose of their testing. Meanwhile, she expressed the challenge of making conversation with students. She explained,

The ILIS classroom asks teachers to share and discuss their claims by providing evidences. It can engage the student in in-depth thinking. But, in the context of oriented-examination, we have got used to teaching students by remembering knowledge. We forget to consider how and where students' ideas originated, and developed. I want to develop my discourse-sharing skills, although this cannot be achieved in one day.

Additionally, a related finding focused on students' worksheets. When asked whether students' worksheets played a role in the ILIS approach, Mrs Wang said that she appreciated students' worksheets, because "it was very necessary to use a designed worksheet to scaffold student's learning and support my teaching, especially at the beginning of using the ILIS approach." She noted that students' worksheets creatively balance the teacher's direction with the students' self-direction. In other words, Mrs Wang admitted that she worried about whether or not her students would be able to complete investigative practices autonomously. However, she found that the students knew what they should do because of the mandatory worksheets. She said, "Students' worksheets not only provide students with scaffolded helps in planning and monitoring their investigative activities, but also provide me with a general structure and recommended topics to make conversations with students." In the ILIS classroom, the structure of the worksheet is consistent with the five-step inquiry sequence, which provides students and teachers with a straightforward blueprint for how the ILIS approach should be implemented, so that they can focus on performing the investigation and exploring relationships. Mrs Wang suggested that the difficulty level of the students' worksheet should be moderate or less. She explained,

Students' worksheets mainly aimed to scaffold students' inquiry process, and to collect data for further discussion and arguments. The moderate worksheets can meet that function.

Contrarily, the too-difficult worksheets could influence students' confidence.

### ***Function of confidence in learning and inquiry process skills***

Mrs Wang provided her observations as teaching assistant in order to interpret the functions of confidence and inquiry process skills in students' conceptual understanding.

Mrs Wang believes that the ILIS approach can afford students more confidence than conventional instruction does. Students' confidence in what they learn can increase if their conceptual understanding improves, which Mrs Wang considered "a natural process". She said, "I think the involvement of the ILIS approach enhanced my students' confidence, because the ILIS approach definitely improved students' conceptual learning." But Mrs Wang did not agree that the students who had higher confidence in learning "absolutely hold a better conceptual understanding". She noted that there was an unstable relationship between conceptual understanding and confidence in learning. For example, Michael was a student in Mrs Wang's class: "If he told me he was confident in his understanding of the relationship between forces and motion, I would only have 80% confidence in his answer", Mrs Wang said, because "I know he is an overconfident person because of his family background." However, Mrs Wang expressed that a student's confidence in their answer can be used as an indicator for predicting the student's conceptual understanding. "After all, I felt for most students, the higher their confidence in learning, the better conceptual understanding they have", Mrs Wang added.

Mrs Wang also believes that the use of the ILIS approach supported the development of inquiry process skills. She said, "Taking me as an example, I think my inquiry process skills such as hypothesis, operation and communication were improved after this time's trial", because the five steps obviously aimed to develop students' specific skills during each step. Mrs Wang mentioned that the use of PhET simulations improved students' operational skills. And the presentation step promoted students' communication skills, especially the use of scientific language to argue with others. Mrs Wang felt that the ILIS approach students actively shared their findings, more so than those students receiving conventional instruction.

Further, she noted the positive effects of inquiry process skills on students' conceptual understanding. From her own teaching experience, Mrs Wang has concluded that involving students in experiments is an effective teaching method in physics. She said, "The PhET simulations helped the students easily complete the investigative experiments. This cannot be achieved in conventional classrooms." The implementation of the investigative experiments provided the potential for students' to understand the inquiry process skills. Mrs Wang believes, "If a student understands the meaning and the purpose of inquiry skill at each step, they will have a better conceptual

understanding”, because the acquisition of inquiry- process skills reduced the students’ cognitive load, especially in the operational aspect. Students who had better inquiry process skills were able to focus on conceptual learning and the construction of new knowledge. In addition, Mrs Wang noted the inquiry process skills could be used as an important contributor in predicting conceptual learning. “In physics, the better the inquiry process skills, the better conceptual understanding the students will have”, she added.

### **4.3.3 Summary**

The qualitative part of the pilot study investigated how people understand the conceptual learning in relation to the performance made by the ILIS approach. The qualitative data in the pilot study explored the initial knowledge, perceptions, and viewpoints from the participating teacher’s perspective.

Contrary to the findings from the quantitative phase, the participating teacher in the qualitative phase argued that the use of the ILIS approach could make positive effects on students’ conceptual learning and confidence in understanding. Mrs Wang elucidated how students’ conceptual learning had developed through each step of the ILIS approach. And she found the activities that emerged from the ILIS approach catalysed the functions of students’ confidence. The ILIS approach students were actively encouraged to discuss topics with Mrs Wang, which enabled support their conceptual learning. Regarding conceptual learning and inquiry process skills, the findings from the qualitative data were consistent with those from the quantitative phase. The implementation of the ILIS approach provided potential to support students’ understanding of the inquiry process and improve students’ inquiry process skills. As Mrs Wang expressed, “the better the understanding of inquiry process skills, the greater conceptual learning students can obtain.”

## **4.4 Discussion and limitations of pilot study**

The current pilot study preliminarily provided evidence for and interpretations of the research questions. This section will include a brief discussion and then explore the limitations of the pilot study.

The pilot study found the effects of different instructional approaches on conceptual learning was ambiguous. According to the results from the quantitative phase, both the ILIS approach students and the conventional instruction students obtained statistically significant gains in their conceptual understanding from pre-tests to post-tests. There were no statistically significant differences in conceptual learning and confidence in answers between the ILIS approach and the conventional instruction. Surprisingly, the interview research showed that Mrs Wang supported the ILIS approach in promoting students’ conceptual understanding and confidence in answers. These findings conflicted with previous investigations (Bell et al., 2008; X. Chen et al., 2010; de Jong et

al., 1998; Geban et al., 1992; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Njoo et al., 1993; Smetana et al., 2011; Vreman-de Olde et al., 2013), which found that inquiry sequence with interactive simulations had the potential to enhance students' conceptual learning.

Regardless, the relationship between conceptual learning and confidence in understanding was clear. Numbers show that confidence in understanding has a significant relationship to conceptual learning. Feedback from the participating teacher implied that the function of confidence in understanding was catalysed by the activities of the ILIS approach. The results were inconsistent with the study of Windschitl (2001), which found that students' assertiveness did not involve in individual's conceptual change. To our knowledge, few studies have investigated this topic in the context of inquiry-based learning with interactive simulations.

Additionally, in regard to the relationship between conceptual learning and inquiry process skills, the quantitative findings were consistent with the qualitative findings. In the experimental groups, inquiry process skills showed a significant relationship with conceptual learning, and the development of conceptual learning enhanced students' inquiry process skills in the context of the ILIS approach. These findings were consistent with previous those of studies (Gerber et al., 2001; Von Secker, 2002; Von Secker et al., 1999). For example, the study of Schwarz et al. (2005) found that students' conceptual leaning was influenced most by the level of inquiry process skills.

In summary, conceptual learning in the inquiry-based learning with interactive simulation is in its infancy. The findings from the pilot study provide positive, neutral and obscure implications for this topic. The limitations of the pilot study could provide some explanation for these findings. Sample size should be first mentioned. There were 38 participating students in the pilot study: the small sample size might have caused inadequate power to reject null hypotheses. And only one teacher was invited for interviewing. While her explanations provided valuable evidence for the qualitative research question, her opinions should be interpreted with caution. Still, the intervention duration should also be discussed as a limitation. The intended three-lesson topics' intervention was not fully implemented. The practical situation resulted in only one lesson module—Newton's first Law—being completely implemented. All of these limitations might have impacted on the findings from the current pilot study.

#### **4.5 Potential modifications in the main study**

The main purpose of pilot study was to identify any potential implementation problems in the main study by running a preliminary instructional intervention. Based on the implementation and findings in the pilot study, eight potential modifications to the main study are suggested, as shown below:

1. Sample size and intervention duration should be modified. More students and teachers should engage in the main study. The intended three-lesson modules should be conducted in the main study with at least eight weeks' intervention period.
2. To strengthen the ILIS approach intervention, the researcher should hold extensive teacher training to help teachers understand the ILIS approach better. The teacher-training workshop should include the underlying theory of the ILIS approach and practice for how to conduct each step of the inquiry-based learning with interactive simulations.
3. To enhance the function of 'elucidation and linking', which is the fourth step of the ILIS approach, Confucius heuristic teaching strategies should be integrated in this step. Mrs Wang who participated into the pilot study proposed the idea. The essential of Confucius heuristic teaching strategies not only focuses on students' practicing the use of scientific language and developing argumentation with evidence, but also providing teachers opportunities to understand students' claims and explanation, and then help students' learning. Further, Chinese teachers are familiar with the Confucius heuristic teaching strategies in the context of most schools in China. The use of the Confucius heuristic teaching strategies is expected to reduce pressures that are caused by participating a new project. The Confucius heuristic teaching strategies would be changed into other teaching strategies that consist of the ideas of the ILIS approach as well as represent school culture or local culture.

The word 'heuristic' (qi fa) in China originates from a Confucius quotation, which is "Bu fen bu qi, bu fei bu fa. Ju yi ou bu yi san ou, ze bu fu ye (不愤不启，不悱不发。举一隅不以三隅则不复也) (《论语·述而》， Analects). The meanings of the quotation include three parts. The first part is "Bu fen bu qi (不愤不启)" that means, "When I teach my students, if he doesn't think of the reason and instead acts as confused, I would not be the one to enlighten him". The second part is "Bu fei bu fa (不悱不发)" that refers to "If he hadn't gone through thinking, but trapped at a critical part and couldn't say it out, I would not be the one to inspire him". And the third part is "Ju yi ou bu yi san ou fan, ze bu fu ye (举一隅不以三隅反,则不复也)" that says "If I set a corner of the house as an example, I had already explained there is a corner and he still couldn't speculate that there are three more corners, then I would not teach him again". The first two parts emphasis when and how the teacher provides learners with guidance. It proposes that a teacher should help the learner acquire knowledge (explicit knowledge) when the learner makes the effort with their own cognitive thinking (implicit knowledge) for a considerable time, but still does not fully understand the concept; and also when the learner does understand the concept, but cannot

form their own thoughts into words. The third part emphasises the way to evaluate students' learning outcomes. It proposes that a teacher should not teach new knowledge until the learner can deduce many things from the knowledge the learner learnt. These teaching strategies were also used in the elucidation and link step of the ILIS approach.

4. To avoid situations where students do not correctly follow the inquiry sequence or interactive simulations, which likely impacted on study results, the researcher should conduct an extra lesson module in the ILIS approach group to further the main three lesson modules. This would allow teachers and students in the experimental group to get used to the inquiry sequence and interactive simulation of the ILIS approach.
5. To encourage students' presentation, which is the fourth step of the ILIS approach, the researcher should discuss with teachers whether or not certain motivational methods could be incorporated, such as chocolate for those who would like to give a presentation.
6. To ensure an appropriate number of questions in the MFIC test and inquiry process skills survey, the researcher should discuss with teachers the deletion of redundant questions in the main study. Eventually, there will be eighteen multiple MFCI questions and twelve inquiry process skills survey questions used in the main study.
7. To eliminate some students' confusion about some expressions on students' worksheets, inappropriate expressions were modified to produce more succinct, understandable language by the researcher and participating teachers. The modified students' worksheets should be used in the main study.
8. Similarly, the MFCI test, confidence scale and inquiry process skills survey should be further reviewed and revised by the researcher and teachers to be applied in the main study.



## Chapter 5 Main Study

What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual understanding? How is conceptual learning in relation to (potential) performance made by the ILIS approach and conventional instruction? In order to address the two research questions, this chapter reports the data collection, data analysis and findings from the main study.

Section 5.1, section 5.2 and section 5.3 respectively introduce the participants, materials, instruments, and procedure of the main study. Section 5.4 presents the quantitative data analysis and findings. The qualitative data analysis and findings were critically interpreted in section 5.5. And supporting evidence observed in the classroom was presented in section 5.6. Section 5.7 highlights the key findings from the quantitative phase and qualitative phase, and concludes with a brief summary.

### 5.1 Participants and trial procedure

Two public high schools, three teachers and 150 grade 10 students from five classes were involved in the main study. Data from students completing both the pre-test (n=150) and the post-test (n=150) were maintained in the analysis. Students who were absent either pre-test or post-test, who did not finish their test papers, who missed any lessons, or whose test paper filled in each answer with the same answer (e.g., “A” over and over) were excluded from the data analysis. In the final analysis 142 subjects were retained for analysis.

As shown in Table 5-1, there were two physics teachers and 117 students from school B. Four intact classes were randomly selected either for the experimental group or the control group. In order to avoid treatment diffusion or treatment imitation, the main study invited one teacher and her 25 students from School C to participate in the main study. These 25 students from school C received conventional instruction as another control group.

**Table 5-1 Participants information about the classes and teachers from the main study**

Schools	Group	Teachers	Classes	Number of students	Number
B	Experimental group	Zhang	3	26	55
		Han	5	29	
	Control group	Zhang	4	30	62
		Han	6	32	
C	Control group	Fang	7	25	25

The procedure of the main study included three steps. In the first step, a two-day teacher-training workshop was conducted. Detailed information has been introduced in Chapter three. A physics teacher group was built up. The teacher group had weekly meetings in order to help Mr Zhang and Mrs Han solve questions. Then the students' pre-test were conducted. Both of the experimental groups and control groups had different learning materials to explore Newton's laws of motion. The parallel-tests were conducted after eight weeks' learning using different

instructional approaches. This step addressed the first research question. Last, two participating teachers and six selected students were interviewed. Their interviews provided answers to address the second research question.

## 5.2 Materials

Regarding materials, all participating students were introduced to the same lesson topics. As shown in Table 5-2, there were four lesson topics. Lesson 1 referred to the buoyancy topic that provided an opportunity for experimental-group students to practice the use of the ILIS approach. Lesson 2, lesson 3 and lesson 4 referred to Newton’s Laws of Motion. These four lesson topics were the compulsory learning elements from the physics curriculum standards for senior secondary school.

**Table 5-2 Teaching schedule**

School	Teacher	Class	Schedule								
			Lesson 1		Lesson 2		Lesson 3		Lesson 4		
			W1	W2	W3	W4	W5	W6	W7	W8	
B	Zhang	3	ILIS	ILIS			ILIS	ILIS			
		4			CI	CI			CI	CI	
		5	ILIS	ILIS			ILIS	ILIS			
	Han	6			CI	CI				CI	CI
		3			ILIS	ILIS				ILIS	ILIS
		4	CI	CI			CI	CI			
C	Fang	5			ILIS	ILIS			ILIS	ILIS	
		6	CI	CI			CI	CI			
		7	CI	CI	CI	CI	CI	CI	CI	CI	CI

Note: W=Week; Week 1=The first week; ILIS=ILIS approach; CI=Conventional instruction

The experimental-group students used the ILIS approach and the control-group students received the conventional instruction. Both of the instructional approaches were introduced and discussed in Chapter one and Chapter three. All participants had relevant lessons once per week. One lesson topic was finished in two lessons. That means each lesson topic was completed in two weeks.

## 5.3 Instruments

The instruments used in the main study were refined and modified based on the pilot study. Specifically, eighteen multiple-choice questions were used from the MFCI test. Accordingly, eighteen questions regarding confidence in understanding were followed with each MFCI question. And there were twelve questions in the inquiry process skills survey. All instruments used in the quantitative phase were conducted using Cronbach’s alpha reliability testing. The Cronbach alpha coefficients of the conceptual knowledge test and confidence-in-learning survey were .81 and .94 respectively, suggesting a relatively high internal consistency for the scale with this sample. The internal consistency reliability of the inquiry skills test was 0.88 for the pre-tests (coefficient for the five sub-scores) and 0.86 for the post-tests. The alpha values above 0.8 presented the items of all instruments to be reliable and internally consistent (Ho, 2006).

Moreover, although the researcher had designed the students’ worksheets, teachers were encouraged to modify and develop students’ worksheets for their current students’ learning

progress. Classroom observation checklists were developed to use for treatment verification. They recorded how the teacher conducted their instructional approaches, as well as how their students engaged in the instructional approaches. The classroom observation checklists provided more evidence for further analyses and explanations.

In the subsequent qualitative phase, semi-structured interview protocols were used to collect interview data. A student interview protocol and a teacher interview protocol were used to support interviewing students and teachers respectively. The protocols also functioned to record key points of interviews. In the main study, the researcher conducted individual interviews with six students and two teachers face-to-face. Prepared questions on predetermined topics provided a starting structure followed by open-ended questions. With the permission of the participants, audio-recordings were made of all interviews. Intra-case analysis was employed to analyse the interview data (Patton et al., 2002). Translation and interpretation of these themes were conducted by a process of re-reading by using the list of code words, and peer-reviewed for consistency and reliability in the coding procedure.

## 5.4 Quantitative findings

### 5.4.1 Whether or not there was diffusion or imitation of treatments

In the main study, there were 25 participants from school C ( $S_C$ ). They had the same instructional materials using the conventional instruction as those who were in the control group from school B ( $S_B$ ). The use of a control group from another school aimed to exclude diffusion or imitation of treatments in school B, where experimental- and control-group subjects could communicate with each other, or the experimental group could pass on some elements of the experimental stimulus to the control group (Stanley et al., 1966).

Actually, the main study found that there was no statistically significant difference between the control groups at the two schools. Table 5-3 shows the conceptual understanding scores of the students who participated in the control group from the main study. Conceptual understanding scores ranged from 0 to 108, with higher scores indicating better achievements.

**Table 5-3 MFCI test score means and standard deviation according to two schools**

	n	MFCI test scores			
		Pre-test		Post-test	
		Mean	SD	Mean	SD
Control group from $S_B$	62	45.35	12.77	55.29	13.75
Control group from $S_C$	25	46.76	8.29	53.44	8.77

As shown in Table 5-3, there was no obvious difference between the control group from school B and the control group from school C. A repeated-measures ANOVA was conducted to statistically examine the treatment effects on students' MFCI test from pre-test to post-test, with

inputting school as a between-subject and time as a within-subject factor. Results showed that there was a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .92$ ,  $F(1, 85) = 7.61$ ,  $p = .007$ , partial  $\eta^2 = .08$ . This indicated that students' conceptual understanding in the two groups differed according to time. To break down this interaction, contrasts were the main treatment effect. The main effect comparing the two types of instructional approaches was not significant,  $F(1, 85) = .006$ ,  $p = .94$ , suggesting no difference in the effects of the two instructional approaches from school B and school C. The substantial main effect was time, Wilk's  $\Lambda = .30$ ,  $F(1, 85) = 198.22$ ,  $p < .001$ , multivariate partial  $\eta^2 = .70$ , showing an increase in conceptual understanding cross the two time periods.

Table 5-4 presented the confidence in learning achievements of the students who participated in the control group from school B and those involved in the control group from school C. The confidence in conceptual learning score ranged from 0 to 90, with higher scores indicating greater achievements in confidence.

**Table 5-4 Confidence-in-learning survey means and standard deviation across two schools**

	n	Conf test scores			
		Pre-test		Post-test	
		Mean	SD	Mean	SD
Control group from $S_B$	62	61.95	14.96	67.60	12.57
Control group from $S_C$	25	61.84	11.55	67.12	12.70

As shown in Table 5-4, participants in the two control groups obtained a similar increase. And a repeated-measures ANOVA was conducted to statistically examine the treatment effects on students' Conf survey from pre-test to post-test, with inputting school as a between-subject and time as a within-subject factor. Results showed that there was no significant Treatment x Time interaction effect, Wilk's  $\Lambda = 1.0$ ,  $F(1, 85) = .09$ ,  $p = .76$ , partial  $\eta^2 = .001$ . There was a main effect for time, Wilk's  $\Lambda = .51$ ,  $F(1, 85) = 83.02$ ,  $p < .001$ , partial  $\eta^2 = .49$ , with both groups indicating an increased confidence in learning in their survey scores cross the two time periods. However, the main treatment effect regarding the two types of instructional approaches was not significant,  $F(1, 85) = .009$ ,  $p = .93$ , suggesting no difference in the effects of the two instructional approaches from school B and school C.

Table 5-5 presents the inquiry process skills scores of the students in the main study who were in the control group from school B and from school C. Inquiry process skills scores ranged from 0 to 60, with higher scores referring to more inquiry process skills improvement.

**Table 5-5 Inquiry-process skills and four dimensions score means and standard deviation according to two schools**

	n	Inq test scores			
		Pre-test		Post-test	
		Mean	SD	Mean	SD

Control group from $S_B$	62	36.30	8.19	38.45	7.09
Control group from $S_C$	25	37.12	5.40	38.72	5.10

As shown in Table 5-5, there was no obvious difference between these two control groups. And a repeated-measures ANOVA was conducted to statistically examine the treatment effects on students' inquiry process skills survey from pre-test to post-test, with inputting school as a between-subject and time as a within-subject factor. Results showed that there was a significant Treatment x Time interaction effect, Wilk's  $\Lambda = .99$ ,  $F(1, 85) = 1.14$ ,  $p = .29$ , partial  $\eta^2 = .01$ . This indicated that students' inquiry process skills in the two groups differed according to time. To break down this interaction, contrasts were the main treatment effect. The main treatment effect comparing the two types of instructional approaches was not significant,  $F(1, 85) = .11$ ,  $p = .74$ , suggesting no difference in the effects of the two instructional approaches on students' inquiry process skills. The substantial main effect was time, Wilk's  $\Lambda = .61$ ,  $F(1, 85) = 53.95$ ,  $p < .001$ , multivariate partial  $\eta^2 = .39$ , showing an increase in inquiry process skills cross the two time periods.

Overall, data analysis of the control groups from the two schools revealed that there was no diffusion or imitation of treatments in school B and school C. The current main study thus discarded data from the school C control group and used data that were collected in school B. In other words, when the following sections mention control and experimental groups, it particularly refers to groups from school B.

### 5.4.2 Quantitative data analysis

The main study explored the relationship between conceptual learning and different instructional approaches. In the quantitative phase, responses to the MFCI test, confidence in learning survey and inquiry process skills survey were transferred into SPSS. Analysis of variance (ANOVA), analysis of covariance (ANCOVA), multiple analysis of variance (MANOVA) and multiple regressions were conducted to analyse the data. Under the first main research questions, Table 5-6 presented sub-research questions, operational research questions, data sources, and data analysis.

**Table 5-6 Quantitative data analysis framework in the main study**

Research question 1:			
Sub-research questions	Operational research questions	Data sources	Data analysis
RQ1 <sub>1</sub> . What effects do the ILIS approach and conventional instruction have on participants' conceptual learning?	Which instructional approaches provide better conceptual learning during the ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test	Repeated-measures analysis of variance (ANOVA)
	And what effects does gender have on participants' conceptual learning during the ILIS approach and conventional instruction?	Scores on MFCI pre-test and post-test	2-by-2 between-groups analysis of covariance (ANCOVA)
RQ1 <sub>2</sub> . What effects are made on participants' confidence in	Which instructional approaches provide better	Scores on Conf pre-test and post-test	Repeated-measures

learning during ILIS approach and conventional instruction?	confidence during the ILIS approach and conventional instruction? And does confidence influence participants' conceptual learning during ILIS approach and conventional instruction?	Predictors: MFCI pre-test scores, Conf post-survey scores, and treatment groups Dependent variable: MFCI post-test scores	analysis of variance (ANOVA) Multiple regression
RQ1 <sub>3</sub> . What effects are made on participants' inquiry process skills during the ILIS approach and conventional instruction?	Which instructional approaches provide better inquiry process skills during the ILIS approach and conventional instruction?  And do the inquiry process skills influence participants' conceptual learning during ILIS approach and conventional instruction?	Scores on Inq pre-test and post-test  Predictors: MFCI pre-test scores, Inq post-survey scores, and treatment groups Dependent variable: MFCI post-test scores	Repeated-measures multivariate analysis of variance (MANOVA) with follow-up ANOVA Multiple regression

### 5.4.3 Research question 1<sub>1</sub>

The research question aimed to answer whether or not there was a statistically significant difference between students' conceptual learning during the ILIS approach and the conventional instruction.

The current study expected that the conceptual learning of students using the ILIS approach would outperform those taught by the conventional instruction when measured through the MFCI test. The results of the main study showed the significantly positive effects of the ILIS approach. Findings are discussed below.

Hypothesis:

$H_{0 \text{ [conceptual learning]}}: \mu_I - \mu_{NI} = 0$ . There is no statistically significant difference in MFCI pre-test versus the MFCI post-test between students using the ILIS approach and those using the conventional instruction.

$H_{0 \text{ [gender, conceptual learning]}} = 0$ ; no interaction gender effects exist. There is no statistically significant gender effect on the MFCI pre-test versus the MFCI post-test between students using the ILIS approach and those using the conventional instruction.

Finding 1:

Null Hypothesis 1 ( $H_{0 \text{ [conceptual learning]}}$ ).

An ANOVA was used to analyse whether or not the two treatment groups had any statistically significant difference in the MFCI pre-test. The result showed there was no statistically significant difference between the two groups in the MFCI pre-test,  $F(1, 115) = 28, p = .60$ , suggesting there was no significant difference in conceptual understanding before the intervention.

Table 5-7 shows the pre- and post-test performance of all participating students according to two treatments, as measured by their scores on the conceptual learning of Newton's laws of motion. Performance scores ranged from 0 to 108, with higher scores indicating better conceptual understanding. Performance scores ranged from 0 to 42, with higher scores indicating better conceptual understanding.

**Table 5-7 MFCI test score means and standard deviation according to two treatments**

		MFCI test scores			
		Pre-test		Post-test	
Treatment	N	Mean	SD	Mean	SD
Experimental group	55	46.58	12.04	67.00	11.19
Control group	62	45.35	12.77	55.29	13.75

Note: N=number; SD=standard deviation.

As shown in Table 5-7, the two treatments revealed mean increases from pre-test to post-test. The greatest difference between the pre-test and post-test exists in the experimental group, with 20.42 points. It reveals that students using the ILIS approach obtained higher scores than those using the conventional instruction. It is noteworthy that the variability measured by standard deviation in the experimental group was less than that in the control group. That indicates the experimental group mean is more accurate to represent students' post-test scores than those who learned using conventional approach in the control group.

A repeated-measures ANOVA was conducted to statistically examine the treatment effects on the students' MFCI test from pre-test to post-test, with inputting treatment group as a between-subject and time as a within-subject factor. Results showed that there was a statistically significant difference between instructional approaches and time, Wilk's  $\Lambda = .58$ ,  $F(1, 115) = 83.08$ ,  $p < .001$ , partial  $\eta^2 = .42$ . This indicated that the conceptual understanding of types of instructional approaches differed according to time. There was a substantial main effect for time, Wilk's  $\Lambda = .14$ ,  $F(1, 115) = 696.59$ ,  $p < .001$ , multivariate partial  $\eta^2 = .89$ , with both groups showing an increase in conceptual understanding of MFCI scores across the two time periods. The main effects comparing the two types of instructional approaches were also significant,  $F(1, 115) = 8.28$ ,  $p = .005 < .01$ , partial  $\eta^2 = .07$ , suggesting a statistically significant difference in the effectiveness of the two instructional approaches.

Therefore, the results demonstrate there was a statistically significant difference in MFCI pre-test versus MFCI post-test between students using the ILIS approach and those using the conventional instruction. The null hypothesis ( $H_0$  [conceptual learning]) was rejected.

#### Finding 2:

The current main study did not find gender effects on students' conceptual learning during the ILIS approach and the conventional instruction.

Table 5-8 shows the pre- and post-test performance of all participating students, according to two treatments, as measured by their scores in conceptual learning. Performance scores ranged from 0 to 108, with higher scores indicating better conceptual understanding.

**Table 5-8 MFCI test score means and standard deviation according to treatments and gender**

Treatment Gender	Pre-test			Post-test			Male		Female	
	Mean	SD	n	Mean	SD	n	Mean	SD	Mean	SD
Experimental group	50.41	11.24	22	44.03	12.04	33	68.14	11.50	66.24	11.10
Control group	47.16	16.38	25	44.14	9.68	37	57.36	17.64	53.89	10.39

Note: SD=standard deviation, n=number.

Table 5-8 shows that from pre-test to post-test the mean scores of male and female in both groups increased. The greatest difference between pre-test and post-test results lies in female students' scores in the experimental group, with 22.21 points which revealed that students in the experimental group obtained higher scores than those in the control group.

To statistically investigate the gender effect on students' conceptual understanding during the ILIS approach and conventional instruction, a 2-by-2 between-groups analysis of covariance (ANCOVA) was used with students' outcomes (pre-test) as a covariate. The results reveal that after adjusting for scores at pre-test, there was a marginally significant interaction between instructional approaches and gender,  $F(1, 112) = 4.14, p = .04, \text{partial } \eta^2 = .04$ . This indicated that students' conceptual understanding in the two groups differed according to gender. To break down this interaction, contrasts were the main gender effect. The main effect comparing male students and female students was not significant,  $F(1, 112) = 1.89, p = .17$ , suggesting no difference in the effects of gender between male students and female students. The substantial main effect was instructional approaches,  $\text{Wilk's } \Lambda = .30, F(1, 85) = 198.22, p < .001, \text{multivariate partial } \eta^2 = .70$ , showing a difference in conceptual understanding across the two types of instructional approaches. Therefore, no interaction gender effects existed. The null hypothesis ( $H_0$  [gender, conceptual learning]) was rejected.

#### 5.4.4 Research question 1<sub>2</sub>

RQ1<sub>2</sub>. What is the relationship between conceptual learning and confidence during the ILIS approach and conventional instruction?

This research question investigated the relationship between conceptual learning and confidence in learning when using the ILIS approach and conventional instruction. The main study expected that the ILIS approach students could gain more confidence in learning than those who used the conventional instruction. The result supported the positive effect of the ILIS approach on increasing students' confidence in learning. The results also showed that students' confidence in learning was a significant factor to predict students' conceptual learning. Findings were discussed below.



Hypothesis:

$H_{0 \text{ [confidence]}}: \mu_I - \mu_{NI} = 0$ . There is no statistically significant difference in student Conf pre-test and Conf post-test during the ILIS approach and the conventional instruction.

Finding 3:

An ANOVA was used to analyse whether the two treatment groups had any statistically significant difference in the Conf survey. The result shows there was no statistically significant difference between the two groups in the Conf pre-test before they participated in the intervention, with  $F(1, 115) = .27, p = .61$ .

Table 5-9 shows the pre- and post-test performance of all participating students, according to the two treatments, as measured by their scores on their confidence in learning. Performance scores ranged from 0 to 90, with higher scores indicating more confidence in learning/answers.

**Table 5-9 Confidence-in-learning survey means and standard deviation according to two treatments**

Treatment	N	MFCI test scores			
		Pre-test		Post-test	
		Mean	SD	Mean	SD
Experimental group	55	60.55	14.39	75.65	8.88
Control group	62	61.95	14.96	67.60	12.57

Note: N=number; SD=standard deviation.

Table 5-9 shows that the means of the two treatments increased from pre-survey to post-survey. The means in the experimental group increased by 15.1 points. This was much higher than those of the conventional instruction group whose means changed by less than 6 points. It is noteworthy that the variability measured by standard deviation in the experimental group was less than that in the control group. That indicates students of the experimental group mean represents more accurate post-test scores than those of the control group.

A repeated-measures ANOVA was conducted to statistically examine the treatment effects on the students' confidence-in-learning survey from pre-test to post-test. With inputting treatment group as a between-subject and time as a within-subject factor, the results showed that there was statistically significant interaction between instructional approaches and time,  $Wilk's \Lambda = .74, F(1, 115) = 40.99, p < .001, \text{partial } \eta^2 = .26$ . This indicates that the confidence in learning of types of instructional approaches differed according to time. There was a substantial main effect for time,  $Wilk's \Lambda = .63, F(1, 115) = 197.13, p < .001, \text{multivariate partial } \eta^2 = .63$ , with both groups showing an improvement in confidence in learning across the two time periods. However, the main effects comparing the two types of instructional approaches was not significant,  $F(1, 115) = 2.11, p = .15, \text{partial } \eta^2 = .02$ , suggesting no statistically significant difference in the effects of the two instructional approaches on confidence in learning.

Therefore, the results showed that there is no statistically significant difference in student Conf pre-survey versus Conf post-survey during the ILIS approach and the conventional instruction. The null hypothesis ( $H_0$  [conceptual learning]) was retained.

Finding 4:

Multiple linear regression analysis was performed to evaluate how well the confidence- in-learning factor predicts the student conceptual learning factor. Factors of the students' MFCI post-test scores were entered in the following hierarchical order: MFCI pre-test score at the first level, Conf post-test scores at the second level, and treatment group at the third level. The assumptions of normality, linearity, and homogeneity of variance were inspected and met. No significant outliers were detected. The skewness and kurtosis for each variable was within the reasonable range. And the multicollinearity assumption was met for this initial analysis, with tolerance statistics was  $> .10$  and VIF values were  $< 10$ .

Table 5-10 presents the correlations of the variables. The factors of the bivariate correlations among the MFCI post-test, MFCI pre-test, and confidence in learning were significantly positive. The factor of the bivariate correlation between MFCI post-test and treatment group was significantly negative. The factor of the bivariate correlation between confidence in learning and treatment group was also significantly negative.

**Table 5-10 Correlations between regression analysis variables in the main study**

Variables	1	2	3	4
1 MFCI Post-test	1.00	.82**	.52**	-.42**
2 MFCI Pre-test		1.00	.40**	-.05
3 Confidence in learning			1.00	-.35**
4 Treatment group				1.00

Note: \*  $p < .05$ ; \*\*  $p < .01$

As Table 5-11 has shown, MFCI pre-test was entered at step 1. The MFCI pre-test presented a significant factor, with  $R^2 = .66$ , adjusted  $R^2 = .66$ ,  $F(1, 115) = 227.08$ ,  $p < .001$ , explaining 66% of the variance in conceptual understanding. After entry of the confidence in learning at step 2, the total variance explained by the model as a whole was 71%,  $R^2$  change = .05,  $F$  change (1, 114) = 18.42,  $p < .001$ . The added confidence in learning measure explained an additional 5% of the variance in conceptual understanding, after controlling for MFCI pre-test. Specifically, confidence in learning was a significant factor,  $\beta = .24$ ,  $p < .001$ , as well as pre-test,  $\beta = .72$ ,  $p < .001$ . In the final model, the treatment group was entered at step 3, the three predictors were statistically significant, with the MFCI pre-test recording a highest beta value ( $\beta = .76$ ,  $p < .001$ ), the treatment group recording a higher beta value ( $\beta = -.35$ ,  $p < .001$ ), and the confidence in learning recording the lowest beta value ( $\beta = .10$ ,  $p < .05$ ).

**Table 5-11 Summary of hierarchical regression analysis for variables predicting conceptual post-test in the main study**

Predictor	B	SE B	$\beta$	t	p
Step 1 ( $R^2 = .66$ )					
Pre-test	.91	.06	.82	15.07	.000**
Step 2 ( $R^2 = .71, \Delta R^2 = .05$ )					
Pre-test	.81	.06	.72	13.16	.000**
Confidence in learning	.28	.07	.24	4.29	.000**
Step 3 ( $R^2 = .82, \Delta R^2 = .11$ )					
Pre-test	.85	.05	.76	17.27	.000**
Confidence	.19	.06	.10	2.13	.035**
Treatment group	-9.72	1.19	-.35	-8.17	.000*

Note:\*  $p < .05$ ; \*\*  $p < .01$

Therefore, this study found that in an inquiry-based learning with interactive simulations environment, confidence in learning played an important role in conceptual learning. Students' confidence in learning emerged as a significant contributor to predicting students' MFCI post-test as well as in pre-test and treatment groups.

### 5.4.5 Research question 1<sub>3</sub>

Research question 1<sub>3</sub> aimed to explore the relationship between conceptual learning and inquiry process skills during the ILIS approach and conventional instruction. This study expected that the ILIS approach would better develop students' inquiry process skills than conventional instruction would. The finding confirmed the positive effect of the ILIS approach on improving students' inquiry process skills on the Inq measures. The findings also found that students' inquiry process skills were a significant factor in predicting students' conceptual learning.

Hypothesis:

$H_0$  [inquiry process skills]:  $\mu_I - \mu_{NI} = 0$ . There is no statistically significant difference between student Inq pre-survey and student Inq post-survey during the ILIS approach and conventional instruction.

Finding 5:

An ANOVA was used to analyse whether or not the two treatment groups had any statistically significant difference in the Inq survey. The result shows there was no statistically significant difference between the two groups in the Inq pre-test,  $F(1, 115) = .07, p = .79$ .

Furthermore, a one-way MANOVA was performed to investigate group difference in four dimensions of the Inq pre-test. The four dimensions used were hypothesis, operation, communication and evaluation. The independent variable was two treatment groups. There was no significant difference between four dimensions in the two groups, Wilk's  $\Lambda = .97, F(4, 112) = .91, p = .46$ , multivariate partial  $\eta^2 = .03$ . When the results for the four dependent variables were examined separately, Analysis of variances (ANOVA) on each dimension shows that there was still no statistically significant difference, with Dimension 1 hypothesis with  $F(1, 115) = .55, p = .46$ , partial  $\eta^2 = .005$ ; Dimension 2 operation with  $F(1, 115) = .93, p = .34$ , partial  $\eta^2 = .008$ ; Dimension

3 communication  $F(1, 115) = .001, p = .74, \text{partial } \eta^2 = .001$ ; Dimension 4 evaluation with  $F(1, 115) = .37, p = .55, \text{partial } \eta^2 = .003$ .

Table 5-12 shows the pre- and post-test performance of all participating students, according to the two treatments as measured by the scores on their inquiry process skills. Performance scores ranged from 0 to 60, with higher scores indicating better inquiry process skills.

**Table 5-12 Inquiry ability score means and standard deviation according to two treatments**

Treatment	Experimental group		Control group	
	Pre-test Mean (SD)	Post-test Mean (SD)	Pre-test Mean (SD)	Post-test Mean (SD)
Inquiry process skills	36.69 (7.01)	48.65(5.82)	36.69(8.19)	38.45 (7.09)
Hypothesis	4.80(1.47)	7.49 (0.94)	5.02 (1.65)	5.60 (1.53)
Practice	8.91 (1.94)	11.58 (1.57)	8.53 (2.25)	9.02(2.04)
Communication	8.25 (2.26)	11.62 (1.87)	8.39 (2.12)	8.68(1.98)
Evaluation	14.72 (2.77)	17.96 (2.52)	14.37 (3.51)	15.16 (2.82)

As shown in Table 5-12, the means of two treatments increased from pre-survey to post-survey in the general inquiry process skills as well as the four dimensions. The means in both the experimental group and control group were increased. Students in the experimental group obtained much higher scores than those in the conventional instruction classes in terms of the general inquiry process skills and the four dimensions. The means in the control group did not change too much.

To statistically examine the difference between the two groups, a repeated-measures ANOVA was firstly conducted on the inquiry process skills from pre-survey to post-survey. With inputting treatment group as a between-subject and time as a within-subject factor, the results showed that there was a statistically significant interaction between instructional approaches and time, Wilk's  $\Lambda = .20, F(1, 115) = 450.26, p < .001, \text{partial } \eta^2 = .80$ . This indicated that the inquiry process skills of two types of instructional approaches differed according to time. There was a substantial main effect for time, Wilk's  $\Lambda = .11, F(1, 115) = 929.72, p < .001, \text{multivariate partial } \eta^2 = .89$ , with both groups showing an increase in inquiry process skills of survey scores across the two time periods. The main effects comparing the two types of instructional approaches was also significant,  $F(1, 115) = 16.67, p < .001, \text{partial } \eta^2 = .13$ , suggesting statistically significant difference in the effectiveness of the two instructional approaches on inquiry process skills. Therefore, the results demonstrate that there was a statistically significant difference in student Inq pre-survey versus Inq post-survey during the ILIS approach and conventional instruction. The null hypothesis ( $H_0$  [conceptual learning]) was rejected.

Further, a repeated-measure MANOVA was conducted to test treatment effect on four dimensions of inquiry process skills between pre-survey to post-survey. Inputting treatment group as a between-subject and time as a within-subject factor, the results showed there was a significant interaction between instructional approaches and time, Wilk's  $\Lambda = .11, F(1, 112) = 118.47, p <$

.001, partial  $\eta^2 = .81$ . This indicated that the four dimensions of the inquiry process skills of the two types of instructional approaches differed according to time.

Specifically, a repeated-measures ANOVA was conducted. There was a significant interaction between instructional approaches and time, Wilk's  $\Lambda = .46$ ,  $F(1, 115) = 137.13$ ,  $p < .001$ , partial  $\eta^2 = .69$ . This indicates that the hypothesis skill developed by the two types of instructional approaches differed according to time. There was a substantial main effect for time, Wilk's  $\Lambda = .26$ ,  $F(1, 115) = 329.59$ ,  $p < .001$ , multivariate partial  $\eta^2 = .74$ , with both groups showing an increase in hypothesis skills across the two time periods. The main effects comparing the two types of instructional approaches was also significant,  $F(1, 115) = 11.23$ ,  $p = .001 < .05$ , partial  $\eta^2 = .09$ , suggesting statistically significant difference in the effectiveness of the two instructional approaches on hypothesis skills.

A repeated-measure ANOVA was conducted. There was a significant interaction between instructional approaches and time, Wilk's  $\Lambda = .44$ ,  $F(1, 115) = 146.53$ ,  $p < .01$ , partial  $\eta^2 = .56$ . This indicates that the operational skill of the two types of instructional approaches differed according to time. There was a substantial main effect for time, Wilk's  $\Lambda = .27$ ,  $F(1, 115) = 304.74$ ,  $p < .01$ , multivariate partial  $\eta^2 = .73$ , with both groups showing an increase in operation skill across the two time periods. The main effects comparing the two types of instructional approaches was also significant,  $F(1, 115) = 17.16$ ,  $p < .01$ , partial  $\eta^2 = .13$ , suggesting statistically significant difference in the effectiveness of the two instructional approaches on operational skills.

A repeated-measures ANOVA was conducted. There was a significant interaction between instructional approaches and time, Wilk's  $\Lambda = .25$ ,  $F(1, 115) = 338.58$ ,  $p < .01$ , partial  $\eta^2 = .75$ . This indicates that the communication skill of the two types of instructional approaches differed according to time. There was a substantial main effect for time, Wilk's  $\Lambda = .19$ ,  $F(1, 115) = 478.60$ ,  $p < .01$ , multivariate partial  $\eta^2 = .81$ , with both groups showing an increase in communication skill across the two time periods. The main effects comparing the two types of instructional approaches was also significant,  $F(1, 115) = 14.17$ ,  $p < .01$ , partial  $\eta^2 = .11$ , suggesting statistically significant difference in the effectiveness of the two instructional approaches on communication skills.

Finally, a repeated-measure ANOVA was conducted. There was a significant interaction between instructional approaches and time, Wilk's  $\Lambda = .51$ ,  $F(1, 115) = 112.53$ ,  $p < .001$ , multivariate partial  $\eta^2 = .50$ . This indicates that the evaluation skills of the two types of instructional approaches differed according to time. There was a substantial main effect for time, Wilk's  $\Lambda = .27$ ,  $F(1, 115) = 304.97$ ,  $p < .001$ , partial  $\eta^2 = .73$ , with both groups showing an increase in evaluation skills across the two time periods. The main effects comparing the two types of instructional approaches were also significant,  $F(1, 115) = 8.78$ ,  $p = .004$ , partial  $\eta^2 = .07$ ,

suggesting a statistically significant difference in the effectiveness of the two instructional approaches on evaluation skills.

Therefore, the results demonstrate there was a statistically significant difference in student Inq pre-survey versus Inq post-survey during the ILIS approach and conventional instruction. The null hypothesis (H0 [conceptual learning]) was rejected.

**Finding 6:**

Multiple linear regression analysis was performed to evaluate how well the inquiry process skills factor predicts the student conceptual learning factor. Predictors of the students' MFCI post-test scores were entered in the following hierarchical order: MFCI pre-test score at the first level, Inq post-test scores at the second level, and the treatment group at the third level. In the main study, the assumptions of normality, linearity, and homogeneity of variance were inspected and met. No significant outliers were detected. The skewness and kurtosis for each variable was within the reasonable range. And the multicollinearity assumption was met for this initial analysis, where tolerance statistics was  $> .10$  and VIF values were  $< 10$ .

Table 5-13 presents the correlations between the four variables including pre-test, post-test, inquiry process skills and treatment group. The factors of the bivariate correlations among the MFCI post-test, MFCI pre-test, and inquiry process skills were significantly positive. The factor of the bivariate correlation between MFCI post-test and treatment group was significantly negative. The factor of the bivariate correlation between inquiry process skills and treatment group was also significantly negative.

**Table 5-13 Correlations between regression analysis variables in the main study**

Variables	1	2	3	4
1 Post-test	1.00	.82**	.36**	-.42**
2 Pre-test		1.00	.20**	-.05
3 Inquiry process skills			1.00	-.62**
4 Treatment group				1.00

Note: \*  $p < .05$ ; \*\*  $p < .01$

As Table 5-14 has shown, MFCI pre-test was entered at step 1. The MFCI pre-test presented a significant factor, with  $R^2 = .66$ , adjusted  $R^2 = .66$ ,  $F(1, 115) = 227.08$ ,  $p < .001$ , explaining 66% of the variance in conceptual understanding. After entry of the inquiry process skills at step 2, the total variance explained by the model as a whole was 71%,  $R^2$  change = .04,  $F$  change (1, 114) = 16.00,  $p < .001$ . The added inquiry process skills measure explained an additional 4% of the variance in conceptual understanding, after controlling for MFCI pre-test. Specifically, inquiry process skills was a significant factor,  $\beta = .21$ ,  $p < .001$ , as well as pre-test,  $\beta = .77$ ,  $p < .001$ . In the final model, the treatment group was entered at step 3. The results showed that the inquiry process skills factor was not significant in this final model. The MFCI pre-test and treatment groups were

statistically significant, with the MFCI pre-test recording a higher beta value ( $\beta = .81, p < .001$ ) than treatment group ( $\beta = -8.06, p < .01$ ).

**Table 5-14 Summary of hierarchical regression analysis for variables predicting conceptual post-test in the main study**

Predictor	B	SE B	$\beta$	t	p
Step 1 ( $R^2 = .66$ )					
Pre-test	.91	.06	.82	15.07	.000**
Step 2 ( $R^2 = .71, \Delta R^2 = .04$ )					
Pre-test	.87	.06	.77	14.92	.000**
Inquiry process skills	.38	.09	.21	4.00	.000**
Step 3 ( $R^2 = .81, \Delta R^2 = .11$ )					
Pre-test	.90	.05	.81	19.31	.000**
Inquiry process skills	-.10	.09	-.06	-1.10	.273
Treatment group	-11.60	1.44	-.42	-8.06	.000**

Note: \*  $p < .05$ ; \*\*  $p < .01$

Therefore, this study found that inquiry process skills had the strongest positive relationship with student conceptual learning. However, it was not the significant contributor to predict students' conceptual learning when comparing the performance of pre-test conceptual understanding and the two types of instructional approaches.

## 5.5 Qualitative findings

### 5.5.1 Who were the eight interviewees?

Two teachers and six students accepted the invitation to be interviewed. The two teachers were from school B, participating in the main study. One was Mr Zhang. He graduated in 1997 with a bachelor degree in physics and he had since worked in school B for 15 years. He was a senior teacher who was in charge of daily teaching activities as well as grade 10's teaching planning in physics. As Mr Zhang had 15 years' teaching experience with a good teaching reputation, he had often been invited to be a judge at national teachers' teaching contests. He expressed that he wanted to practice the inquiry-based teaching approach because he found that inquiry-based approaches "can engage students in deeper thinking through doing". This thought came from a national teachers' teaching contest titled "Action in different teaching methods". He explained, "Since inquiry-based teaching was proposed in 2003, my colleagues and I were eager to use it. However, we are still struggling with how to practise the inquiry-based teaching in our classes." There were several reasons that "stop the implementation of the inquiry-based teaching and learning". Mr Zhang provided examples such as "restriction of current examination system, conventional culture of teaching, lack of support from research, lack of knowledge about inquiry-based teaching methods etc." Mr Zhang said, "As a teacher, I feel shamed because I cannot explain what scientific inquiry is, and the way of conducting inquiry-based teaching and learning in practice". Mr Zhang expressed his interest in participating in relevant educational trials. And his perception and situation were the same as many Chinese physics teachers.

The other teacher was Mrs Han. She earned a bachelor degree in physics education from a prestigious public university in China in 2005. Since then, she has worked as a physics teacher at school B for seven years. Her daily work mainly focused on preparing lesson plans, teaching activities and marking assignments. Mrs Han became familiar with using the didactic teaching method in her classrooms. She explained, “Because I am good at language expression, I can effectively organise my class through talking with my students.” ‘Talking with my students,’ in other words, meant ‘using an auditory-verbal method to help the students understand or memorise the canonical concepts’. Mrs Han added, “I felt that my students also have got used to this type of class, because my students’ performance showed they received good scores.” However, Mrs Han expressed the same opinions as Mr Zhang—that she was eager to learn the inquiry-based teaching method. She said, “Even if my students received good academic achievements, I also felt the students are losing their curiosity and enthusiasm in learning physics.” Mrs Han wanted to develop her professional teaching literacy, especially the practice of the inquiry-based teaching and learning method. She also said, “This instructional approach was encouraged to be implemented by physics curriculum standards. I think it can meet my needs.” However, Mrs Han also noted that it is not an easy job to conduct the inquiry-based learning method. In China, students are heavily burdened as their futures are decided by a single college entrance examination, therefore, as Mrs Han said, “teachers firstly think about helping them obtain high scores. And a lecture-oriented class is an efficient way to transfer a large amount of important knowledge to students.” Recently, the patterns of the examination system were changed and curriculum standards requested the implementation of inquiry-based teaching. Mrs Han would like to join this research and expected it to help her “become the teacher who guides students’ learning instead of feeding them.”

Besides the two teachers, six students were invited to participate in an interview. Six students was a reasonable qualitative sample size, because it could reveal the full range (or nearly the full range) of potentially important perceptions. Based on the quantitative data analysis, 2 interviewees were selected from the participants whose scores fell in the upper quartile of the distribution, 2 interviewees from the middle quartile and the remaining 2 from the lower quartile. Accordingly, Hanson and Hank (H stands for high), Mike and Marie (M refers to middle), and Lily and Leo (L stands for low) were selected from upper quartile, middle quartile and lower quartile respectively.

When asked whether or not they liked physics, Marie and Leo expressed they did not like physics because “physics is too hard to understand. I felt bored of memorising laws and formulas.” Other students, including Hanson, Hank, Mike, and Lily, expressed interested in physics. Their reasons were different: for example, “I like physics because I think I am good at it, since I first studied it at junior high school” (from Hanson); “I am not sure whether I like it, but I know I have



to learn it with high scores” (from Hank); “I like experiments. They are interesting” (from Mike); and Lily explained, “I like my physics teacher. He is great at making complicated things more understandable.”

To sum up, the main study selected and invited two participating teachers and six students to engage in individual interviews.

### **5.5.2 What did the ILIS approach mean to the eight participants?**

The qualitative data set comprised two parts – interview transcripts for teachers and students and classroom observations. Thematic analysis was used to analyse quantitative data. Each data set was independently analysed and compared and contrasted to identify commonalities and points of divergence. Specifically, each student transcript was first coded according to the main interview questions. For instance, initial codes emerged from students’ reflections about their experiences with the ILIS approach and if and how the ILIS approach supported their conceptual understanding. These codes were analysed and classified based on similar theoretical or descriptive ideas. The second layer of coding focused on specific opinions. For example, interviews recorded how students and teachers interpreted their understanding of the five steps of the ILIS approach. Thus, similar descriptive ideas were extracted and categorised based on experiencing each step. Emergent themes were conducted at this layer. In the third layer of coding, students and teachers provided detailed explanations according to emergent themes. The percentage of each descriptive idea expressed by participants was also calculated and provided. After finishing each participant’s data analysis, the main themes and emergent themes were compared and contrasted across all participants. The data analysis further illustrates the thematic framework of this study by providing a unifying profile of all participants.

In order to explore how the students and teachers understood the concepts in relation to performance using the ILIS approach, the qualitative phase explored the following research questions: 1) In what ways did the ILIS approach affect student conceptual understanding? 2) How students’ confidence in learning influenced their conceptual understanding? 3) How students’ inquiry process skills influenced their conceptual understanding? More questions were provided in Appendix N and Appendix O in detail.

Students’ interviews were triangulated with teachers’ interviews across all participants. For instance, data analysis explored evidence that proved there were similarities and differences based on students’ and teachers’ responses. Furthermore, classroom observation ensured the trustworthiness of participants’ interviews. This will be discussed later. In addition, two researchers independently conducted qualitative data coding first. Final codes were created through discussion and reconciliation based on 96% alignment from two researchers.

Specifically, the six students and two teachers responded differently to the ILIS approach. Their initial conceptions focused on three main themes (see Table 5-15). The first theme was the five steps of the ILIS approach that used instructional activities for scaffolding students' conceptual learning. The second theme, confidence in learning, and the third theme, inquiry process skills, were produced through learning with the ILIS approach, and in turn convert into scaffolding conceptual learning.

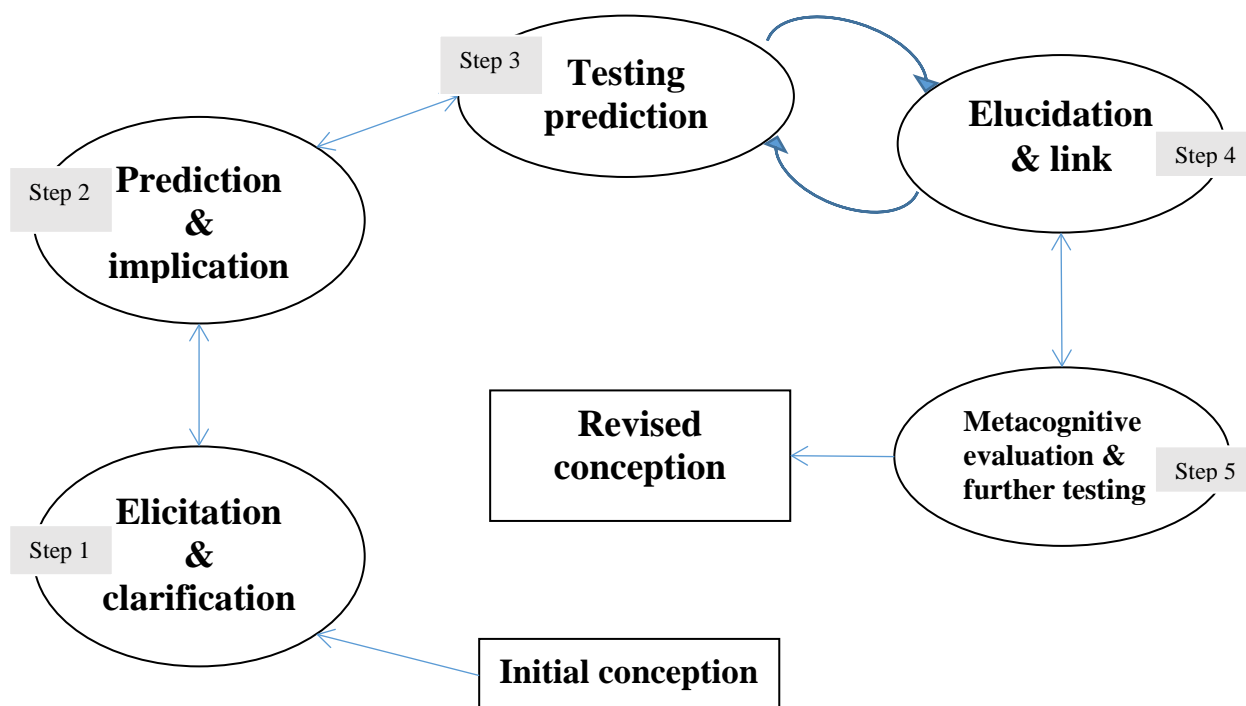
**Table 5-15 Main themes and features of the main study**

Main themes	Scaffolds	Specific features of scaffolds
Function of the ILIS approach on conceptual understanding	Roles of existing knowledge	Knowledge about existing concepts; Cognitive conflict
	Testing hypothesis through PhET	Easy operation; Virtual experiment; Multiple representations
	A style of scientific discourse	Claim with evidence; Two heuristic teaching strategies
Confidence in learning	Notions of metacognition evaluation	Benefit to internalising the understanding of ILIS approach; Metacognition thinking
	Confidence from specific ILIS steps	From students' presentations; From using the precise language
Inquiry process abilities	The steps of ILIS approach	Prediction skill, operation skill, communication skill, and evaluation skill;
	A mandatory scaffold	Student's worksheets

Based on the three themes, functions regarding specific features of scaffolds are interpreted and discussed in the following sections.

### 5.5.3 Making sense of conceptual learning through ILIS approach

As argued in previous studies, conceptual learning is recognised as an actual process through educational activities (Posner, 1998). The ILIS approach provided students with different activities across five steps to support their conceptual learning of forces and motion, as shown in Figure 5-1.



**Figure 5-1 Procedure of the ILIS approach**

***Step one and two: Roles of existing knowledge***

Six students and two teachers alluded to notions of the first two steps as “学情”. The translation of “学情” is “learning situation”, which aims to understand what students know about physics concepts. This term has been well known by students and teachers since the latest curriculum reform in China. In the conventional classroom setting, the implementation of the learning situation was to ask students to finish their worksheets before the next lesson. In the ILIS context, students offered their opinions: “Although the ILIS classroom cancels learning situation worksheets, I felt Mr Zhang actually facilitated me to understand how much I know about force and motion” (Hanson). Hank and Mike expressed similar opinions that learning situation worksheets forced them to memorise all knowledge before each topic. These were “boring”, “wasting time” and “adding to study load”. Thus, they preferred the ILIS approach without the learning situation worksheet, but it still “engaged me in the teacher’s clarification of physics phenomena when compared with their conventional class.”

Conversely, teachers said that they should modify learning situation worksheets instead of abolishing them, because “the original purpose of learning situation worksheets is to help students and teachers understand where they are”. In the ILIS class, a learning situation examination was integrated into the first step of the ILIS approach. As Mr Zhang said, “I felt the learning situation examination was removed from before-class to on-class, from students’ examination to both teacher and students’ work-together.” Before-class refers to the conventional way where students

independently completed learning worksheets before the lesson was conducted. On-class means teachers used different strategies (e.g., a scenario, quick tests, small experiments) to enable students to understand their existing knowledge. This was implemented during the first step in the ILIS classroom: elicitation and clarification. Mr Zhang commented,

I felt the ILIS approach provides me a real opportunity to understand students' existing knowledge. Take the inertia lesson as an example. I employed a daily scenario to engage students with my questions. The questions were about the relationship between force and motion that usually makes students confused. This way is different from my conventional classroom, where I usually summarised what I taught during the lesson, and then introduced the new topic of the lesson without examination of what students already know about what I am going to teach.

When further probing teachers' transcripts, a related finding focused on the term of misconception. Teachers highlighted the motivational aspect of the ILIS approach, which offered alternative conceptions to elicit students' existing knowledge. Mr Zhang viewed it as teaching strategies and expressed that using common misconceptions "can make students engage in surprising thinking. When you find something is different from your understanding, it can become a motivation for further learning". In addition, Mrs Han noted that misconceptions promoted actual engagement in learning: "it was effective because the teacher clarified how they have that misconception. When you were told something in class, especially that something is different from what you thought, you usually want to test it." Likewise, students noted that "I am looking forward to testing my own thoughts" (Mike); "I feel excited I can manage a computer to do physics experiments" (Hank). Although Lily expressed she was not confident in operating the computer for investigation, she admitted that, "Conducting PhET simulations is more fun to test my ideas and others." Ultimately, based on students' existing knowledge and current new scientific conceptions, the teacher led students to outline each individual's predictions for testing through PhET simulations.

Marie was the only student who stated she found the learning situation worksheet useful. She explained, "They can help improve my physics scores if I understand all the questions." However, she also expressed, "I prefer Mr Zhang leading us to learn a new physics concept, which is the faster way for me to understand new knowledge." Indeed, Marie's view presented an interesting dilemma that appeared among a number of teaching strategies—how to let teachers and students become aware of what they already know. Indeed, it emphasised that a good beginning should provide opportunities for students to reduce their conflicts and clarify why they had the conflict and what the scientific understanding is. After that, the students should have time to test both opinions.

### ***Step three: Testing hypotheses through PhET***

Examination of students' and teachers' voice-recordings led to the identification of three functions of testing hypotheses through PhET: namely, easy operation, virtual experimental environment, and multiple representations. Specifically, students revealed a dichotomous perception of these three functions when they were involved in conceptual learning through the ILIS approach.

Students ascertained that testing hypotheses through PhET simulations was easy because "I can easily manipulate variables to test what the worksheets asked and what I wanted. I like the computer software", Hanson explained. Lily highlighted "(PhET simulation) made it easy to see my experiments. For example, when I changed different forces on objects, I can immediately see what the changes are." Hanson noted that PhET simulations made learning become efficient because "there were certain buttons that easily let you figure out how to conduct software interface. And instant outputs showed how I input." In contrast, Hank and Mike expressed that there was "no challenge" when they tested their hypothesis. For example, "inputting numbers (mean how much force there is) and then seeing what motion the objects had. This is too easy to have challenges." (Hank). Likewise, Mike said that "I click some buttons, and the computer can do it all for me. It's not necessary for me to think about the variables I should control." Hank and Mike suggested that before or after they conducted the PhET simulations to test their hypothesis, teachers should discuss with them the differences between the use of PhET simulations and the practice in the lab regarding 'doing experiments'.

Another related finding was participants' explanations of the virtual experiments provided by PhET simulations. Students commended the virtual environment for motivating their interactive learning. For example, regarding the force and motion simulation, "a lot of us enjoyed playing with computer-based experiments. I like choosing the iced surface and brick surface with extreme force, which brings me more fun" (Leo). More specifically, Hank explained "the extreme situation tested my hypothesis in a special way that I cannot do in labs. I also needed to calculate the forces that made objects move as I wanted." Lily expressed that PhET simulations provided an alternative to lab experiments that asked them to follow instructions because, "if we do not follow the instruction, we will either damage lab instruments or hurt ourselves. But I don't like following instruction. It's so boring." Similarly, Mike expressed opinions like Lily's. He added, "I prefer testing something I want to. The computer virtual environment provided me opportunities to test lots of things." Only student Marie expressed different opinions. She said there was no difference between the use of PhET simulations and the practice in the lab, because "I followed students' worksheets to finish all tasks in the ILIS approach classrooms. Similarly, I followed teachers' instructions in the conventional instruction class." When probing teachers' transcripts, Mr Zhang elaborated on the difference. He said, "The ILIS approach asks students to finish the worksheets, and meanwhile it

also encourages students to test their own hypothesis.” Mrs Han added, “Especially when the students explored their own hypothesis, they could become more engaged in constructing conceptual understanding and the relationship of different variables.”

There was still a related finding focused on participants’ opinions about representations of PhET. The multiple representations of the PhET simulations supported students’ conceptual understanding. Hanson first mentioned the animations. He said the PhET animations were vivid, because “The graphics showed me the little man’s changing position, velocity and acceleration during his movement.” Hanson expressed he was deeply engaged in observing different movement with different forces. Likewise Hank noted, “The numbers on the graphics provided me specific parameters that helped me understand the relationship among movement, applied forces, and surface situation.” Mike added, “The computer saves me time. In the ILIS approach classroom, I focused on observing the little man’s movement through playing with playback and pause buttons.” Based on the assistance of multiple representations, students followed their worksheets and finished tasks (i.e., forces and motion), discussing the relationship between forces and motion through the data they collected and made initial conclusions.

In contrast, some students stated that they needed more interpretation when facing the multiple representations of PhET simulations. Leo commented that it was easy for him to play with the little man and fill in all tasks; however “It was difficult to understand the relationship between numbers and the law I was learning.” He also told the researcher his partner also had this problem. Lily noted, “I expected Mr Zhang would have interpreted how to explain the numbers. But he did not.” These viewpoints were only from Leo and Lily who were struggling with learning physics. Regarding the other four selected students, they did not mention this kind of problem. Indeed, it was necessary for teachers to provide extra support for those who had learning difficulties in physics, such as an example that could explain the reasons for testing, and interpret the relationship between movement and different forces under different surfaces, because “Teachers’ explanations not only supported students’ experiments, but also monitored students experiments” (Mr Zhang). Similarly, Mrs Han emphasised the importance of teacher roles: “I felt that teachers should provide extra interpretations especially for students with learning difficulties.” Otherwise, students did not understand “the underlying relationship between the little man’s movement, and the number from parameters’ graphs,” Mrs Han found. She noted that she only had limited time to support several students to interpret their data. When she found most students completed the worksheets, she led the students to the next step that focused on interpreting the experimental data.

#### ***Step four: A style of scientific discourse***

Consistent with students’ views, two teachers not only noted a style of scientific discourse that emphasised argumentation with claim-and-evidence, but also mentioned heuristic strategies.

Overwhelmingly, the two teachers found that the style of discourse functioned to support students' conceptual understanding. In the context of ILIS, six students acquired the style of discourse. Five students ascertained that they had deeper understanding about Newton's laws of motion. For example, Hank expressed that the ILIS approach class allowed them to present ideas differently: "You know, when my classmates did presentations, simulations provided them interactive animations that not only showed their findings, but also made them like scientists." Similarly, Mike explained that some physical phenomena were difficult to understand. For example, when one group claimed that it did not need force to keep objects moving, they provided evidence with simulations, "I remember, the vivid simulation picture directly supported the presenter's claims. It was very straight."

Hanson, who did a presentation during the main study, felt that step 4 was the most important part at the ILIS approach class. He did not have difficulties in testing his hypothesis. But he said, "Although the use of vivid PhET animation supported my group's presentation, and I did make claims with evidence, I also needed support when I discussed with others." He added, "When my teacher noticed my expression difficulties, Mr Zhang told me the exact words I should use. The feeling was great. I learned." It seemed that students had gained awareness of generating claims with evidence from the ILIS lessons. Hanson and his partner expressed an active desire to share claims with evidence. Hanson also added, "my partner and I felt more confident in what we learned through the ILIS approach." But it was obvious that the teacher's support in language expression was also needed.

Likewise, Mike also mentioned the style of argumentation using claim-with-evidence. He said, "my claim was  $F = ma$ . I used the numbers, the animation, and figures that helped me explain my claims." He also expressed at the very beginning that it was hard for him to explain the relationship in words. But "it became easier during the third ILIS lesson."

The ILIS approach emphasised the function of precise language. During students' presentations, teachers were requested to facilitate students' interpretation using precise language. Mr Zhang noted the importance of using science-precise language during students' argumentation, "not only because my students can describe physics phenomena properly, but also I felt my students became more confident when they introduced their claims." Mrs Han said, "I felt students' argumentation skills were improving. I am so glad they actively joined in with my questions." In particular, Leo, who was Mr Zhang's student, explained, "I learned a lot from the conversations from teachers and presenters. I felt sometimes what they were talking about was exactly what I was confused about." Conversely, Leo criticised the conventional instruction class, saying, "I did not understand the laws and rules in my physics book. I did not like memorising them." When Leo was asked why he preferred the ILIS approach to the conventional instruction, he told the researcher,

“Because I was involved in sharing my thoughts. I felt good when I could understand others’ talking that I did not know before.”

And, during step 4, two teachers highlighted the teaching strategies regarding the Confucian heuristic teaching concept. Mr Zhang and Mrs Han supported the use of Confucian heuristic teaching strategies, because “these especially helped teachers facilitate students’ learning instead of feeding students” (Mr Zhang). Mrs Han expressed that the strategies “helped me transfer from a lecturing-orientated teacher to a inquiry-based teacher”. For example, during the students’ presentation, the teaching strategies asked the teacher to listen to students’ findings. And then the teachers were allowed to “tell the students” canonical expressions. This was one strategy named “bu fen bu qi, bu fei bu fa”, Mrs Han said. Mr Zhang added that step 4 “asked teachers to wait until students finished their tests. And then the teachers provided support in language expression”. Otherwise, there were no productive results to “interpret the physics concepts, because the students, they did not want to understand them.” The Confucian heuristic teaching strategy asked the teachers to emphasise the time for supporting.

As the selected students and two teachers said, there was a problem regarding the use of scientific words to communicate with others in physics. The two teachers confirmed they did their best to provide the students with the necessary information to use scientific words in answering questions. However, most of the students did not achieve their expectations. However, the ILIS students were confident in the use of scientific words after the eight-week intervention. Mr Zhang found the difference was “the time”. He explained by comparing learning Newton’s first law using different instructional approaches:

In the conventional instruction classroom, I often directly told my students what they should learn. And I also directly interpreted the right answer if their answers were wrong. I found that my students paid more attention to memorising concepts, laws even if they did not understand them. In contrast, the ILIS approach asked me to wait for the time when the students independently wanted to share their findings, but they used inappropriate words, terms, or sentences to describe their findings. Then it’s time for teachers to support the students’ language expressions.

Alongside this experience, Mr Zhang was confident that it facilitated students’ argumentation: I really like this notion. It should not push students to memorise laws and principles that are written in a textbook. We should encourage students to speak their findings. We also should facilitate students to use appropriate language.

With the further probing of the participants’ scripts, another strategy important to conceptual understanding emerged. Students were encouraged to ask the teacher questions; meanwhile the students prepared to use the physics knowledge to deduce other things. Mrs Han said, “After the



students presented their findings, the presenters named other students to ask me questions. This was so fun. I was engaged.” She also said, this was a good time for teachers to “further interpret the meaning of the laws or give a brief summary.” Mr Zhang added, “I remember one student asked a question that should be learned at university. I never thought he knew physics.” Both of the teachers admitted that this strategy also motivated physics teachers’ professional development.

Leo said that presenting in class “was a challenging task for me. However, I can participate in discussing with presenters in another way. Especially, I can ask teachers questions.” Leo felt proud because “I on behalf of my group asked my teacher a question. And I can use Newton’s third law to explain the question. I felt great.”

Hanson noted that presenting and speaking in public was challenging, but “after my group asked one of my classmates a question, I really felt a new sense of achievement. I can explain why their claim was actually the same as ours using scientific language. Exciting!”

Likewise, Mike noted, “Mrs Han paid more attention to presenters’ interpretation. Sometimes she corrected them, sometimes asked them questions, and also asked us to ask questions.” What’s more, Mike admitted he appreciated the ILIS approach, because this approach changed his way of communicating with others. He said, “I am a faster learner. I always directly told my partner answers no matter his understanding. Now I learned to listen to my partner’s ideas and opinions.” Mike added, “I also asked my partner to ask me questions like we did during the ILIS class.”

Besides, Mr Zhang also used students’ questions to identify where the students’ understanding was. He said while he answered the students’ questions, he was leading the students to the lesson topic they were learning. Mr Zhang provided an example from his class. He said there was a student who asked him where the equal and opposite force went when he hit a wall. “Firstly, the student used ‘equal and opposite’ words. That meant he might understand Newton’s third law, but still with misconceptions.” Mr Zhang said, “I showed him two examples. One was regarding two students sitting on chairs. One used PhET simulations with its multiple representations.” Mr Zhang looked proud of his instructional strategies and told the researcher, “With my interpretation, the student understood Newtons’ third law. And he concluded, “For every action, there is an equal and opposite reaction on the other object. And the equal and opposite reaction on the other object is balanced or cancelled.”

As previously noted, Marie was the only student who did not support the use of the ILIS approach. Regarding the opinions of step 4, Marie also expressed negative feelings towards this step. She said, “The presentation and communications were not efficient. I can use that time to finish lots of exercises that are good for my examinations.” However, when Marie was asked whether discourse sharing supported her conceptual understanding, she expressed disappointment in it, explaining, “You know, Newton’s laws are not difficult for me to understand. Why should I

spend so much time arguing with others?” Regarding this point, Mrs Han might explain Marie’s question. Mrs Han said, “Students who have got used to the didactic learning method need time to get used to ‘speaking’, because this can benefit students’ learning.”

Contradictorily, Marie admitted, “Discussing with my partner helped me become more clear about the relationship between force and motion. And it was not bad to listen to the presentations.” Again, a conflict existed in Marie’s opinions. Actually Marie admitted her conceptual understanding was improved through the assistance of language. Although Marie first expressed negative feelings, she later told the researcher, “Since Mr Zhang encouraged us to share and discuss findings in class, I also found it’s not bad. I think I need time to get use it.”

### ***Step five: Notions of metacognition evaluation***

In the pilot study, Mrs Wang questioned the use of the metacognition evaluation step. She suggested that teachers should work with students to fill in the metacognition evaluation forms, meanwhile explaining its function to students. It functioned to help the students understand the aims of each step and foster a habit of monitoring the learning process. Based on modifications, the participating interviewees from the main study considered the metacognition evaluation as a practical step when they explored the physics questions.

Specifically, the six selected students expressed that the metacognitive evaluation provided them an opportunity to reflect on their learning process. It made them understand “learning was a dynamic inquiry-based process instead of a conclusion” (From Hanson, Mike and Lily). Mike said that metacognitive evaluation provided him with “the evidence of my conceptual learning. It was great to have a look at my original thoughts and my final claim.” He explained, “Even if my original thought was right, I think my understanding was still improved when tracking with students’ worksheet.” Lily also expressed a similar opinion and said, “When I finished a lesson, I never went back to review my original thoughts and the learning process. I always focused on the final answer.” Leo added, “My group never thought we collected so many data through twenty tests. When we went through the worksheets, I realised science is not an easy job.” Hanson, who was a student with better academic performance, emphasised the relationship between each step and the entire inquiry-based sequence. He said, “The ILIS approach is a great on-going learning way. If my group did not understand each step well, we might not be actively involved in the following step.” Thus, he suggested students should pay attention to the metacognitive evaluation step, because “after we had the metacognition thinking, it would support us to do better at each step and finally achieve higher conceptual understanding.” However, he also said, “If we acquired the metacognitive thinking, it was not necessary to spend too much time reviewing all steps.” His reasons were similar to those of the two teachers: “metacognitive evaluation should be introduced by teachers, but how and how long should be up to students.”

In terms of teachers, they emphasised internalisation regarding the metacognitive evaluation step. Mr Zhang said, “The metacognitive evaluation step is a way that can help students internalise the process of the ILIS approach.” Mrs Han added, “Metacognitive evaluation thinking is a great way to foster students’ inquiry-based habit. This habit is good for students’ lifelong learning.” Both of them demonstrated there was hardly an opportunity to teach students metacognition thinking in conventional instruction. They affirmed that they can integrate the metacognition thinking into other classes after the ILIS approach trial was finished.

#### **5.5.4 Contribution of confidence in learning through ILIS approach**

The pilot study found a relationship between confidence in learning and conceptual understanding. In the main study, five of the six students expressed that they obtained confidence in learning from using the ILIS approach. For example, Leo explained, “The ILIS approach made me realise I am not bad in physics because I can finish most parts of the students’ worksheet. And I do understand Newton’s laws.” Lily put it this way: “I felt my teacher spent more time getting us clear on what force and motion are. It made me confident in learning others.”

All six students emphasised the effects of class presentations on their confidence in learning. Hanson, who did a presentation during the main study, said that the ILIS class “pushed me better”. When asked the meaning of “pushing you better”, he explained, “I have known Newton’s law well. But the class presentation is new for me. I felt great when I did a good job during the presentation.” He also told the researcher that it was a different feeling that he thought of himself as a scientist to use the computer to present his group’s findings and discuss with his classmates and the teacher.

Further analysing students’ transcripts, the use of precise language was a factor that improved students’ confidence in learning. In particular, Leo, who was Mr Zhang’s student, told the researcher he learned a lot from the ILIS class; in particular he learned from others’ mistakes. Leo said, “When Mr Zhang corrected presenters and other students’ expression, I was learning. When it’s my turn to present, Mr Zhang said the words I used were precise.” Mike also supported the notion: “From the ILIS class, I understood there are other meanings of forces. Now I think I can use precise meaning to interpret the force in physics.” Mr Zhang also noted the importance of using science-precise language when learning physics. He felt happy when he found the method supported students’ understanding, and told the researcher, “Not only because my students can describe physics phenomena properly, but also I felt my students became more confident when they discussed with others.”

Five interviewees also mentioned that the ILIS approach offered those opportunities to understand that everyone had strengths and weaknesses in physics learning. And everyone has a

potential to become better in the “operational aspect, presentation aspect, communication aspect or high academic scores”, Mike said.

Only Leo mentioned how the use of the computer supported their inquiry-based learning. This way also provided him with confidence in understanding. But when the other five selected students were asked whether the use of PhET simulations influenced their confidence in learning, their opinions were similar: “I felt engaged in playing with PhET simulations” (from Hank, Mike and Marie), or “I am not confident in using computer to investigate questions, but PhET is not difficult to conduct” (from Lily).

In turn, the confidence in learning also supported the ILIS students’ investigation. As Lily said, “My confidence in understanding of Newton’s laws was from the ILIS approach classes. I think this can motivate me to learn others.” Likewise, Hanson, Hank and Mike also expressed they can confidently explain the relationship between forces and motion regarding Newtons’ three laws. This feeling would stimulate them to explore other concepts through using the ILIS approach.

To sum up, the ILIS approach provided instructional activities to support students’ confidence in learning. The main study found the ILIS approach improved students’ confidence in learning, especially regarding step 4: elucidation of findings and linking results to the scientific conception. During this step, the students developed confidence in learning through presentations with the style of scientific discourse and the use of precise language expressions. As Mr Zhang and Mrs Han noted, the students’ confidence in learning was improved by learning with the ILIS approach, and then converted into the motivation of learning physics.

### 5.5.5 Contribution of inquiry process skills through ILIS approach

When asked about whether or not the ILIS approach enhanced the inquiry process skills, participants’ transcripts indicated two aspects. First, the process of the ILIS approach naturally produced inquiry process skills. As the six students said, each step of the ILIS approach aimed to improve one particular skill. They thought their inquiry process skills were improved after the eight week intervention finished. Table 5-16 showed the inquiry process skills mentioned by student participants.

**Table 5-16 Summary of students’ understanding about inquiry process skills**

ILIS approach steps	Inquiry process skills	Contributions to conceptual understanding and specific description
Prediction & implication	I <sub>1</sub> . Prediction skill I <sub>1</sub> . Identification of problem I <sub>2</sub> . Skill of proposing hypothesis	“I understand the problem situation. I remember, my friend was standing on icy playground. The scenario asked me to think about force exerted on my friend.” (Lily) “The original force is the only one force that continuously exerted on my friend in the direction of motion.” (Lily) “Actually my partner proposed a guess. I think it was also mine. Besides the gravitational force and ground reaction, there was no force exerted on my friend.” (Mike)

Testing & prediction	I <sub>2</sub> . Operation skill I <sub>2.1</sub> Skill of conducting educational tools; I <sub>2.2</sub> Skill of gathering information I <sub>2.3</sub> Skill of making a claim I <sub>2.4</sub> . Skill of cooperation	“Testing so many times provided all information that was useful to finish all activities.” (Hanson) “Simulations make out the number and information that my group needed.” (Hank) “My partner and I like using simulations. It’s easy to test what we want and finished our tasks.” (Leo and Lliy). “Using simulations is ok. I am looking forward to more challenging way. My partner also thinks like me.” (Marie)
Elucidation & linking	I <sub>3</sub> . Communication skill I <sub>3.1</sub> Claim with evidence; I <sub>3.2</sub> Arguing with evidences; I <sub>3.3</sub> Using scientific language I <sub>3.4</sub> . Skill of cooperation	“I modified my expression based on my classmates’ presentation and Mr Zhang’s suggestion. It sounds more scientific – since there was no surface friction, my partner is influenced only by the gravitational force.” (Marie) “Yes, my group’s claim was that there is no force exerted on the little boy. According to the evidence we collected though simulation, the numbers showed no acceleration and the velocity kept the same.” (Mike) “My group also provided our example. A ball was thrown into the air. We thought this can let my classmates understand our claim well.” (Hank)
Metacognitive and further testing	I <sub>4</sub> . Evaluation skill I <sub>4.1</sub> Forward to further test or go back to the current one. I <sub>4.2</sub> Evaluate whether using metacognitive thinking	“I felt that my experiment was innovative because of involving the computer.” (Leo) “At the beginning, I thought it was fun to test my guess. After all lessons, I had a clear thought about how to solve the question. It’s good to learn further knowledge. I am looking forward to using other simulations to test my thoughts.” (Hank) “Although my original thought was consistent with my results, I learned how to solve problems using inquiry process.” (Mike) “Until now, I was still confused with this. I thought there was force exerted on that little boy, because the boy was moving. According to Mrs Han’s suggestion, I re-do my investigation. I still cannot understand. Being a physics scientist is too hard for me.” (Marie) “At the first time, I felt the group next to me did better than my group. I noticed they finished all tasks faster than us. But, we did much better at the second time. I can follow my partner’s pace.” (Lily)

Noticeably, five of six students expressed that the ILIS approach improved their cooperative ability, especially when they used PhET simulations to test their hypothesis and made presentations to share their findings. Hanson told the researcher the ILIS approach taught him teamwork and asked the researcher whether his understanding was right. He said, “Teamwork is individual’s thinking, meanwhile working together to finish tasks.” He and Mike expressed that the teamwork was mutual. Mike explained, “I learned from working with my partner, especially good for their computer skills and the scope of knowledge. My partner also learned from me.” Hank added, “There was hardly any cooperative activity in the conventional instruction class where we listened to teachers’ lectures and individually finished tasks.” For students such as Leo and Lily, they noted the cooperative testing and presentation was meaningful because working together reduced their thinking burden. Lily told the researcher, “I need a partner during the ILIS approach. Particularly, when I did not know why my thinking was different from others, I could talk with my partner.”

When the researcher asked her whether she needed a partner as an emotional support, she explained, “Maybe yes. My partner was good at the computer. I am not. It’s great to work together.”

And, six students overwhelmingly made positive responses regarding the contributions of communication skills to conceptual learning. Marie expressed, “I preferred the conventional instruction to the ILIS approach”. However, she also admitted, “The ILIS did modify my expression. Based on my classmates’ presentations and Mr Zhang’s suggestion, I could use more scientific words to explain my findings.” Other participating students also admitted their communication skills and language expression improved after learning with the ILIS approach. Although most of them felt pressured by the ILIS approach that pushed them to “speak, discuss and explain”, they were satisfied with their learning outcomes. Leo told the researcher that he can link what he learned to daily phenomenon. “I interpreted inertia phenomenon when I took my father’s car. My father said my explanation was correct” (Leo). Hank shared that he wanted to become a scientist in the future. “Thus firstly, I think I should talk like a scientist, like my teacher. It’s cool when I communicate with others using the way the ILIS approach asked”, Hank said.

In addition, when asking interviewees about how they thought of their investigative activities, the six selected students could evaluate their performance through proper evaluation words. These words revealed that the ILIS approach had the potential to improve participants’ evaluation ability. Leo and Hanson used the word ‘innovation’ to describe their work. Leo explained the use of computer-based simulations made his test process “innovative and creative”. Other students, such as Hank, Hanson and Mike, used ‘logic’ to evaluate their investigative process.

Interestingly, when the six students were asked how they knew the inquiry process skills, all six students answered “from their teachers”. Mr Zhang said, “During the last step, I explained to the students the inquiry process skills of each step”. So did Mrs Han. She told the researcher, “When I worked with the students to evaluate their performance, I introduced the meaning of each step, including the skills that step expected them to focus on”. When further analysing their transcripts, the word ‘worksheet’ related to inquiry process skills. The six selected students stated that the students’ worksheets supported and monitored the development of their inquiry process skills.

As the teacher was introducing the meanings of each step, the students finished evaluating the other groups’ performances. When further analysing students’ transcripts, the ‘worksheets’ related to the acquirement of inquiry process skills. As some students said, the teacher’s interpretation helped them understand the function of each step. Meanwhile, “The worksheets were practical to help me understand the relation between each step and its particular inquiry skills”, Hanson said. Other students also expressed the same opinions. For example, Hank said the worksheets recorded the learning process with lots of information: “With Mr Zhang’s interpretation, I got a very impressive understanding of each step, especially when I evaluated others’ work from the

worksheet.” Lily and Leo also expressed that the students’ worksheets not only scaffolded their evaluation tasks, but also provided an opportunity to learn the ILIS approach from an evaluator. As Mike said, “When I evaluated others’ performance, it’s easy to recall what I wrote down on my group’s worksheet.” He told the researcher that evaluating another’s work motivated him to reflect on his performance. Mike said, “I think I learned a lot when I evaluated another’s worksheets.” Similarly, Hank and Hanson also mentioned the self-reflection from evaluating another’s work using the worksheets. They still added, “This way let us quickly become familiar with the ILIS approach, which was good for future learning.” Noticeably, Hank and Hanson expressed that the evaluation step was interesting the first time. But, as Hanson said at the last ILIS lesson, “I felt it’s boring”. He suggested that “the worksheets should provide extra activities to satisfied students who were familiar with the ILIS approach.”

In brief, the ILIS approach improved inquiry process skills, mainly including four dimensions. The use of student’s worksheets not only helped the ILIS students evaluate their performance, but also internalised or familiarised the sequence of inquiry-based learning. The participants’ transcripts indicated that the development of inquiry process skills was useful for the further learning of concepts. As Mrs Han said, “These skills were heritable. They finally can be converted into supporting conceptual learning.”

### 5.5.6 Summary

This section reported a comprehensive interpretation of qualitative data. Findings addressed the question of how the students and teachers understood conceptual learning in relation to performance by using the ILIS approach. The results from the qualitative phase showed that there were three contributors enhancing students’ conceptual understanding. The first contributor was the use of the ILIS approach. The second contributor was students’ confidence in learning that was improved by using the ILIS approach and in turn supported students’ concept construction. The third contributor was inquiry process skills. Like confidence in learning, the four dimensions of inquiry process skills were also developed by each step of the ILIS approach. They then functioned to support conceptual learning.

In conclusion, the ILIS approach offered meaningful opportunities for students in producing or reproducing conceptual learning of forces and motion. Table 5-17 summarises the main finding from the interviews.

**Table 5-17 Interview data summary**

Main themes	Contributor	Specific concepts	Hank	Hanson	Marie	Mike	Leo	Lily	Mr Zhang	Mrs Han
Steps of the ILIS	Roles of existing	Knowledge about existing	√	√	√	√	√	√	√	√

approach	knowledge	concepts;								
		Cognitive			√	√	√	√	√	√
		conflict								
		Testing	Easy operation;	√	√	√	√	√	√	√
		hypothesis	Virtual	√	√	√	√	√	√	√
		through	experiment;							
		PhET	Multiple	√			√		√	√
			representations							
		A style of	Claim-with-	√	√		√	√	√	√
		scientific	evidence;							
discourse	Two heuristic				√			√		
	teaching									
	strategies									
	Notions of	Benefit to	√	√	√	√	√	√	√	
	metacogniti	learning as								
	on	process;								
	evaluation	Metacognition	√	√		√	√	√	√	
		thinking								
Confidence	Confidence	From students'					√	√	√	
		presentations								
in learning	specific	From using the	√	√	√	√	√	√		
		ILIS steps								
Inquiry	The steps of	Prediction skill	√	√		√	√	√		
		Operation skill	√	√		√	√	√		
		Communication	√	√	√	√	√	√		
		skill								
abilities	approach	Evaluation skill	√	√	√	√	√			

## 5.5 What happened in the classroom?

Throughout the eight-week educational trial, two researchers observed all lessons to ensure that teachers followed the experimental protocol and control protocol. A total of 32 classroom observations (sixteen observations in ILIS classrooms and sixteen observations in conventional classrooms) were made in accord with protocols. During observations, Professor Liang and Ms Fan sat at the back of classrooms and completed different copies of observation checklists.

Before each lesson, the teachers were requested to fill in relevant lesson plans (see Appendix J). The lesson plans were to assist the teachers in understanding their teaching approaches. They also provided a way for the teachers to evaluate whether or not they followed their previous lesson plan.



After all lessons, analysis of classroom observation data showed one significant similarity and five differences between the ILIS approach class and the conventional instruction class. The only similarity was the use of certain teaching models. The teaching models were aimed to support students to become accustomed to the learning procedure and then focus on understanding concepts. While the model was used by teachers in the conventional classrooms and rarely by students, conversely, the model was used by students in the ILIS approach classrooms and teachers facilitated the students' engagement and understanding. It seemed that both types of teaching models obeyed physics curriculum standards, although in different ways, especially details of teaching procedure.

The differences between the ILIS approach classrooms and the conventional instruction classrooms have been reflected in the MFCI test, surveys and participant interviews. As shown in the following table, it reveals six differences from a classroom-observation perspective. The first substantial difference related to 'what teachers were doing'. In the ILIS approach classroom, we verified that (a) teachers focused on students' alternative concepts for engagement; (b) teachers provided opportunities with computer-based simulations for students to test their hypothesis with peers to test hypothesis; (c) teachers facilitated students' presentation through style of scientific discourse and with heuristic teaching strategies; (d) teachers encouraged students metacognition about the entire learning process, and then brought closure to further learning; (e) teachers and students engaged in teaching and learning.

In the conventional instruction classrooms, we verified that (a) teachers controlled instructional procedures; (b) teachers concentrated on student mastery of concept facts; (c) teachers explained all key concepts during direct-lectured instruction; (d) teachers controlled students' learning pace; (e) teachers were much more engaged in learning but students just followed teachers' step by step instruction.

The second distinct difference concerned 'what were students doing'. In the ILIS approach classroom, (a) most of time was devoted to students working individually or with peers; (b) students proposed their hypothesis and then conducted simulations to test them; (c) students drew their claims and explanations for solving problems; (d) students received teacher's assistance through the entire experimental process; (e) students seemed to be engaged in the entire process. In the conventional instruction classrooms, (a) students focused on listening to teachers' lectures; (b) students did not have self-learning and with seldom discussions; (c) students were encouraged by providing correct answers.

The third difference involved 'resources being used'. In the ILIS approach classrooms, (a) students used computer-based simulations for testing; (b) students used worksheets that monitored their learning and scaffolded inquiry-based learning. On the other hand, in the conventional approach classrooms, (a) students used very traditional materials such as paper and pencil, ramps,

test tubes, plants, mechanical devices; (b) students had ‘learning situations’ that helped them preview what they were going to learn; (c) students had ‘testing worksheets’ that helped their summative evaluation about current lesson.

**Table 5-18 Key points observed with the ILIS approaches and conventional instruction**

	In ILIS approach classroom	In conventional instruction classroom
What teachers were doing	<ul style="list-style-type: none"> <li>• Posing open-ended problems which started from students’ alternative concepts;</li> <li>• Supporting students to integrate their investigative skills through ‘doing’;</li> <li>• Fostering students scientific discourse with presentation;</li> <li>• Encouraging students’ metacognition habit with reflection.</li> </ul>	<ul style="list-style-type: none"> <li>• Using controlled and structured instruction to manage class;</li> <li>• Using scripts and lesson plan to lead students’ learning;</li> <li>• Using lectures to support students’ concepts understanding and problem solving strategies.</li> </ul>
What students were doing	<ul style="list-style-type: none"> <li>• Learning through conducting simulations;</li> <li>• Learning through experiencing investigative activities;</li> <li>• Learning with peers and teachers;</li> <li>• Learning from sharing ideas about how to solve problems;</li> </ul>	<ul style="list-style-type: none"> <li>• Learning through listening to teacher lectures;</li> <li>• Learning from finishing ‘learning situation’ worksheets and tests.</li> </ul>
Resources being used	<ul style="list-style-type: none"> <li>• Computer-based interactive simulations for testing;</li> <li>• Students’ worksheets that monitored their learning and scaffolded inquiry-based tests.</li> </ul>	<ul style="list-style-type: none"> <li>• Traditional materials such as paper, pencil, ramps, student ‘learning situation’ worksheets, and test worksheets.</li> </ul>
Effectiveness at promoting conceptual change	<ul style="list-style-type: none"> <li>• Encouraged students’ conceptual change through engaging students in an inquiry-based process;</li> <li>• Prompted student to report their hypothesis and claims through presentation;</li> <li>• Supported students to co-construct conceptual understanding during presentations.</li> </ul>	<ul style="list-style-type: none"> <li>• Conceptual change by “reproductive conception of learning or the rote learning of the texts”.</li> </ul>
Effectiveness at supporting inquiry-based process	<ul style="list-style-type: none"> <li>• Iterating-oriented inquiry process through students’ doing;</li> <li>• Metacognition reflection on the entire procedure.</li> </ul>	<ul style="list-style-type: none"> <li>• Structured inquiry process through teacher’s lecture;</li> <li>• No metacognition reflection.</li> </ul>
Effectiveness at Improving confidence	<ul style="list-style-type: none"> <li>• Active discussions;</li> <li>• Using affirmative words and casual-relation words during presentations;</li> <li>• Engaging in explaining claims;</li> <li>• A few eureka moments when students conducted simulations for testing.</li> </ul>	<ul style="list-style-type: none"> <li>• Lecture-oriented learning setting;</li> <li>• Learning by doing exercise.</li> </ul>

The fourth significant difference related to ‘effectiveness at addressing conceptual change’.

The ILIS approach and conventional instruction aimed to address students’ conceptual change using different ways. The ILIS approach (a) encouraged students’ conceptual change through engaging students in an inquiry-based process; (b) prompted students to report their hypothesis and claims through presentation; (c) supported students to co-construct conceptual understanding during presentations. In contrast, there were few interactive activities for students’ conceptual change in the conventional instruction setting. The rote learning and lots of exercises were mainly observed at

conventional classrooms. To show detailed difference, excerpts of the ILIS and the conventional classrooms are presented below.

Excerpt 1 was taken from Mr Zhang’s Newton’s first law lesson in ILIS setting.

Evidence	Category
S <sub>group1</sub> : Before testing, we wrote down our hypothesis.	(a) Engage in inquiry-based process
T <sub>Zhang</sub> : Can you describe your hypothesis? That can make us understand what your hypothesis is?	
S <sub>group1</sub> : We thought objects do not move if there is no force acted on the objects.	(b) Promote students to report their hypothesis and claims through presentation;
T <sub>Zhang</sub> : And after testing, do you have different understanding about your hypothesis?	
S <sub>group1-A</sub> : Yes, we did have different opinions at the first testing. Then we did several times testing and Susan agreed with my thought.	
T <sub>Zhang</sub> : You told us there is an argument between you two. What’s that?	(a) Encourage students clear of their understandings
S <sub>group1-A</sub> : Yes, and I find I am wrong later.	
S <sub>group1-B</sub> : I also found my thought was wrong.	(c) Support students to co-construct conceptual understanding during presentations
T <sub>Zhang</sub> : What do you think before? And why you think you are wrong?	
S <sub>group1-A</sub> : I don’t think there was a balanced force if you want objects to keep moving. For example, when I push a desk and want the desk to keep moving. I have to push it harder and harder.	
T <sub>Zhang</sub> : What do you mean harder and harder?	
S <sub>group1-A</sub> : That means the desk can stop moving if I keep pushing it with the same size force.	
T <sub>Zhang</sub> : Does anyone have that experience?	
S <sub>some</sub> : Yes/no.	
T <sub>Zhang</sub> : How was your partner thinking at that time?	
S <sub>group1-B</sub> : I don’t agree with her. I think using the same size force can make the desk keep moving and stay a balance movement.	
T <sub>Zhang</sub> : Now it seems both of you have made an agreement with this question. Am I right?	
S <sub>group1</sub> : Yes, both of us have changed our thoughts.	(a) Engage in inquiry-based process by using interactive simulations
T <sub>Zhang</sub> : How did you make that?	
S <sub>group1-A</sub> : We conducted different experiments though wooden surface and iced surface. And we found a same rule that is our conclusion.	(a) Encourage students clear of their understandings
T <sub>Zhang</sub> : How do you conduct your experiments to make the conclusion?	
S <sub>group1</sub> : Playing with simulation.	
T <sub>Zhang</sub> : Could you show the experiments for us?	
S <sub>group1-A</sub> : If you push the object with the same size force after the object starts to move, the object can move with the accelerated motion.	
T <sub>Zhang</sub> : How did you know the object is moving with an accelerated motion?	
S <sub>group1-A</sub> : From this force graph with numbers.	
T <sub>Zhang</sub> : So the motion was accelerated?	
S <sub>group1-A</sub> : Yes, look at this (He pointed at the PhET simulation interface). And if you push the object with the harder and harder force after the object starts to move, the object can also move with the accelerated motion.	
T <sub>Zhang</sub> : This happens in any situation? Like icy surface and non-icy surface? Thank you for group one’s presentation. Any other group wants to answer this question?	
(Then there was another group named Group 2 answered this question.)	(c) Support students to co-construct conceptual understanding
S <sub>group2-B</sub> : Our group think it depends.	
T <sub>Zhang</sub> : What do you mean by “depend”?	(b) Promote students to report their hypothesis and claims
S <sub>group2-B</sub> : If you suddenly withdraw your force after the object starts to move, the situation changes on different surfaces.	
T <sub>Zhang</sub> : Can you show for us through simulations?	(b) Promote students to report their hypothesis and claims
S <sub>group2-A</sub> : You can see these (animations). On the wood surface, the object would become slower and slower until it stops. But on the ice surface (no friction), the object would keep moving with the same velocity.	

T<sub>Zhang</sub>: Can you explain your conclusion with the numbers showing on PhET simulation? through presentation;

All conversations were observed and noted during group presentation that is the fourth step of ILIS approach. These conversation demonstrated students who were aware of their original concepts, struggled with conceptual understanding and overcome conceptual changes in the ILIS setting.

This study also observed Mrs Han's Newton's first law lesson at the conventional instruction classroom. All information was observed and noted during Mrs Han's lecturing. The lesson was started from Mrs Han's questions?

T<sub>Han</sub>: Do you know Aristotle, Galileo, Descartes, and Newton?

S<sub>some</sub>: Yes/No.

T<sub>Han</sub>: They are physics scientists. Their studies were related to today's topic. I will give you ten minutes to read the textbook. Please have a look at their different opinions on force and motion's relation.

Then Mrs Han led students' to review the scientists' viewpoints that were presented in the students' textbook and spent several minutes discussing the relevant viewpoint. In order to provide the students with an ongoing learning experience from one scientist's viewpoint to another, Mrs Han used an animation and texts that proved why and how the different viewpoints challenge, enrich and confirm others. The animation was about Galileo's ramp experiment in an ideal condition. After that, Mrs Han presented the scientific expression of the Law on screen: An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force. She introduced inertia as the name of this kind of force. Following that, Mrs Han further proposed the questions: 1) what factors could impact an object's inertia property; 2) Does water or gas have inertia? She organised the students to discuss in groups. Finally, Mrs Han suggested students complete their exercises related to Newton's first law.

The fifth distinct difference involved 'effectiveness at addressing inquiry processes'. In the ILIS approach classroom, (a) students engaged in an iterating-oriented inquiry process; (b) it also provided an opportunity with the metacognition step to foster students' inquiry process reflection habit. Conversely, the conventional instruction relied more on the teacher's structured lectures to lead students to understand the inquiry-based process. There was no relevant metacognition of inquiry process in the conventional classrooms.

The sixth substantial difference concerned 'effectiveness at improving confidence'. (a) In the ILIS classroom, students were observed involving in conducting PhET. Most groups had actively discussions to finish questions on students' worksheets. The learning atmosphere was different from conventional classroom's atmosphere. (b) Students were confident in presenting their results, and explaining their claims. The sentences such as "The experiment strongly proved our hypothesis",

“This numbers proves our claim sufficiently” were used during students’ presentation. Some words such as “therefore, because, reason of, conclude” were also used to explain students’ claims. Oppositely, these sentences were hardly recorded at the conventional classes. These words were used by teachers to explain causal relation. Most students paid attention to their teacher’s lectures and notes. There were not many interactive activities at conventional settings. (c) In the ILIS classroom, there were a few ‘eureka’ moments when students conducted simulations for testing their hypothesis. The sound attracted the teacher to take a look of the group’s outcomes. There were three teacher-student-conversation observed at the ILIS classroom. However, in the conventional instruction classroom, students revise and consolidate concepts and knowledge doing exercise. They received feedback from teacher’s answers and explanations.

Data from classroom observations indicated significantly different teaching approaches between the ILIS approach and the conventional instruction. As shown in Table 18, these highlighted key points suggesting that the ILIS approach offered students more learning resources and investigative experiences when compared with the controlled and structured conventional instruction. These findings were consistent with participants’ interviews. It also provided evidence to explain quantitative data. The consistency of data analysis is further discussed in Chapter Six.

## **5.6 Summary of the main study**

This chapter offered a summary of the research findings based on the quantitative phase and the qualitative phase from the main study. Data from the quantitative phase has indicated that students using the ILIS approach statistically outperformed those using conventional instruction in terms of conceptual learning of forces and motion. Furthermore, the findings from the sequent interview data were consistent with the findings from the initial quantitative phase. Eight participants interpreted how the ILIS approach contributed to their conceptual learning through using the ILIS approach. In addition, relevant evidence emerged from classroom observations that also supported these findings.

In summary, students’ conceptual understanding arose from implementing each step of the ILIS approach. And the improvement of students’ confidence in learning and the development of students’ inquiry process abilities in turn contributed to conceptual understanding of forces and motion. These findings were consistently identified by the data analysis from the initial quantitative phase and the subsequent qualitative phase.

The next chapter will provide discussion through theoretical perspectives and make a conclusion based on research questions.

## **Chapter 6 Discussion and conclusion**

The purpose of this study was to investigate the effects and efficacy of the ILIS approach on conceptual learning of forces and motion. In the pilot study, 38 grade 10 students and one physics teacher from one public school participated. In the main study, 142 grade 10 students and three physics teachers from two public schools participated.

This chapter covers the discussion and conclusion of the current research study. Section 6.1 presents important findings of the study. Each finding is discussed from quantitative and qualitative perspectives. Section 6.2 suggests some theoretical implications. Section 6.3 draws implications for science education based on the findings. Section 6.4 outlines the limitations of the study. Finally, section 6.5 concludes the study and summarises the educational trial conducted within the study.

### **6.1 Overview of findings and discussion**

#### **6.1.1 ILIS approach intervention enhanced students' conceptual learning of forces and motion**

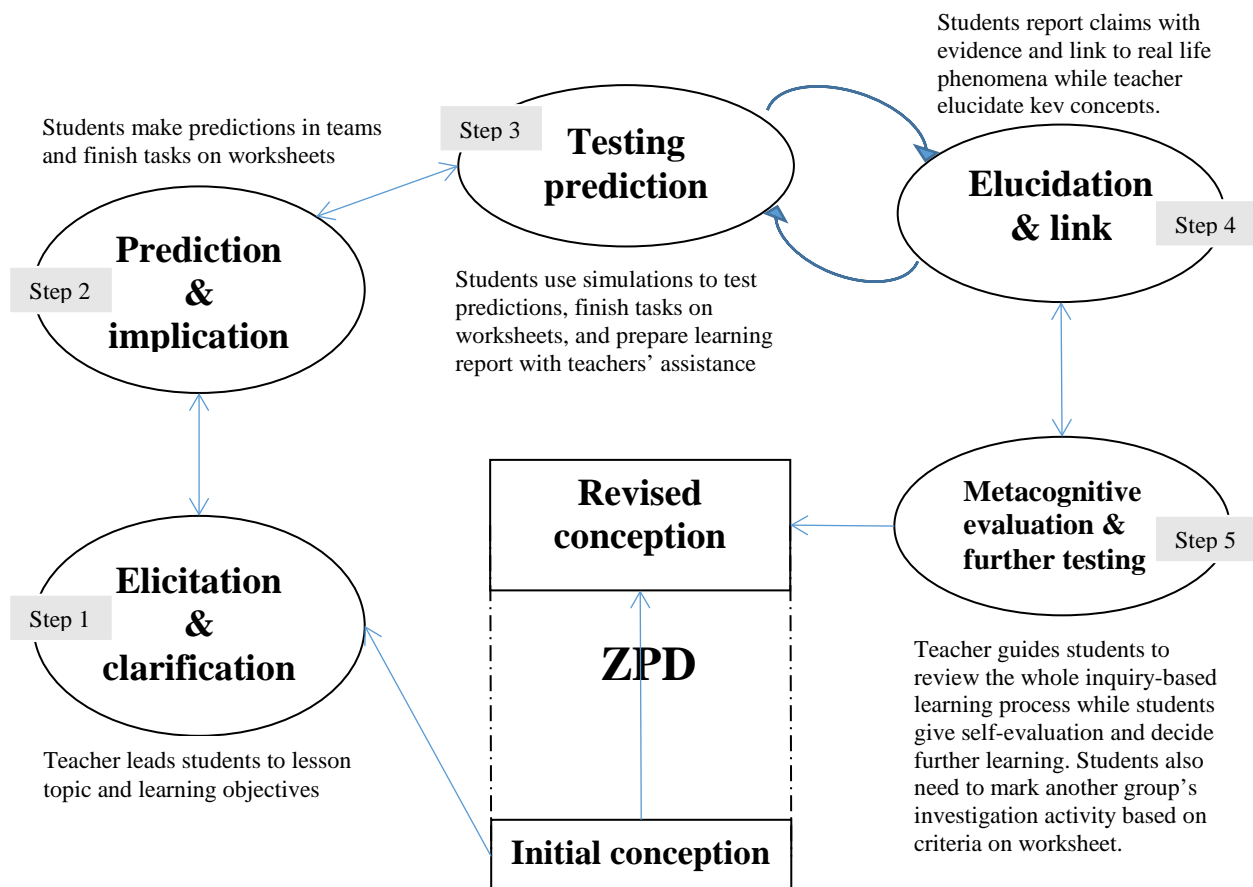
This study found that the inquiry-based learning with interactive simulation approach enhanced students' conceptual understanding of forces and motion. The ILIS approach provided different activities to support students' acquisition and integration of physics concepts. And, this study proved that conventional instruction improved students' conceptual understanding but not as good as learning by ILIS approach (Bryce et al., 2005; Driver et al., 1994; Falconer et al., 2001; Hake, 1998; Mills et al., 1999; Redish, 1999; Zavala et al., 2007).

The ILIS approach was designed with different instructional activities that correspond to each step, as shown in Figure 6-1.

In the first step, elicitation and clarification, the use of experiments, videos, or questions contextualises the alternative conceptions in order to activate students' existing knowledge and experiences. Students are encouraged to describe their understanding of the alternative conceptions, their intuition regarding the phenomenon, and any experience of it in their personal life. Studies have found that students construct new knowledge and understandings based on what they already know (Bransford et al., 1999; She, 2004). They suggest that linking students' existing knowledge to the new concept may enable students to take more responsibility for their learning. In this study, the alternative conceptions are addressed in class when they are located, tested and discussed.

In the second step, prediction and implication, the ILIS approach uses worksheets that enable students to write down their predictions regarding the lesson topics. Meanwhile, teachers provide short explanations to make sense of students' opinions. The ILIS approach suggests that teachers give students specific learning goals, such as clearly telling students to explore the relationship between velocity and distance during the lesson. Studies have found that a clear learning goal tends

to facilitate more learning (T. H. Lin et al., 2009; Simon et al., 2009). In this study, the learning goal was a conceptual change from alternative concepts to canonical concepts. The specific learning goals, on one hand, helped the students to ‘locate’ an investigative question. On the other hand, the clarification of the ill-structured concepts influenced more in-depth learning (J. R. Anderson, 2010; Posner et al., 1982). The instructional speculations were supported in the pilot study and the main study. Participating interviewees noted that the clarification of alternative concepts led them to a “clear” learning goal. And the clarified learning goal supported their tests.



**Figure 6-1 Conceptual change through the ILIS approach – Details of description in Chapter 2.**

In the testing-with-simulation step, students have more opportunities with the PhET simulations to test their predictions in pairs. PhET simulations that allow students to manipulate parameters and observe changes (de Jong et al., 1998; Sokolowski et al., 2010), establish cause-effect relationships between conceptual information and multiple representations (Kozma et al., 1997), and provide a virtual environment where students test, develop, and evaluate their learning (Gobert, 2000). This issue will be discussed further in the next section.

To synthesise a coherent understanding of the phenomenon, step four, elucidation and link, asks students to present their investigation activities and report their claims with evidence. This step enables students to acquire and practise the skill of using evidence to support claims. The

importance of claims is proposed in the *Framework for K-12 Science Education* (NRC, 2012). It is proposed that supporting a claim with evidence is a basic aspect of scientific argumentation that a scientist or a science student should use. Meanwhile, teachers play a role in facilitating students' ability to interpret their data. As facilitators, teachers should help students interpret their data using the Confucius heuristic teaching strategies proposed in this study. That is, teachers should provide opportunities for students to present their investigative learning process and results. And teachers should also grasp this opportunity to support students' use of scientific language. After students present their report, the presenters can ask other students to link their claims to the phenomenon in daily life.

To ensure the new conception is intelligible, plausible, and fruitful, the third step of the ILIS approach supports students to test their predictions by using interactive simulations. In this testing step, there will often be two (or more) concepts 'competing': a common student misconception (or a few) and a canonical scientific concept. Alternative conceptions are resilient. Thus, the necessity of repeated experiences and exposures means that more than one cycle through steps 2, 3 and 4 may be required in a single teaching sequence.

In the final step, metacognitive evaluation and further test, students evaluate another group's ILIS learning worksheet. In doing so, students realise the strength and limitations of their own ILIS learning experience, internalise the process of inquiry-based learning, and establish a metacognitive thought in another ILIS learning experience. This step also focuses on reinforcing students' ideas, and thus constructs—or re-constructs—a deeper conceptual understanding of forces and motion. The achievement of conceptual change does not end with the current topic. It will lead students to another topic, because “science learning is very much a connected whole, and both knowledge and skills from one topic are relevant to other topics” (Geelan et al., 2014, p. 265).

The ILIS approach students' results were compared to those of conventional instruction students, who acquired knowledge from typical science lectures and test exercises. They participated in activities similar to those in the ILIS classroom, such as engagement activities and evaluation activities. In contrast, the purpose of the engagement activities was to review what the students had learned from the last lesson. The evaluation activities were based on reciting physics concepts from the textbook. Pencil-and-paper tasks were used to examine whether the students could choose the correct answers. A particular difference between the two teaching methods was that conventional instruction encouraged the students to follow the teacher's instruction rather than developing students' interests. As a result, in the main study the ILIS approach group revealed a more significant conceptual change in understanding of forces and motion than the conventional instruction group.



While the ILIS approach intervention was effective in improving conceptual learning in the main study, it did not do as well in the pilot study. As speculated in the earlier discussion, the length of intervention may have diminished the pilot study's significant effectiveness in the post-test. Boone (1988) found no significant difference between the treatments when there were only a few weeks of intervention. Lowering the length of intervention may impact students' learning (J. L. Flowers, 1986).

### **6.1.2 Alternative conceptions immediately engaged students in learning**

In this study, engagement using alternative concepts was adapted into the ILIS approach. This study found that the use of alternative concepts attracted students' attention actively. Cognitive conflicts have potential to engage students in an active process of constructing knowledge (NRC, 2000).

In practice, ILIS teachers can use instructional videos, pictures, stories, simple experiments and questions to attract students' attention. ILIS teachers are encouraged to use alternative concepts to elicit students' existing conceptual understanding. As observed in classrooms, some students held existing conceptual understandings that were canonical. There were also some students who held misconceptions. The classroom observers reported that the majority of ILIS students were engaged in thinking and discussion regarding the alternative concept.

Interviewees provided reasons why alternative concepts immediately involved them in conceptual learning. Six interviewed students reflected two kinds of answers. Two of them said that the alternative concepts "surprised" them, in terms of their understanding of inertia. They expressed that they wanted to know more. Five interviewed students admitted that they held the alternative conceptions that teachers mentioned. When they realised the alternative conceptions were incorrect, they were willing to engage in further learning because, "After I overcome the alternative conceptions, I could get more scores" (From Mike). However, there was one interviewed student, Marie, who did not think she had alternative conceptions. Although she ignored the conceptual conflicts evoked by being exposed to alternative conceptions, under such circumstances, she may maintain her alternative conception but still develop other conceptual understandings. Studies have found that students can add new information to their existing knowledge framework, rather than replace the old concepts (Scott et al., 2007; Tao et al., 1999). It is worth noting that Marie (17%) in this study did not reject the use of alternative conceptions. She was also actively involved in learning.

Therefore, the finding supports the literature that suggests instructional activity should begin from cognitive conflicts, such as the use of alternative concepts in physics, because it can stimulate students' enthusiasm to engage in learning.

### **6.1.3 The combination of PhET simulations with inquiry-based instruction was effective in learning**

In this study, inquiry-based learning with PhET interactive simulations successfully leads to students' conceptual learning, when compared with students in the conventional instruction classroom. This result was consistent with increasing studies that showed the combination of interactive simulations with the pedagogical framework works for students' learning (Bybee et al., 1995; Sahin et al., 2009; Schwarz et al., 2005). The simulation-based inquiry learning environment provides students with more effective learning opportunities, and students' achievements outperformed conventional instruction (Chen, 2010; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Vreman-de Olde et al., 2013).

The findings from the pilot study and the main study showed why the use of PhET simulations facilitated conceptual understanding. Firstly, PhET simulations provided an interactive virtual lab. The virtual lab supported implementation of experiments, particularly those that people cannot carry out in the real world. For example, force and motion simulations created a non-friction setting where students changed parameters to test their hypotheses. The unlimited testing hypotheses influenced students' understanding such as they said "we either changed our conceptual understanding or need to do more learning". Six interviewed students expressed that they were more interested in interactive operations than in following the cookbook experiments. Studies showed that conventional cookbook laboratories cannot promote students' science process skills (Kilinc, 2007). However, the study of Donnelly et al. (2013) found that students tend to trust the results that they created by themselves rather than those provided by computer-based simulations in a virtual world (Chinn et al., 2002). This study proposed it is more important to explore the way how teachers interpret data and their casual relation than to discuss where the data and results come from.

Secondly, PhET simulations provided multiple representations that could be used to share cognitive load. This study found there were three channels for supporting students' conceptual understanding: the auditory-verbal channel, visual-pictorial channel, and tactile-operational channel. Educators have known the first two channels that proposed by Paivio (1986) and developed by Mayer (1992). Findings of this study proved that students learning through multimedia-based two channels outperformed those who learned the same topics by conventional approaches. In conventional learning settings, when information was presented to ears (such as teacher's questions and lectures), students processed that verbal information in the auditory channel. And when information was showed to eyes (such as printed words on textbooks), students processed that pictorial information in the visual channel. However, ILIS classrooms provided more types of verbal information (such as teacher's questions and lectures, students' discussions and

explanations) for students to make sense of a specific concept. Studies showed that language could help students to understand and acquire the terms needed to describe relevant phenomena properly (Clark et al., 2007, 2008). What's more, when students conducted PhET simulations to test their hypothesis, dynamic animations, images, charts, tables showing on the computer interface and printed words on textbooks helped students' understanding. When the information was presented to students' eyes, they could begin to process the information in the visual channel. The finding supported studies that representations of scientific concepts were effective in consolidating students' learning (Gijlers et al., 2013; Jari et al., 2014; Vreman-de Olde et al., 2013). In addition, in the ILIS learning setting, when students made presentations to explain their claims, in-depth conceptual understandings had taken place in the combination of verbals and visual materials, rather than isolated from one another (Mayer et al., 1992).

This study proposed a third assumption that there is a third channel (i.e., tactical-operational channel) for students' learning. The tactical-operational channel processed procedural actions mainly in the tactical-operational channels, but processing of procedures in words takes place initially in the visual/pictorial channel and then moves to the tactical-operational channels. The processing of procedures from verbal way also takes place initially in the auditory/verbal channel and then moves to the tactical-operational channels. Students responded the use of PhET simulations made their experiments much "easier". They concentrated on testing their hypothesis, discussion and presentation rather than worrying about "using different experimental instruments and operational mistakes". The two participating teachers also reflected that the use of PhET simulations helped them to overcome teaching limits. Experimental safety would be the last thing in their mind. And they found they had more time to observe students' actions and listen to students' discussion in groups. These findings were consistent with the study of Sokolowski and Rackley (2011). Differently, in the conventional instruction classroom, the didactic teaching method provided mainly auditory-verbal information and fixed pictures in textbook for conceptual learning. The results of this study were consistent with findings of previous studies that effective conceptual learning needs more than one channel (Paivio, 1986; Sadoski et al., 2001). And all three channels serve as a starting point for learning and retrieving knowledge. The ILIS approach offered the auditory-verbal channel, visual-pictorial channel, and tactile-operational channel that could create optimal learning environment.

Lastly, through the use of PhET simulations, teachers were afforded more time to observe students' learning instead of focusing on students' safety in laboratories. Interestingly, the two teachers (Mr Zhang and Mrs Han) showed a consistent opinion on their use of PhET simulations in supporting students' presentation and leading to a rich discussion. They reported it was apparent that PhET simulations created more discussion of interpretations and arguments in the experimental

group compared to those in the control group, who were taught by the teacher's demonstration and lectures. More interactive conversations took place in the ILIS inquiry-based instruction situation, where students explored simulations to complete their own tasks. For example, students in pairs discussed how to conduct the computer-based simulations. They negotiated the representative meaning and relationship between different numbers. During the presentation, more convincing evidence was provided to explain and support their conclusion. Using scaffolding with the simulations was an efficient way to find out where students made mistakes and where they misunderstood. This led to more inspiring discussions. In another example, where Mr Zhang asked students the same questions in the ILIS approach classroom and the conventional classroom, he felt that the ILIS students outperformed those using the conventional instruction. Mr Zhang also noted that he used different types of questions in the ILIS classrooms, such as inference, interpretation, reflective, and hypothesising, because the ILIS students expressed an enthusiasm for communicating. This provides a platform for teachers to diagnose their students' problems and then support their further learning.

#### **6.1.4 Students' conceptual understanding benefited from the style of scientific discourse**

In this study, a style of scientific discourse enhanced the depth of students' conceptual understanding. The style of scientific discourse was defined as 'an argument with a claim, data, and reasons'. It is a way of sense-making and developing meaning within a group of individuals. It involves teachers, students, and scaffolds in verbal communications. In practice, the ILIS students were asked to present their claims based on data and explanation, to express arguments with claims, evidence, and reasons. The interviewed students reported that the use of scientific discourse was effective in their understanding of forces and motion. Particularly, they benefitted from practising their use of scientific language. Previous research has found that it is important for science learning to practise scientific language (Brown et al., 1989; Lemke, 1990; Yore et al., 2007). China's physics standards also explicitly called for the development of scientific language through learning core concepts (MoE, 2001). The ILIS approach provides a step to help students understand and practise scientific language. It could facilitate students "making the language of science their own" (G. J. Kelly et al., 2003).

When compared with the conventional instruction class, the argumentation from the ILIS approach students was supported by evidence. The interviewed students explained the evidence was collected when they tested their hypothesis through conducting the PhET simulations. They still noted that they benefitted from the previous steps. The previous steps provided them a better understanding of investigative questions. This finding was consistent with the study of K. E. Chang

et al. (2008), which indicated that students can gain greater learning outcomes if they gain a better understanding of the knowledge background.

Based on a better understanding of learning objectives, information background, and investigative questions, the interviewed teachers found that students were more engaged in their presentations than before. And during students' presentations, the teachers were able to provide specific instructions about using scientific expressions. It was vital to teach the students scientific expression because the language of daily science is different to the language that has been developed and used in the science community (Scott et al., 2007). What is more, in the ILIS classroom, teachers supported students' presentations, especially use of language. It was easier to make students realise their incorrect expression in the context of specific situations.

### **6.1.5 Metacognitive evaluation of the ILIS approach impacted students learning**

This study found that most grade 10 students did not know metacognitive thinking. And metacognitive thinking is missing knowledge in the participating school. Some studies have found that metacognitive thinking has the potential to enhance students' conceptual change (Fulton et al., 2009; Murphy et al., 2006; Vosniadou et al., 2001). This current study set out to help students consciously engage in metacognitive evaluation tasks. As the six interviewees expressed, the metacognitive evaluation encouraged them to become aware of their original concepts, the modified outcomes, and the process of conceptual change. This last step of the ILIS approach provides students with a metacognitive evaluation activity to develop consciousness in their planning and monitoring of their learning (Georghiades, 2006; Huang et al., 2003). Students may not construct the knowledge if there are few opportunities for metacognitive activities (Gunstone, 1991).

The pilot study suggested that the metacognitive evaluation step should be either deleted or modified. After modification was made for the main study, the metacognitive evaluation demonstrated an effect on students' comprehensive understanding of the process of conceptual change. The findings from the main study suggested that the metacognitive evaluation step should be kept in the ILIS approach, because four interviewed students (67%) reported that they were aware of reflecting on their learning, and also monitoring their learning process when they had other set tasks. Additionally, teachers should spend time in working together to finish the metacognitive evaluation activities, such as explaining the activities' meaning, leading students' in reviewing the ILIS approach procedure, and guiding students to focus on the function of each step when students engaged in metacognitive evaluation.

### **6.1.6 ILIS approach intervention established the relationship between conceptual understanding and students' confidence in learning**

Results from the main study also showed a positive correlation between conceptual learning and confidence in answers during the post-test, for both the ILIS approach group and the conventional instruction group. This finding was consistent with the study of Puncochar et al. (1994). Although in the pilot study, there was no statistically significant difference between the ILIS approach groups and the conventional instruction groups, the ILIS approach students' confidence in their answers showed a significant difference from pre-test to post-test. The insignificant difference between the groups in the pilot study was caused in part by the limited intervention time. After twelve weeks' intervention in the main study, the ILIS group showed significantly higher confidence in their post-test answers than the conventional group. The finding is consistent with related literature (Levine et al., 1998; Y. Zhang et al., 1997), which speculates that participants' confidence in learning can be improved when they engage in using computer-based learning resources.

One explanation for the increase in confidence in the ILIS approach group came from the use of PhET simulations. The study of Blum, Borglund, and Parcells (2010) found that the use of simulations can increase students' confidence because simulations provide an opportunity to conduct experiments. Likewise, Lundberg (2008) maintains that when students engage in PhET simulations, the immediate feedback and adequate testing opportunities promotes students' self-confidence. The interviewed students of this study also expressed that they felt a sense of achievement when they tested and received satisfying results from PhET. The sense of achievement encouraged students to make presentation and discussion with confidence.

This study also used pair work, aiming to support students with low confidence in learning. Capable peers supported students with low confidence to complete investigative activities, provide immediate solutions, and offer emotional support. At the same time, capable students also gained further understanding of old concepts. This was supported by the theory of "learning by teaching" (Roscoe et al., 2007), which indicates that help is mutual. On one hand, it helps others. On the other hand, helping another also promotes the helper's understanding. Results of the study showed both capable students and students with low confidence gained significant increases in confidence.

Additionally, Bunker (1991) found that students' confidence could increase when they are challenging others' results. This study observed students in the ILIS inquiry-based instruction setting not only engaging in the investigative activities, but also participating in discussion and argumentation. For example, the fourth step of the ILIS approach involves students' presentations. It encourages students to share their ideas and other students to challenge the results by using a style of scientific discourse. Two of the interviewed students expressed that their confidence was improved during this step where they used their evidence to defence their claims and "we won".

The study also found that in an inquiry-based learning with interactive simulations environment, confidence in learning played an important role in conceptual learning. Students' confidence in learning emerged as a significant contributor to predicting students' conceptual understanding. This finding was consistent with Flowers and Marston's study (1972) that demonstrated that confidence in learning contributed to motivating their conceptual learning.

In the conventional instruction class, the classroom observations recorded that teachers demonstrate experiments in front of the classroom while students observed the teacher's experiments. Before experiments, the students were requested to read the lectures and textbooks. After demonstrating the experiments, the teacher provided relevant lectures with explanation in order to support students' conceptual understanding. Courses were ended with summative evaluations such as exercises and quick quiz. The instructional activities were not positively interactive. In the conventional learning setting, students actively answered teacher's questions when their teacher proposed questions. There was not observed that students challenged teacher's explanation and their peer's opinions. Although in this study the increase of students' scores in confidence was not significant as those in the ILIS approach groups, this study and other research showed that conventional instruction can improve students' confidence (Mazur et al., 1997; Puncochar et al., 1994). One explanation for the conventional instruction groups' confidence emphasised the function of epistemological beliefs. According to the study of Schommer et al. (1992), students became confident, or overconfident, when they believed that knowledge was simply like a list of facts. In this study, the conventional classes used a didactic approach that pushed students to memorise isolated facts. This could lead students to a "misunderstanding" that knowledge construction is a simple process like remembering concepts. The didactic teaching method might create a 'metacognitive illusion' where students think they knew more than they actually do (Houghton et al., 2000).

#### **6.1.7 ILIS approach intervention influenced students' inquiry process skills, which potentially benefits conceptual learning**

The framework of this study anticipated that there was a relationship between conceptual understanding and inquiry process skills. Findings from the pilot study and the main study showed that students in the ILIS groups received significantly higher scores on inquiry process skills than those in the conventional instruction groups. But the numbers from the quantitative phase showed that the students' process skills were not a significant predictor of their conceptual learning. Interestingly, words from the interviewed students demonstrated that the development of inquiry process skills contributed to their conceptual understanding. The results showed there was a conflict between quantitative results and qualitative results. Although the conflict indicated that the topic

needs to be more investigated, the findings in the current study showed knowledge of inquiry process skills had a positive relationship with students' conceptual understanding. The conclusion was supported by the study of Settlage (2007) that regarded the showed knowledge of inquiry process skills as the utmost necessity for inquiry-based learning and scientific literacy.

In the current study, the first step focuses on students' prediction skills. The ILIS students are first involved in elicitation to clarify what they know about concepts. And then the ILIS approach facilitates students to develop predictions.

Testing using PhET simulations in the next step help students to develop operation skills. Conventional classrooms have few opportunities for students' to develop operation skills. This study used PhET simulations to create a virtual experiment environment where students can safely and effectively test their hypotheses. The ILIS students' operation skills improved significantly more than their peers using conventional instruction. The results from the study of Geban et al. (1992) showed students' science process skills were enhanced by the use of computer-based simulation. Monaghan et al. (1999) also found that computer simulations were effective in supporting students in inquiry skills. For instance, the PhET simulations used in this study functioned as cognitive tools that supported students engaging in a series of investigative activities to practice integral inquiry skills (D. H. Jonassen, 1996; Linn et al., 2004; Manlove et al., 2007).

And, students in physics classes in China have few opportunities to engage in a scientific communication environment, where students can explain and defend their thinking. In the fourth step of the ILIS approach, elucidation and link, students work in pairs to report their investigative process and results. This step provides students an opportunity to practise their communication skills. In particular, there is a focus on using a style of scientific discourse in these communications. That is, the ILIS students present, explain, and defend their thinking using the claim-evidence-reason method. Previous studies have indicated that inquiry-based instruction increases students' argumentation skills (Baron, 1991; Driver et al., 2000; Taraban et al., 2007; Tsai, 2001). This study further found that using scientific discourse in presentation provides opportunities to develop students' scientific communication skills. Interviewed students demonstrated better communication skills (e.g., the use of the claim-evidence-reason method), which helped them better conceptualise understanding of forces and motion.

The last step of the ILIS approach, metacognitive evaluation, facilitates students' evaluation skills. The ILIS students use evaluation rubrics to mark their own and another group's performance in learning with the ILIS approach. This step not only fosters the consolidation of the entire process of inquiry-based learning, but also helps students understand how to appropriately evaluate their learning process. In addition, these evaluation skills can help students obtain better understanding of



learning in the future (Keil et al., 2009). In summary, the five steps comprise inquiry-based process scaffolds that can cue important components of inquiry process skills.

The finding supports the theory from John Dewey (1938), which notes that students learn better when they are engaged in learning processes. The finding also aligned with previous empirical studies (C.-Y. Chang, 2001; Kipnis et al., 2008; Lord, 1997; Roegge et al., 1990; Windschitl, 2000), which found that the inquiry-based approach with visualisation technologies supports the development of inquiry process skills. Further, the findings added more practical meaning to the work of Posner et al. (1982). This current study integrated Posner et al.'s (1982) four situations into the practice of the inquiry-based process. For example, the first step stimulated students' conceptual conflicts. Other inquiry-based steps were utilised in the three situations, so that students could make sense of the new knowledge. In brief, this study found there was a bidirectional relationship between conceptual learning and inquiry process skills. The ILIS approach increased students' inquiry process skill levels, and in turn the development of inquiry process skills supported students' conceptual learning.

#### **6.1.8 Male students did not benefit from ILIS approach intervention as much as female students**

The result from this study challenges the statement that sex-related differences closely relate to concepts in the science curriculum, favouring boys. In this study, female students' performances were as good as male students'. And female students' achievements were even better than male students' in conceptual understanding as shown in Table 5-8. And the results from pilot study demonstrated that gender did not account for the significant variable in post-test scores when the pre-test scores were controlled in the ILIS approach groups. Studies could support the statement that sex-related differences closely relate to concepts in the science curriculum, favouring boys (Fogelman, 1970; Linn et al., 1983) in conventional setting. But the statement did not be proved in the current study. Researchers have noted biological differences with respect to quantitative skills and spatial visualisation (Trankina, 1993), in that girls are less confident than boys about their performance in male-type tasks (Kahle et al., 1994). And studies have found that girls feel more anxiety than boys in a computer-based learning environment (Dobosenski, 2001; Volman et al., 2001).

The results from the current study support the original speculation: when girls are engaged in the ILIS environment they can achieve the same success as boys in domains that are typically considered 'boy tasks' (Kumar et al., 2000; Wilson et al., 2010). The ILIS approach provided a constructivist environment where students gained knowledge through active interactions. This encouraged assimilation and accommodation of the new construction within existing knowledge (Tuttle, 2009). The findings from this current study are supportive of the theory of Lev Vygotsky

(1978) and empirical studies. It suggests that optimal learning is achieved when the series of activities are supported by either a capable person (Gijlers et al., 2013; Heift et al., 2001; Mitrovic, 2003; Roscoe et al., 2007), cooperatively working with peers (Duffy et al., 1998; Mazur et al., 1997; Webb, 1982), or scaffolded by technology tools (Azevedo et al., 2004; Hmelo-Silver, 2006; Hmelo-Silver et al., 2007), regardless of whether they are male or female students.

Despite science education calls for science for all (American Association for the Advancement of Science, 1989; MoE, 2003), an achievement gap between genders remains in China. The use of the ILIS approach could help to make the gap smaller.

## **6.2 Theoretical implications**

In research on conceptual change, the learning outcomes are often conceptualised and measured by alternative conceptions. This study adapted FCI to quantitatively examine the changes in alternative conceptions of forces and motion. The study used two different teaching approaches to investigate which approach would benefit students' learning; it confirmed the effectiveness of the inquiry-based learning with interactive simulations (ILIS) on reducing students' alternative conceptions. The study also found that when students showed improved scores on the FCI test, confidence in answers and inquiry process skills simultaneously increased.

Theoretical implications were drawn from the study to inform research on conceptual change. First, this study found that conceptual change for grade 10 students is a progressive process. This progressive process includes several continuous stages, such as students' prior conceptions, intermediate conceptions, and finally the scientific conceptions for conceptual change (Hsu et al., 2008; Niedderer et al., 1994). The findings support the constructivist perspective that contends knowledge is constructed progressively by students, rather than transmitted directly by teachers. For instance, the elicitation and clarification step comprises the students' prior conceptions stage. The further four steps of the ILIS approach aim to help students reach the intermediate conceptions stage, and finally the scientific conception stage. In practice, the instructional activities of each step of the ILIS approach are underpinned by conceptual change theory (Posner et al., 1982). Before a new conception can be accommodated there has to be dissatisfaction with an existing conception. The new conceptions must be challenged with different instructional activities, and then they will be recognised as intelligible, plausible and fruitful. For example, in the testing prediction step, students use PhET simulations to test their hypotheses and record data. They need to preliminarily analyse the data and make claims. These instructional activities help students think of the new conceptions as intelligible. In the elucidation and link step, more instructional activities, such as the teachers' explanation, aim to make students' conceptual understanding plausible. Finally, the students' applications enable them to see the conception as being fruitful. In this study, each step of

the ILIS approach is supported in facilitating effective conceptual change by the use of scaffolds, such as a knowledgeable teacher, instructional simulations, scientific language, and students' worksheets.

Second, this study found that when students are involved in the ILIS learning experience, scaffolds are essential to engaging them in problem-solving activities. As Vygotsky's theory of ZPD states, learning exists in "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). This highlights the importance of providing scaffolds within a learner's ZPD (Hogan et al., 1997). Studies have shown that scaffolds benefit both instructional teaching and students' learning (Knaggs et al., 2012; McNeill et al., 2006; Tabak, 2004). Ge et al. (2004) found that scaffolds can "support students to activate schemata, organize and retrieve knowledge, monitor and evaluate, and reflect on their learning". Scaffolds in this study are consistent with the definition proposed by the previous study. Quintana et al. (2004) regarded scaffolds as a range of assistance that can support the completion of problem-solving activities that cannot be completed by learners. The definition of scaffolds in this study is extended from 'adult guidance and capable peers' (Vygotsky, 1978), and writing and images (Quintana et al., 2004), to clarifying the function of scientific language and instructional technology tools. These scaffolds provide different functions during different learning steps. They could be emphasised in the specific learning stage. And they could fade after some period of time, which depends on learner development (Jackson et al., 1999).

Third, this study confirmed that language has a significant effect on conceptual change. According to Vygotsky's view, the higher mental function of individual learning is derived from social setting (Vygotsky, 1978). Language and other semiotic mechanisms are regarded as means for internalising scientific concepts in the social context. Driver et al. (1994) argued that there is a technical language for teachers to practice in science classrooms. The technical language is different to daily language, and even different between scientific communities. Driver et al. (1994, p. 4) states that learning is the "co-construction of scientific knowledge by teachers and students" and that teachers should help students understand the "symbolic world". This means that science learning involves how individuals' understand technical language that describes particular concepts, and also involves how teachers scaffold their teaching to explain scientific concepts in that context to students. When applied to pedagogy, this interaction between teacher and students could be realised during inquiry-based courses. In the ILIS classroom where students work in groups, language serves as a social tool to enable them to seek clarification. When the students discuss and argue with each other, language conveys their opinions. And the ILIS approach provides a style of scientific discourse when students give presentations and engage in argumentation. From a social

constructivist perspective that values interaction (Pritchard et al., 2010) and collaboration (Palincsar, 1998), the role of language does play a critical role to revise learners' alternative conceptions in the ILIS approach.

Based on these theoretical implications, further research should explore ways of taking full advantage of inquiry-based approaches, such as the ILIS approach, in achieving conceptual change. There should be a focus on the process of the inquiry-based approach and its role in adapting learners' cognitive structure. The use of scientific discourse and interactive simulations in inquiry-based learning is also worth further investigation. Further, research using more students in multiple international contexts is also required to better understand the educational affordances of combining inquiry-based pedagogy with computer-based interactive simulations. Finally, the current study found a relationship among conceptual learning, inquiry process skills, and confidence in answering. But further research is sorely needed to investigate the functions of those relationships in conceptual change.

## **6.3 Implication for science education**

### **6.3.1 Supporting the use of inquiry-based learning with interactive simulations (ILIS) approach**

The effectiveness of inquiry-based learning in science education has been widely asserted. Inquiry-based learning engages students in a process of active learning that supports students' conceptual understanding through stimulating conceptual conflicts, testing hypotheses, discussing ideas, sharing opinions, developing evidence-based explanations and drawing conclusions (NRC, 2000). However, its implementation has met with challenges in the context of China. Without a structured inquiry sequence and proper experiment tools, teachers are not likely to implement the inquiry-based instructional approach. With the development of educational technology tools, studies have found that a simulation-supported inquiry learning environment can provide students with more effective learning opportunities, and also showed that ILIS approach students' achievements outperformed conventional instruction students (Chen, 2010; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Vreman-de Olde et al., 2013).

This study evaluated the effectiveness of an inquiry-based learning with interactive simulations on conceptual learning in physics. The results of the study quantitatively and qualitatively supported the previous studies. Studies on how Chinese teachers integrate conventional teaching into inquiry-based learning shed light on conceptual change. The results of this study encouraged teachers to use the ILIS approach in science education. And the ILIS teachers were asked to play different roles when they assisted students' conceptual learning. For example, at the beginning of each lesson, the ILIS teachers needed to stimulate students' learning curiosity in

order to balance their cognitive conflicts. And then they needed to guide the students to propose and test their hypotheses. During the fourth step, the ILIS teachers needed to facilitate discussion and argument, using a style of scientific discourse, throughout the students' presentations. In the last step, the ILIS teachers needed to foster their students' acquisition of metacognitive thinking. It was quite apparent that there were more requirements placed on the ILIS teachers when they used the ILIS approach. However,

the teacher has considerable freedom to rearrange these steps [to] fit the constraints of the timetable, although these five steps are listed in instructional order, because it's necessary to choose a means of presenting them. While (a) if it's necessary to, say, switch the second and third activities, that is fine and (b) rather than a linear progression with a beginning, middle and end, sometimes a learning sequence will involve cycling through the middle steps multiple times to ensure deeper understanding (Geelan et al., 2014, p. 261).

To implement inquiry-based learning, it is recommended to integrate the use of computer-based interactive simulations. Interactive simulations can support students in exploring scientific phenomena in a virtual environment. In the ILIS classroom, students can be assured that inquiry-based instruction will be available to all when it uses interactive simulations to experiment with unseen processes (nuclear fusion process), manipulate toxic or costly materials (radioactive materials), explore very small or very large objects (gravitational force between planets), and investigate very fast or very long movements (trajectory of rockets) (Barbara C. Buckley et al., 2004; Vattam et al., 2011).

In this study, PhET simulations were selected to help students test hypotheses and collect evidence. PhET simulations are an example of well-designed educational technology tools (Adams et al., 2008). They provide computer-based virtual labs that can scaffold the implementation of ILIS inquiry-based learning efficiently. Further, PhET simulations can give immediate feedback that provides evidence to support students' communication, argumentation and discussion during their presentations. K. E. Chang et al. (2008) found that the students' arguments were more scientific and logical using the evidence gathered from their investigation using simulations. Additionally, PhET simulations provide multi-representations such as words, diagrams, graphs, equations, animation and so on. Studies have found that multi-representations could lead to better understanding of the phenomenon (Tabak, 2004). This satisfies their complex phenomena (Österlind, 2005) and helps students to achieve higher levels of knowledge integration (H. Z. Zhang et al., 2008).

Therefore, this study encourages physics teachers to use PhET simulations in their future teaching. However, it should be noted that interactive simulations do not replace the teachers' role or the conventional experiment labs. There is a zeroth step that should take place before these five steps. The findings of this study suggest that, if it is at all possible, students should gain experience

of the physical phenomena being studied. This is not always possible—one of the affordances of interactive simulations is to allow students access to phenomena that are too large, small, slow or fast to be directly observed in the classroom, and to concepts that are not directly visible in the physical world (such as magnetic field lines). But wherever it is possible for students to lift something, look at it, make measurements, collect data, mix solutions and so on, this study would suggest that this is essential. After all, scientific ideas are meant to explain our experience of the world around us, so as far as possible, giving students access to direct experience (and asking them to carefully attend to its features) is valuable. In some cases the phenomena might also be too dangerous to conduct in the classroom, or inaccessible because of distance or other factors. In these cases, video or other media may also be helpful in giving students experiences to use in testing theoretical perspectives. These media are less effective than direct experience, but more effective than no experience. It is therefore important to offer direct experience whenever possible, rather than default to the easier alternative of finding a video on the internet. This study argues that the interactive simulations should always function to complement students' experience rather than to replace it.

### **6.3.2 Improving students' confidence and inquiry process skills in the physics classroom**

As demonstrated in this study, confidence in answers and inquiry process skills are two important contributors to conceptual learning. Students using the ILIS approach gained more confidence in their learning than those receiving conventional instruction. Likewise, students gained multifaceted benefits in inquiry process skills. The results statistically showed that the ILIS students' development of inquiry process skills outperformed of the conventional instruction students.

The ILIS approach provided students with a structured inquiry-based learning to explore the new knowledge. It provided a new learning environment where students conducted experiments through virtual labs. Students were engaged in testing individual hypotheses through PhET simulations. Meanwhile, the ILIS approach also provided students with a familiar learning setting where students also needed to follow teachers' instruction, and discuss their findings with their teachers and fellow students. Additionally, the ILIS approach employed metacognitive evaluation as its last step. It helped students internalise their inquiry process skills in their mental constructs and in turn apply them to future learning. This study concluded that the ILIS students had benefited from the five steps in the inquiry-based learning. And science process skills are of the utmost importance for science achievements, as has been shown in the previous studies (P. N. Brotherton, 1993; P.N. Brotherton et al., 1996).

While students' confidence did not increase in the pilot study during the four weeks' intervention, the main study, which provided eight weeks' ILIS approach learning, was able to

promote a significant increase in students' confidence in their answers. Considering the successful modifications to the main study, it is recommended that teachers use the ILIS approach in physics classrooms. The six interviewed students expressed that they felt more confident in their understanding of concepts when using the ILIS approach than when using conventional instruction. The ILIS approach values the constructivist environment, where student-driven activities help students to actively engage in reconstruction of knowledge, and possibly improve their confidence in learning. However, there were many other factors influencing students' confidence in learning. Furthermore, the current study also showed there is an interwoven relationship between confidence and inquiry process skills when students participate in the ILIS approach lessons. This means that students' confidence in their answers improves when they are involved in investigative activities, specifically the five steps of the inquiry-based activities in the ILIS approach. With respect to the relationship among conceptual learning, confidence and inquiry process skills, this study only illuminates the need to explore its effectiveness in the technology-based learning environment. This study encourages teachers to use the ILIS approach in their teaching and calls for educators and researchers to further investigate this issue.

### **6.3.3 Confucius heuristic teaching strategies established in the context**

The integration of Confucian heuristic teaching strategies aims to mitigate cultural resistance from teachers and students who are unfamiliar with inquiry-based methods. As the study demonstrated (Bhattacharyya et al., 2009), teachers often feel significant pressure when adopting a new teaching approach. They lack the experience to integrate new teaching approaches into classrooms. And they also lack knowledge about integrating new teaching approaches into the approaches they are already using. After modifications to the main study, the ILIS approach added Confucius heuristic strategies into the students' presentation step. Confucian heuristic strategies are popularly used in China's classrooms. The participating teachers in the current study also used the Confucius heuristic strategies in their classrooms. The study asked teachers to conduct instructional activities using Confucius heuristic teaching strategies. The use of Confucius heuristic teaching strategies provided participating teachers an opportunity to integrate familiar teaching strategies into a new teaching approach. In addition, the teachers noted the positive effects of Confucius heuristic strategies on students' learning. They showed more confidence when they used the Confucius heuristic strategies because they were familiar. The teachers stated that they felt psychologically involved in the implementation of the ILIS approach when they became confident.

This study found that with the Confucius learning culture in schools, the implementation of the ILIS approach for teachers is not so alien. Therefore, this study suggests that the successful use of the ILIS approach in other countries should consider the integration of other teaching strategies

into the ILIS approach. The other teaching strategies should be contextualised in the schools, which ensures there is no extra pressure on the schools and that teachers will use the ILIS approach. Further, the teaching strategies should be consistent with the philosophy of inquiry-based learning. This would allow easy integration into the ILIS approach.

#### **6.4 Limitations of the study**

Every research study, especially conducted in a naturalistic setting, contains limitations. The following are six noticeable limitations that threaten the internal and external validity of the current study.

First, it was impractical to set out a rigorous experimental study in the context of schools. Therefore, in both the pilot study and the main study, quasi-experimental research was conducted during the quantitative phase. It required random assignment of participating teachers and their intact classes into the two treatment groups in the context of the schools. Although this study used a pre-test to ensure the comparison of the two groups, the school setting still might have affected the results of the study, such as student absences, school training classes and extraneous influences.

Next, the researcher recruited participants from the large population of public schools in Beijing. When compared with the large population in Beijing, this project is a comparatively small sample size study. With respect to the sample size, the results of this study would decrease the generalisation of the students from those schools, who have different backgrounds to the participating schools.

Another important limitation was the period of time in which the ILIS approach was used. It was only possible to conduct the pilot study over four weeks. Consequently, the results were not significant in conceptual learning and confidence in learning. However, in the main study the experimental groups experienced eight weeks of ILIS approach learning. The results became significant in conceptual learning, confidence in learning and inquiry process skills. Thus, this study suggests that possible conceptual change, inquiry process skills and confidence in learning can be influenced more significantly if students have a longer period using the ILIS approach. In future studies, this issue should be taken into consideration.

Fourth, the conceptual learning of experimental groups took place in the educational technology environment. The results showed that the Force and Motion PhET simulations selected in the current study were effective scaffolds for students' conceptual learning. However, it is important to ask if other PhET simulations meet the purpose of teaching and learning. Thus, more evidence of PhET simulations' efficacy is required.

Fifth, the advantages and disadvantages of a well-designed study would limit the results of the study. The advantage of well-structured study design ensured the significant results that this study



speculated. For example, teachers had two days' training before the educational trial. And participating teachers and students in the experimental group had one lesson to become familiar with the ILIS approach. During the educational trial, participating teachers developed a teacher community that provided instructional support if they met difficulties in teaching force and motion lesson modules. However, successful implementation of the ILIS approach not only needs teachers' efforts, but also support from the teachers' communities and schools. This might be a challenge for other teachers and schools that would like to use the ILIS approach.

Sixth, the investigative activities in the ILIS approach classrooms were well structured. Teachers did not allow students to have space for open-inquiry learning, which might have resulted in students not developing their initial thoughts about physics questions. If there were more intervention time, this study could have been designed to gradually reduce scaffolds for students' investigations. Thus, this study suggests that future studies should allow students to explore their ideas while learning through the ILIS approach.

Last, this study used a mixed-method design to explore the effectiveness of the ILIS approach. The initial quantitative phase provided 'number' evidence. The subsequent qualitative phase provided 'words' to add meaning to the 'numbers'. However, due to the complex nature of social science studies, the results need to be treated with the appropriate caution. In the long-term future, similar studies will provide further insights into the interpretation of this study.

## **6.5 Overall conclusion of the study**

Science education in China aims to integrate technology, engineering and mathematics education into science learning, particularly with respect to conceptual change. Conceptual change is related to students' existing conceptions that impact on students' on-going learning. It has been widely asserted that the achievement of conceptual change takes place in a constructivist learning environment (Bransford, 2000). And there are a number of empirical studies showing that inquiry-based learning can provide a constructivist environment where students are engaged in conceptual understanding. If inquiry-based learning is well supported, it can prove more effective than conventional instruction on students' performance (Furtak, Seidel, et al., 2012; Vreman-de Olde et al., 2013). Recently, more and more studies have revealed that a simulation-supported inquiry learning environment can provide students with more effective learning opportunities, and students' achievements have outperformed conventional instruction (Chen, 2010; Goh et al., 2013; Hagemans et al., 2013; L. F. Lin et al., 2012; Mulder et al., 2012; Vreman-de Olde et al., 2013). Therefore, this study devised an inquiry-based learning with interactive simulations (ILIS) to promote conceptual change in physics classrooms in the context of China.

The research design adapted methodological pluralism to combine positivist ontology with constructivist epistemology. Accordingly, this study used a mixed-method design. The research design included initial quantitative data to address the first research question and subsequent qualitative data to answer the second research question. The initial quantitative phase conducted a controlled-comparison educational intervention. It addressed the first research question: What is the effectiveness of the ILIS approach and conventional instruction respectively on student conceptual learning? And quantitative data showed that the ILIS students outperformed the students using the conventional instruction regarding conceptual change of forces and motion. Then in the subsequent qualitative phase, six students were selected to participate in 60-minute interviews, and two participating teachers were involved as well. This qualitative phase answered the second research question: How do the students and teachers understand the conceptual learning in relation to the (potential) performance made by the ILIS instruction? The results of the subsequent qualitative data complemented, refined and enriched the quantitative results.

Specifically, the findings from the initial quantitative phase showed that the ILIS approach offered notable contributions to students' conceptual learning. These findings justified Vygotsky's ZPD theory that if teachers provide relevant meaningful instructional activities that foster the construction of knowledge, then "today will be the actual developmental level tomorrow – that is, what a child can do with assistance today [they] will be able to do by [themselves] tomorrow" (Vygotsky, 1978, p. 86). In this study, the ILIS approach provided the students with the opportunity to engage in an inquiry sequence with various scaffolds, such as PhET simulations, knowledgeable teachers, capable peers, and mandatory worksheets. The results of this study not only confirmed previous studies' conclusions that students' performance in conceptual learning using the ILIS approach is better than those using the conventional instruction (Alfieri et al., 2011; N. Rutten et al., 2012; Vreman-de Olde et al., 2013), but also provided evidence that the ILIS approach can increase students' confidence in learning and inquiry process skills. In addition, confidence and inquiry process skills in turn contributed to students' conceptual learning.

The findings from the subsequent qualitative phase demonstrated the meanings of conceptual learning according to the interviewed participants' perceptions. The qualitative phase explained how the ILIS approach facilitated students' conceptual outcomes. And the meanings behind conceptual learning confirmed and complemented the findings from the initial quantitative phase. Depending on a well-structured inquiry sequence and various meaningful scaffolds, the students constructed or re-constructed their conceptual understanding of forces and motion through the ILIS approach. Meanwhile, the students benefitted from confidence increases and inquiry process skills development as a return on conceptual change.

In conclusion, this study has illuminated the topic of conceptual learning. Learning experiences arising from the ILIS approach engaged students in a scaffolded environment where teachers guided students' learning. This study, therefore, contributes to the growing body of evidence demonstrating that students can clarify and revise their alternative conceptions using inquiry-based learning in a technological environment. This study also advocates the integration of inquiry-based learning methods and computer-based simulations, as has been suggested in national and international physics education reforms. Further, the findings from this study challenge the claims that technology could replace teachers. In the case of this study, successful curriculum is complex and involves the interaction of technology, the pedagogical approach, and teachers.

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# Appendices

## Appendix A: Information Sheet



THE UNIVERSITY  
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### **Effectiveness of Inquiry-based learning with Interactive Simulations for Enchaining Student Physics**

#### **Conceptual understanding**

This research project will develop and evaluate the effectiveness of an instructional approach – inquiry-based learning with interactive simulation approach (ILIS approach) on students’ conceptual understanding about force and motion. The ILIS approach involves five steps: 1) elicitation and clarification of existing conceptions and the ‘target’ scientific conception; 2) outlining the predictions and implications of students’ existing conceptions and the scientific conception; 3) testing predictions of competing conceptions using interactive simulations; 4) elucidation of findings and linking results to the scientific conception; 5) metacognitive evaluation and further testing to develop and deepen understanding of the scientific conception.

Approximately 200 grade-10 students, and four physics teachers, in three Senior Middle Schools in Beijing will participate in the study.

Student participants will learn four lesson topics through two different instructional approaches. The four lesson topics are buoyancy, Newton First Law, Newton Second Law and Newton Third Law. One instructional approach is inquiry-based learning with interactive simulation. The other instructional approach is conventional instruction. Pre- and post-test will be used for collecting data. Classroom observations will be used to record the implementation of inquiry. A small group of students and teachers will be interviewed following. The data explanation from the interviews will provide evidence about the contribution of the interactive simulations to the inquiry instruction their effect on conceptual change. Practically, the research will be of immediate benefit to your school, the teachers and students involved. The researcher will conduct this study and teach students as an instructor. The feedback from the research will be provided to the teachers. Furthermore, the result of this study will add to the empirical evidence about this kind of research and the improvement of instruction with interactive simulations.

The data collection process will be of minimal disturbance to the normal class routines. All information gathered during the study will be maintained in the strictest confidence. Names of the participants will be kept confidential. Participation in the study is voluntary. Participants can withdraw from the study at any time without prejudice. A summary of the findings will be provided at the completion of the PhD thesis upon request.

This study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University’s principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are free to discuss about this study with me or with the supervisors of the project at the contact addresses below. If you would like to speak to an officer of the University not involved in the study, you may contact the School Ethics Officer on 001-61-7-3365 6502.

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## Appendix B: Letter to the Gatekeeper



THE UNIVERSITY  
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Dear Sir/Madam,

I am conducting a research project on physics education as part of my doctoral study at the School of Education, The University of Queensland. This letter is an invitation for your school to be part of the project which is focussed on helping students to improve their learning about important conceptual ideas in physics.

In the Information Sheet, I outline the study. With your permission the study will involve teachers and students in your school. Participation in the study will provide the teachers with useful professional learning and students with useful learning experiences.

For your information, this study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University's principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are free to discuss about this study with me or with the supervisors of the project at the contact addresses below. If you would like to speak to an officer of the University not involved in the study, you may contact the School Ethics Officer on 001-61-7-3365 6502.

Thank you for your consideration.

Yours faithfully,

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## Appendix C: Letter to Teachers



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Dear Ms/Mr (teacher's name),

Thank you for showing an interest in participating in the study "Effectiveness of inquiry-based learning with interactive simulations for enhancing student physics conceptual understanding" which I am conducting as a PhD student of the School of Education, The University of Queensland. This letter is a follow-up to our recent conversation about the study to provide you with information related to the study. Please see the Information Sheet enclosed.

This research project will develop and evaluate the effectiveness of an instructional approach – inquiry-based learning with interactive simulation approach (ILIS approach) on students' conceptual understanding about force and motion. The ILIS approach involves five steps: 1) elicitation and clarification of existing conceptions and the 'target' scientific conception; 2) outlining the predictions and implications of students' existing conceptions and the scientific conception; 3) testing predictions of competing conceptions using interactive simulations; 4) elucidation of findings and linking results to the scientific conception; 5) metacognitive evaluation and further testing to develop and deepen understanding of the scientific conception.

You and student will have four lesson topics through two different instructional approaches. The four lesson topics are buoyancy, Newton First Law, Newton Second Law and Newton Third Law. One instructional approach is the ILIS approach. The other instructional approach is conventional instruction. Each lesson will take approximately 60 minutes. Pre- and post-test will be used for collecting data. Test will take about 60 minutes, and the interview will take 60-90 minutes. Classroom observations will be used to record the implementation of inquiry. You and a small group of students will be interviewed.

The confidentiality of your participation will be maintained and all data collected will be kept under secure conditions. Your identity and involvement in the project will not be revealed in any way. You may withdraw your consent at any time and the data collected would be removed from the project. A summary of the findings will be provided at the completion of the PhD thesis upon request.

This study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University's principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are free to discuss your participation in this study with me or with the supervisors of the project at the contact addresses below. If you would like to speak to an officer of the University not involved in the study, you may contact the School Ethics Officer on 001-61-7-3365 6502.

Thank you for your consideration.

Yours faithfully,

Xinxin Fan  
PhD student  
Tel.: +61 0406179886  
Email: xinxin.fan@uqconnect.edu.au

Dr. David Geelan  
Supervisor  
Tel.: +61 0755528647  
Email: d.geelan@uq.edu.au

Dr. Tony Wright  
Supervisor  
Tel.: +61 3365 6634  
Email: tony.wright@uq.edu.au



## Appendix D: Teacher Consent Form for the Study



THE UNIVERSITY  
OF QUEENSLAND  
AUSTRALIA

**School of Education**  
Brisbane Qld 4072 Australia  
Telephone + 61 7 3365 6550  
Facsimile + 61 7 3365 7199

I am willing to take part in the study of the project “Effectiveness of inquiry-based learning with interactive simulations for enhancing student physics conceptual understanding” being conducted by Ms Xinxin Fan, a PhD student of the School of Education, The University of Queensland, Australia.

I have seen the outline of the study and understand what the study hopes to achieve and what my participation entails.

I understand that my students will be participated in this study.

I understand my class will be observed.

I understand I will be interviewed.

I understand that my confidentiality will be respected, and my identity and involvement in the study will not be revealed in any way.

I understand that I can withdraw my consent at any time without prejudice, and my documents will be destroyed and the related data will be removed from the analysis.

I hereby give my consent to participate in this research.

Name (please print): \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

This study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University’s principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are free to discuss your participation in this study with me or with the supervisors at the contacts listed below. If you would like to speak to an officer of the University not involved in the study, you may contact the School Ethics Officer on 001-61-7-3365 6502.

Xinxin Fan  
PhD student  
Tel.: +61 0406179886  
Email: xinxin.fan@uqconnect.edu.au

Dr. David Geelan  
Supervisor  
Tel.: +61 0755528647  
Email: d.geelan@uq.edu.au

Dr. Tony Wright  
Supervisor  
Tel.: +61 3365 6634  
Email: tony.wright@uq.edu.au

## Appendix E: Letter to Parent/Guardian and Student



THE UNIVERSITY  
OF QUEENSLAND  
AUSTRALIA

**School of Education**  
Brisbane Qld 4072 Australia  
Telephone + 61 7 3365 6550  
Facsimile + 61 7 3365 7199

Dear (Parent/Guardian's name),

This is an invitation to allow your son or daughter to participate in the physics education project I am conducting at your son or daughter's school as part of my doctoral studies. The project is exploring the effects of different instructional approaches in order to enhance students' conceptual understanding about forces and motion in physics.

The title of the project is "Effectiveness of inquiry-based learning with interactive simulations for enhancing student physics conceptual understanding" which I am conducting as a PhD student at the School of Education, The University of Queensland. This letter is a follow-up to our recent conversation about the study to officially provide you with the information related to the study, See the Information Sheet enclosed.

This research project will develop and evaluate the effectiveness of an instructional approach – inquiry-based learning with interactive simulation approach (ILIS approach) on students' conceptual understanding about force and motion. The ILIS approach involves five steps: 1) elicitation and clarification of existing conceptions and the 'target' scientific conception; 2) outlining the predictions and implications of students' existing conceptions and the scientific conception; 3) testing predictions of competing conceptions using interactive simulations; 4) elucidation of findings and linking results to the scientific conception; 5) metacognitive evaluation and further testing to develop and deepen understanding of the scientific conception.

Your son or daughter's participation will involve special lessons which researchers will observe, test and/or interview my son or daughter.

The confidentiality of your son or daughter's participation will be respected. All information will be kept under secure conditions. Your son or daughter's identity and involvement with the project and that of the school will not be revealed in any way. You son or daughter's may withdraw your consent at any time and their data collected would not be used for the research.

A summary of the findings will be provided at the completion of the study upon request.

This study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University's principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are free to discuss your participation in this study with me or with the supervisors of the project at the contact addresses below. If you would like to speak to an officer of the University not involved in the study, you may contact the School Ethics Officer on 001-61-7-3365 6502.

Thank you for your consideration.

Yours faithfully,

Xinxin Fan  
PhD student  
Tel.: +61 0406179886  
Email: xinxin.fan@uqconnect.edu.au

Dr. David Geelan  
Supervisor  
Tel.: +61 0755528647  
Email: d.geelan@uq.edu.au

Dr. Tony Wright  
Supervisor  
Tel.: +61 3365 6634  
Email: tony.wright@uq.edu.au

## Appendix F: Parent/Guardian and Student Consent Form for the Study



THE UNIVERSITY  
OF QUEENSLAND  
AUSTRALIA

**School of Education**  
Brisbane Qld 4072 Australia  
Telephone + 61 7 3365 6550  
Facsimile + 61 7 3365 7199

I am willing to take part in the study of the project “Effectiveness of inquiry-based learning with interactive simulations for enhancing student physics conceptual understanding” being conducted by Ms Xinxin Fan, a PhD student of the School of Education, The University of Queensland, Australia.

I have seen the outline of the study and understand what the study hopes to achieve and what my participation entails.

I understand that I will be asked to complete a test, will be observed in class and/or will be interviewed.

I understand that my confidentiality will be respected, and my identity and involvement in the study will not be revealed in any way.

I understand that I can withdraw my consent at any time without prejudice, and my documents will be destroyed and the related data will be removed from the analysis.

I hereby give my consent to participate in this research.

Name of Parent/Guardian (please print): \_\_\_\_\_

Signature of Parent/Guardian: \_\_\_\_\_

Date: \_\_\_\_\_

Name of Student Participant: \_\_\_\_\_

Signature of Student Participant: \_\_\_\_\_

Date: \_\_\_\_\_

This study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University’s principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are free to discuss your participation in this study with me or with the supervisors at the contacts listed below. If you would like to speak to an officer of the University not involved in the study, you may contact the School Ethics Officer on 001-61-7-3365 6502.

Xinxin Fan  
PhD student  
Tel.: +61 0406179886  
Email: xinxin.fan@uqconnect.edu.au

Dr. David Geelan  
Supervisor  
Tel.: +61 0755528647  
Email: d.geelan@uq.edu.au

Dr. Tony Wright  
Supervisor  
Tel.: +61 3365 6634  
Email: tony.wright@uq.edu.au

## Appendix G: Teacher Training Schedule

### 1) Project introduce

This research project will develop and evaluate the effectiveness of an instructional approach – inquiry-based learning with interactive simulation approach (ILIS approach) on students' conceptual understanding about force and motion. The ILIS approach involves five steps: 1) elicitation and clarification of existing conceptions and the 'target' scientific conception; 2) outlining the predictions and implications of students' existing conceptions and the scientific conception; 3) testing predictions of competing conceptions using interactive simulations; 4) elucidation of findings and linking results to the scientific conception; 5) meta-cognitive evaluation and further testing to develop and deepen understanding of the scientific conception.

Student participants will learn four lesson topics through two different instructional approaches. The four lesson topics are buoyancy, Newton First Law, Newton Second Law and Newton Third Law. One instructional approach is inquiry-based learning with interactive simulation. The other instructional approach is conventional instruction. Pre- and post-test will be used for collecting data. Classroom observations will be used to record the implementation of inquiry. A small group of students and teachers will be interviewed following. The data explanation from the interviews will provide evidence about the contribution of the interactive simulations to the inquiry instruction their effect on conceptual change.

### 2) Participants

- a. Researchers
- b. Xinxin Fan, Professor Wei Liang
- c. Teachers: Five physics teachers from three grade 10 senior high schools.
- d. Students: About 200 grade10 students from seven classes.

### 3) Procedure of the Project

- a. 15/03/2013-22/03/2013  
1<sup>st</sup> week Install computers and teacher training
- b. 25/03/2013-29/03/2013  
2nd week Pre-test  
01/04/2013-05/04/2013  
3rd week Students used the software twice  
08/04/2013-19/04/2013  
4th and 5th week Preliminary experiment  
22/04/2013-10/05/2013  
6th and 7th week Lesson topic 1  
13/05/2013-24/05/2013  
8th and 9th week Lesson topic 2  
27/05/2013-05/06/2013  
10th, 11th and 12th week Lesson topic 3

06/06/2013-14/06/2013

13th and 14th week School Day Off

c. 17/06/2013-28/06/2013

15th and 16th week Post-test and Data Explore Analysis

d. 01/07/2013-12/07/2013

17th week Teacher Interview

18th week Student Interview

4) Project Feedback

a. Research allowance for teachers and relevant assistants

b. Share teachers all software and research resources

c. Publish a conference paper

d. Send back the results of this project

5) PhET simulation introduction

Installation requirements: Microsoft System XP/Vista/7; 256MB RAM; 312MB hard disk space for installation

The use of simulation software is designed to allow students to experience: "How to use computer software technology" in their exploratory learning process.

Description of the operation: The software is simple with easy-to-understand interface; the Grade-1 students in senior middle school are fully capable of operation without the need to learn the information technology specifically. However, reading the following instructions before use will help you learn greatly.

a. Students will use only one kind of software for each class and they may study other software after-school.

b. Having opened any one software, the first thing is to understand the main window, control buttons, selecting button, text contents and corresponding icons and colors on the interface of the software. And then, to have a quick experience so as to help your operations in the experiment.

c. During the experiment, imagine what will be the result of the computer, and is it the same as your expected results?

d. Carefully read the topics in the "Exploration Experiment Form"; carefully record the experimental data; fill out the "Exploration Experiment Form" in accordance with the requirements.

e. You can do the experiment repeatedly.

f. In case of the difficulties encountered in the experiment, seek help from your teacher or your classmates in a timely manner.

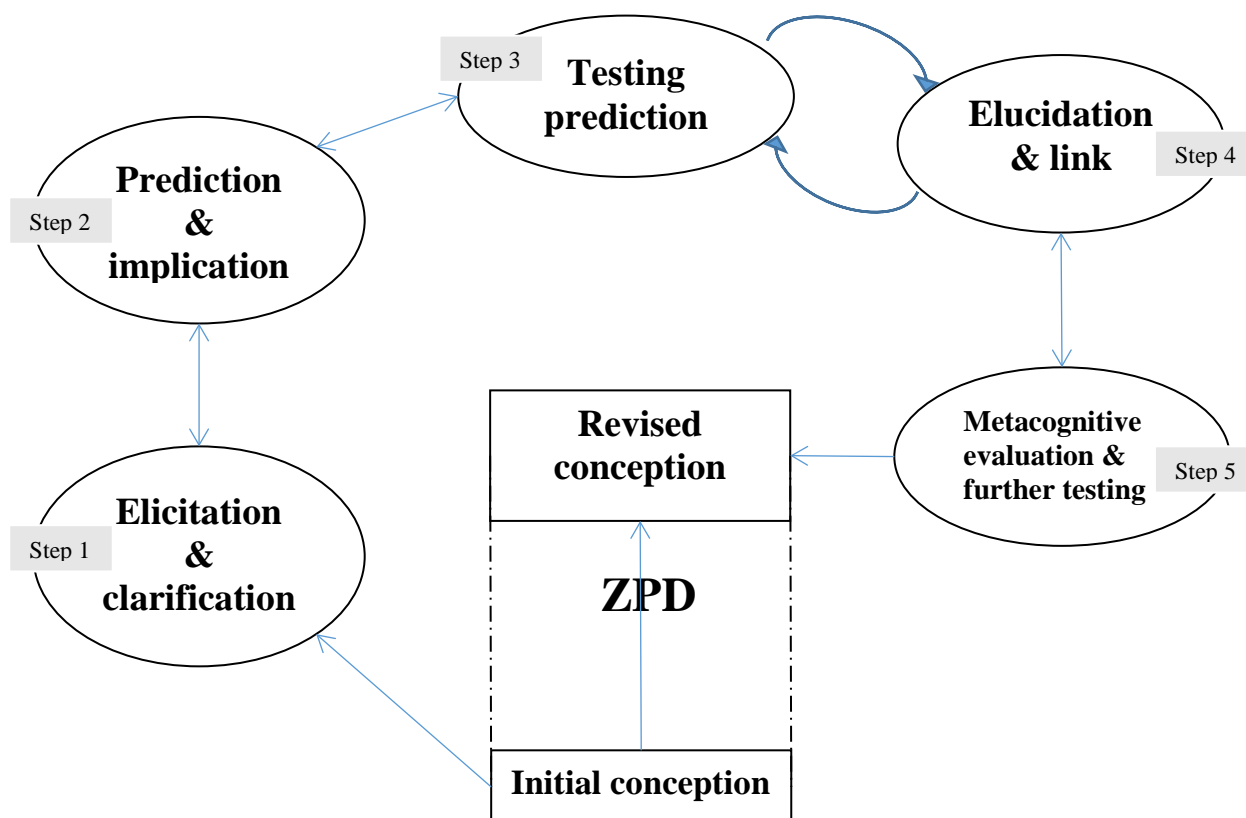
6) Conduct PhET simulations

7) Discussion about how teachers use the simulations to facilitate students' learning

- 8) Introduce conceptual change theory and alternative conceptions
- 9) Introduce the FCI test
- 10) Introduce inquiry process skills and its survey
- 11) Introduce the ILIS approach
- 12) Learning objectives
  - a. Knowledge:
 

Able to understand physics concepts: force, speed, acceleration, friction
  - b. Comprehension:
 

Able to know the difference among physics concepts
  - c. Inquiry Skills:
    - i. Able to propose hypothesis (be aware of new knowledge; be eager to learn more new knowledge; be aware of the exist of their misconceptions)
    - ii. Able to know operation (be clear to their hypothesis and then design a proper inquiry experiment)
    - iii. Able to know analysis (known to organize the data and then analyze the data)
    - iv. Able to communicate (know to express themselves in daily-life and scientific language)
    - v. Able to know synthesis (known to make conclusions through their research; known to use different resources to learn)
    - vi. Able to know application (known to integrated their research with life experience; known to put their conclusion into new situation)
    - vii. Able to know evaluation (known their exploration is one of different ways to solve the problems; known evaluation criteria; known how to justice their own works and theirs; known the different opinions between them and scientists; known the differences between scientific hypothesis and the real world)
- 13) The theoretical framework of the inquiry-based learning with interactive simulations and its implementation



#### 14) Teacher language use and instructional activities

Steps of the ILIS approach	Language expression	Student's activities	Teacher's activities
Elicitation & clarification and Prediction & implication	Why do we explore What have we known What do we want to find out What are your feelings or opinions What are the issues of the exploration How many levels are there for the issue What's the cause of the issue	Teacher guidance Group discussion	The scenario comes from creation and design Stimulate interest Set the target
Testing & Prediction prediction	Can I make a guess Assuming ... what will happen ... When... we are most likely to find ... How should we explain ... What should we do to test If so, what should we need to address	The use of "brainstorming" Assumption Propose a scheme Forecast the results Clarify the issue to be explored Form a tentative explanation	Suppose guess provide assumptions planning strategy Encourage bold guess Integrate the correct false assumptions Organize the exploration Guide Aid Inspiration and
Operation	How to prove assumptions by experiment What instruments do we need What are the tools we also need How do we set up an experiment	Participate in the exploration process Cooperation Observation, analysis, processing and measurement	

	<p>program</p> <p>What are our approaches for exploration</p> <p>Do we need to divide the work</p> <p>What are the responsibilities of each person</p> <p>What are the predicted results of the theoretical exploration</p>	<p>Try to explain each result</p> <p>Contingency preparation</p>	<p>finding</p> <p>Guide suspicion</p>
Analysis of data, and data demonstration	<p>How should we make analysis and argumentation</p> <p>Do we have concrete evidence what means do we use</p> <p>What is the division of our joint forces</p> <p>What problems will appear in the argument</p> <p>Are there any other links between the experimental results and the assumption</p> <p>What forms do we use to draw out conclusion</p> <p>What is the conclusion we have made</p>	<p>Logical thinking</p> <p>Elaboration and argumentation</p> <p>Information processing and integration</p> <p>Induction, deduction, reasoning and sorting</p> <p>Expression of the conclusion</p> <p>Systematization and structuralization</p>	<p>Coaching, clearing up of doubts, disambiguation, problem-solving, help build cognitive structure</p>
Elucidation & link	<p>Is exchange valuable</p> <p>Do our problems have been solved yet</p> <p>How do we express views</p> <p>What is the best way</p> <p>What is the individual responsibility</p> <p>Can the new problems be discovered in the exchange</p>	<p>Communication and cooperation with others</p> <p>Dialogue, debating and response</p> <p>Assess their own exploration process</p> <p>Exploration reflection</p> <p>Further improve and consolidate the conclusions</p> <p>Share the results with others</p> <p>Apply the conclusion to solve problems</p>	<p>Guide the discussion</p> <p>Concluding remarks</p> <p>Evaluation</p> <p>inspire, diagnose</p> <p>Integration of results</p> <p>Propose new assumptions or guess</p> <p>Action study</p> <p>Guide</p>
Metacognitive evaluation & further testing	<p>Are our conclusions helpful</p> <p>How to use the conclusions to explain phenomena</p> <p>What else phenomenon can be explained with the conclusions</p> <p>What will be the conclusions if the experimental conditions are changed</p> <p>Are there any other ways to do for us</p> <p>How to evaluate the exploration results</p>	<p>Explanation</p> <p>Switching, problem solving</p> <p>Process integration</p> <p>Establish the physical model</p> <p>Try expanding</p> <p>Try to improve experimental</p> <p>Evaluate your own and others</p>	<p>Enlightenment</p> <p>Provide the necessary problems of expansion</p> <p>Encourage innovation</p>

15) Discussion the details of lesson plan and students' worksheets;

16) A summary table of the educational experiment's schedule

## Appendix H: Letter of Permission for Use of the FCI

from pgsrack@comcast.net  
to "Ms Xinxin Fan" <xinxin.fan@uqconnect.edu.au>  
date Thur, 09 Aug, 2012 at 02:24 AM



subject Re: Request for FCI  
mailed-by comcast.net  
signed-by comcast.net

We are happy to give you permission in your work toward your thesis, and, naturally, we are interested in what you find out!

Best wishes on your project.

Gregg Swackhamer

-----  
-----Forwarded message-----

from David Hestenes <hestenes@asu.edu>  
to Jane Jackson <jane.jackson@asu.edu>  
date Fri, 10 Aug, 2012 at 17:00:03  
subject Fwd: Request for FCI

Jane, I'll let you take care of this.....David

-----  
from Jane Jackson <jane.jackson@asu.edu>  
to Ms Xinxin Fan <xinxin.fan@uq.net.au>  
date Mon, 13 Aug, 2012 at 16:33  
subject Request for FCI from Univ of Queensland AU (PhD dissertation)

Dear Xinxin Fan,  
The Modeling Instruction staff at Arizona State University respectfully GIVE PERMISSION to use the Force Concept Inventory in your doctoral dissertation study.

Cheers,  
Jane Jackson  
Co-Director, Modeling Instruction Program  
Arizona State University

-----  
Quoting  
**From:** "Ms Xinxin Fan" <xinxin.fan@uq.net.au>  
**To:** PGSwack@comcast.net  
**Sent:** Tuesday, August 7, 2012 10:31:53 PM  
**Subject:** Request for FCI  
mailed-by uqconnect.edu.au

Dear Dr. Swackhamer,

I am a PhD student at School of Education, The University of Queensland, Australia. For my doctoral dissertation, I am conducting a study on Effectiveness of Inquiry Instruction with Interactive Simulations for Addressing Student Physics Misconceptions in Mainland China.

I am writing to ask for your permission to use your **Force Concept Inventory (FCI)** in my study. I would, of course, identify the origin of this scale in my thesis, as well as in any future conference presentations and/or publications that may result from this study. In addition, upon completion of the study, I will provide you with the results of the study if you are interested.

I am looking forward to receiving your permission.

Thank you for your consideration.

Yours sincerely,  
Xinxin Fan  
PhD student  
School of Education  
The University of Queensland  
Australia

Quoting

**From:** "Ms Xinxin Fan" <xinxin.fan@uq.net.au>

**To:** Hestenes@asu.edu

**Sent:** Tuesday, August 7, 2012 8:34 PM

**Subject:** Request for FCI

mailed-by uqconnect.edu.au

Dear Professor Hestenes,

I am a PhD student at School of Education, The University of Queensland, Australia. For my doctoral dissertation, I am conducting a study on Effectiveness of Inquiry Instruction with Interactive Simulations for Addressing Student Physics Misconceptions in Mainland China.

I am writing to ask for your permission to use your **Force Concept Inventory (FCI)** in my study. I would, of course, identify the origin of this scale in my thesis, as well as in any future conference presentations and/or publications that may result from this study. In addition, upon completion of the study, I will provide you with the results of the study if you are interested.

I am looking forward to receiving your permission.

Thank you for your consideration.

Yours sincerely,  
Xinxin Fan  
PhD student  
School of Education  
The University of Queensland  
Australia

## Appendix L: The MFCI used in the Study

- 1) Name: \_\_\_\_\_
- 2) Age: \_\_\_\_\_
- 3) Class: \_\_\_\_\_
- 4) Gender: A Male B Female

**There are three steps to complete for each question: the first is to select the answer, and then explain the reasons for selecting this answer, finally, select the assurance level of your selection for the answer. Discussions are not allowed when students are answering questions. Please complete all questions carefully and independently.**

1. 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 truck.
  - (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 the force on the car as the car exerts on the truck.

☺: Please write down the reasons why you choose the answer in your own words.

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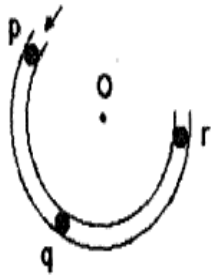
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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

**Use the statement and figure below to answer the next two questions (2 and 3)**

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "p" and exits at "r".



2. Consider the following distinct forces:
1. A downward force of gravity.
  2. A force exerted by the channel pointing from q to O.
  3. A force in the direction of motion.
  4. A force pointing from O to q.

Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

- (A) 1 only.  
(B) 1 and 2.  
(C) 1 and 3.  
(D) 1, 2, and 3.  
(E) 1, 3, and 4.

☺: Please write down the reasons why you choose the answer in your own words.

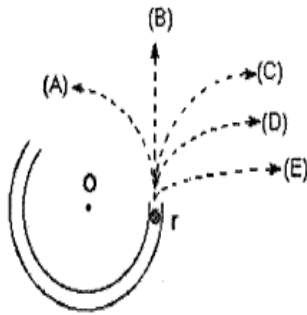
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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

3. Which path in the figure at right would the ball most closely follow after it exits the channel at “r” and moves across the frictionless table top?



☺: Please write down the reasons why you choose the answer in your own words.

---

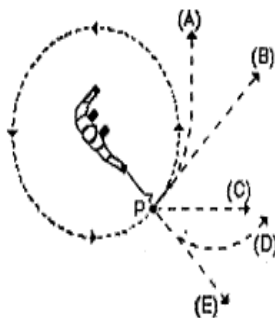


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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

4. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.



At the point P indicated in the figure, the string suddenly breaks near the ball.

If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

☺: Please write down the reasons why you choose the answer in your own words.

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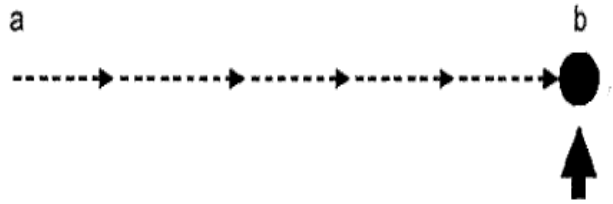
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☺: Are you sure about your answer selected?

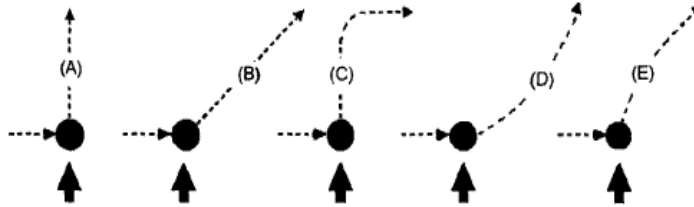
A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

**Use the statement and figure below to answer the next four questions (5 through 6)**

The figure depicts a hockey puck sliding with constant speed  $v_0$  in a straight line from point “a” to point “b” on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point “b”, it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point “b,” then the kick would have set the puck in horizontal motion with a speed  $v_k$  in the direction of the kick.



5. Which of the paths below would the puck most closely follow after receiving the kick?



☺: Please write down the reasons why you choose the answer in your own words.

---



---

☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

6. The speed of the puck just after it receives the kick is:

- (A) Equal to the speed " $v_0$ " it had before it received the kick.
- (B) Equal to the speed " $v_k$ " resulting from the kick and independent of the speed " $v_0$ ".
- (C) Equal to the arithmetic sum of the speeds " $v_0$ " and " $v_k$ ".
- (D) Smaller than either of the speeds " $v_0$ " or " $v_k$ ".
- (E) Greater than either of the speeds " $v_0$ " or " $v_k$ ", but less than the arithmetic sum of these two speeds.

☺: Please write down the reasons why you choose the answer in your own words.

---



---

☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

7. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):

- (A) A downward force of gravity along with a steadily decreasing upward force.
- (B) A steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.
- (C) An almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.
- (D) An almost constant downward force of gravity only.

(E) None of the above. The ball falls back to ground because of its natural tendency to rest on the surface on the earth.

☺: Please write down the reasons why you choose the answer in your own words.

---

---

☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

**Use the statement and figure below to answer the next two questions (8 and 9).**

A large truck breaks down out on the road and receives a push back into town by a small computer car as shown in the figure below.



8. While the car, still pushing the truck, is speeding up to get up to cruising speed:
- (A) The amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
  - (B) The amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
  - (C) The amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
  - (D) The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
  - (E) Neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

☺: Please write down the reasons why you choose the answer in your own words.

---

---

☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

9. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
- (A) The amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
  - (B) The amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
  - (C) The amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.

- (D) The car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
- (E) Neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

☺: Please write down the reasons why you choose the answer in your own words.

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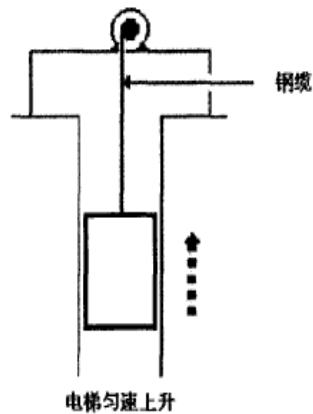


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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

10. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:



- (A) The upward force by the cable is greater than the downward force of gravity.
- (B) The upward force by the cable is equal than the downward force of gravity.
- (C) The upward force by the cable is smaller than the downward force of gravity.
- (D) The upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.
- (E) None of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

11. The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:



1. A downward force of gravity.
2. A force exerted by the rope pointing from A to O.
3. A force in the direction of the boy's motion.
4. A force pointing from O to A.

Which of the above forces is (are) acting on the boy when he is at position A?

- (A) 1 only.
- (B) 1 and 2.
- (C) 1 and 3.
- (D) 1, 2, and 3.
- (E) 1, 3, and 4

☺: Please write down the reasons why you choose the answer in your own words.

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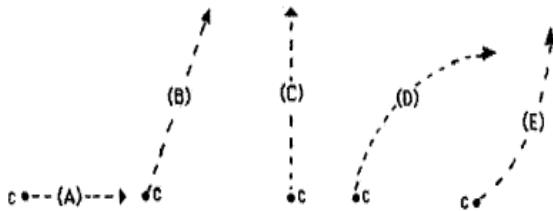


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☺: Are you sure about your answer selected?

- A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

12. At point "c" the rocket's engine is turned off and the trust immediately drops to zero. Which of the paths below will the rocket follow beyond point "c"?



☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

- A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

13. Beyond position "c" the speed of the rocket is:

- (A) Constant.
- (B) Continuously increasing.
- (C) Continuously decreasing.
- (D) Increasing for a while and constant thereafter.



(E) Constant for a while and decreasing thereafter.

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

14. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed  $v_0$ . The horizontal force applied by the woman.
- (A) Has the same magnitude as the weight of the box.
  - (B) Is greater than the weight of the box.
  - (C) Has the same magnitude as the total force that resists the motion of the box.
  - (D) Is greater than the total force that resists the motion of the box.
  - (E) Is greater than either the weight of the box or the total force that resists the motion.

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

15. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves
- (A) With a constant speed that is double the speed  $v_0$  in the previous question.
  - (B) With a constant speed that is greater than the speed  $v_0$  in the previous question, but not necessarily twice as great.
  - (C) For a while with a speed that is constant and greater than the speed  $v_0$  in the previous question, then with a speed that increases thereafter .
  - (D) For a while with an increasing speed, then with a constant speed thereafter.
  - (E) With a continuously increasing speed.

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

16. If the woman in 14 suddenly stops applying a horizontal force to the block, then the block
- (A) Immediately comes to a stop.
  - (B) Continues moving at a constant speed for a while and then slows to a stop.
  - (C) Immediately starts slowing to a stop.

- (D) Continues at a constant speed.
- (E) Increases its speed for a while and then starts slowing to a stop.

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

- A. Quite sure
- B. Sure
- C. No opinion
- D. Uncertain
- E. Quite uncertain

17. In the figure at right, student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chair facing each other.



Student "a" places his bare feet on the knees of student "b", as shown. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.

During the push and while the students are still touching one another:

- (A) neither student exerts a force on the other.
- (B) student "a" exerts a force on student "b", but "b" does not exert any force on "a".
- (C) each student exerts a force on the other, but "b" exerts the larger force.
- (D) each student exerts a force on the other, but "a" exerts the larger force.
- (E) each student exerts the same amount of force on the other.

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

- A. Quite sure
- B. Sure
- C. No opinion
- D. Uncertain
- E. Quite uncertain

18. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity.
2. An upward force exerted by the floor.
3. A net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?

- (A) 1 only.
- (B) 1 and 2.
- (C) 2 and 3.
- (D) 1, 2, and 3.
- (E) None of the forces. (Since the chair is at rest there are no forces acting upon it.)

☺: Please write down the reasons why you choose the answer in your own words.

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☺: Are you sure about your answer selected?

A. Quite sure    B. Sure    C. No opinion    D. Uncertain    E. Quite uncertain

## Appendix I: Inquiry Process Skills Questionnaire

- 1) Name: \_\_\_\_\_  
2) Age: \_\_\_\_\_  
3) Class: \_\_\_\_\_  
4) Gender:    A Male    B Female

**There are 14 questions. Please complete all questions carefully and independently.**

1. I'm not able to put forward my own guess in accordance with the real-life physical phenomena.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
2. I'm not able to express what I propose with daily language.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
3. I'm not able to express what I propose with scientific language and form a scientific study problem.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
4. I want to explore a physics question, but I do not know how to do the inquiry activities.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
5. When I explore a physical problem, I do not think my research is innovative.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
6. When I explore a physical problem, I think my process is logical. But afterwards, I think, if the experiment is done again, I will make the exploration more logical.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
7. When I explore a physical problem, I think my process is rigorous. But afterwards, I think, if the experiment is done again, I will make the exploration more rigorous.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
8. I am not able to properly use the physical experimental tools selected in the exploration activities.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree
9. I am not able to use the physical knowledge learned to interpret the living phenomenon.  
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

10. I understand the physical problems that I am exploring, but there are still some people who do not understand what I said or wrote.

5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

11. In the group experiment, I was not able to work together properly with team members to smoothly get the results.

5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

12. I am not able to use the objective criteria to evaluate my own exploration activities.

5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

13. I am not able to use the objective criteria to evaluate the exploration activities of others.

5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

14. Do you know physics interactive simulations?

A. Yes, I know. (What kind of physics interactive simulations you have already known?

Please write down here \_\_\_\_\_)

B. No, I don't know.

## Appendix J: ILIS Approach Lesson Plan

Teaching Date:			Class Number:		
Teacher's name:			Lesson topic:		
Time	Teaching steps	Teaching objectives	Student activities	Teacher role:	Practice reflection
First lesson					
	Step 1: Elicitation and clarification				
	Step 2: Prediction and implication				
	Step 3: Testing prediction through interactive simulations				
	Close the first class				
Second lesson					
Teaching Date:					
	Engagement				
	Step 4: Elucidation and linking				
	Step 5: Metacognitive evaluation and further testing				
<p>Note: The teacher has considerable freedom to rearrange these steps fit the constraints of the timetable, although these five steps are listed in instructional order, because it's necessary to choose a means of presenting them. While (a) if it's necessary to, say, switch the second and third activities, that is fine and (b) rather than a linear progression with a beginning, middle and end, sometimes a learning sequence will involve cycling through the middle steps multiple times to ensure deeper understanding.</p>					

## Appendix K: Example of Student worksheet for Newton's Second Law Inquiry-based learning with interactive simulation in Physics – Newton Second Law of Motion

Group Member: \_\_\_\_\_ Recorder:

## 1. Scenario Engagement

Complete the following sentences:

On weekend, a few friends and I went to suburb for fun by bus. We found that the riding bus was in the accelerating state of drive, a good friend Xiao Ming asked us, is the acceleration of the bus in a \_\_\_\_ (proportional or reciprocal) relation with the acting join force? With getting on & off of some passengers in the midway, he asked again: is the acceleration of the bus in a \_\_\_\_ (proportional or reciprocal) relation with the total mass of the bus and the all passengers on the bus? Also, is the direction of the acceleration \_\_\_\_ the (same or opposite) as that of the join force?

## 2. Exploration

When you've completed the above scenario, how to ensure your answer is correct? In science, experiments are the common approach to prove our understanding. A complement of scientific experiment often includes certain steps. Proposing hypothesis is commonly the first step of conducting a scientific experiment.

1) **Your hypothesis: (also called your question)**

2) **Your investigative plan:**

**Based on your question, can you make an investigative plan to test your hypothesis?**

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### Investigation through ILIS approach

**Note: Scientists use evidence to prove a scientific claim. Accordingly, let's find out and collect data to test our hypothesis. Here we introduce a computer-based simulation to test our hypothesis. Meanwhile, the computer-based simulations help us collect data that will be used as evidence for making a claim and supporting our discussion.**

Experimental tool: PhET simulation software

**3) Experiment:** The specific exploratory contents: **(Please complete the exploration in the "Force Image" of the simulation software. Change the surface in the simulation software to frictional wooden surface, without changing the starting position of the object.)**

Please complete the following form by group. This is a continuous operation process, before you haven't seen changes of all acting forces in the form; please do not touch the "Reset All" button. Please pay attention to the control of time. You may review your experiment repeatedly by selecting the "Playback" button. Having completed the entire form, you may review your experiment repeatedly by selecting the "Playback" button.

Time	Intensity of the acting force	Frictional force	Is the acting force greater than, smaller than, equal to the frictional force?	Speed	Acceleration	Mass of the object	What acting on the case is... (Select an answer)		By observing the experimental results, answer the following questions after the group discussion:
2s	200N					100Kg	Balance/Imbalance	$F_{sum} =$	What is the state of motion of the object at this point of time?
2s	500N					100Kg	Balance/Imbalance	$F_{sum} =$	What is the state of motion of the object at this point of time?
2s	-500N					100Kg	Balance/Imbalance	$F_{sum} =$	How and why does the state of motion of the object change?
2s	500N					200Kg	Balance/Imbalance	$F_{sum} =$	What is the state of motion of the object at this point of time?
2s	1000N					200Kg	Balance/Imbalance	$F_{sum} =$	What is the state of motion of the object at this point of time?

**4) Your conclusion (please answer questions based on evidence your collected):**

Does your data support your assumption in review of your study assumption?

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If so, please draw a study conclusion according to your study assumptions and the data obtained from your exploratory experiment.

If not, what do you think is the reason for it? What will your group do to improve your experiment?

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**After completion of the above contents, please raise your hands to the teacher.**

**3. Students' presentation:**

After students' presentations, discussion in class:

- 1) Linking with practice: (only if the new results deduced from your study conclusions are consistent with the fact, these conclusions can become the "law.") Can your experimental result become the law serving our life? Please illustrate with example(s) by linking with practice.
  
- 2) Simulation technology:  
 In what circumstances is the simulation technology useful for the experimental study?  
 And what restrictions does it have?

**4. Evaluation of your study**

- 1) We have provided scoring criteria that can be referred by the students in the following table. Students should give your work an objective evaluation.

Please give your entire study a score with your group members according to the following criteria or their own criteria.

Topic and the score	Concise & clear for the issue studied (20 Points)	Reasonable assumptions and interpretation of the study (20 Points)	Scientific and rational for design of the experiment (20 Points)	Practical for study applications (20 Points)	Coherent & consistent from the study question to the conclusion (20 Points)
Your score					

- 2) You can also let your friends to give your entire study a score according to the following criteria or their own criteria.

Topic and the score	Concise & clear for the issue studied (20 Points)	Reasonable assumptions and interpretation of the study (20 Points)	Scientific and rational for design of the experiment (20 Points)	Practical for study applications (20 Points)	Coherent & consistent from the study question to the conclusion (20 Points)
Your score					



## Appendix L: Classroom Observation Guide for Teacher

### I. Basic information

Instructional content: \_\_\_\_\_  
 Name of teacher: \_\_\_\_\_  
 Location of class: \_\_\_\_\_  
 Years of Teaching: \_\_\_\_\_  
 Observer: \_\_\_\_\_  
 Date of observation: \_\_\_\_\_  
 Start time: \_\_\_\_\_  
 End time: \_\_\_\_\_  
 Announced observation? \_\_\_\_\_

### II. Classroom Observation Guide for Teacher

Item	Concerned (1)	Developing (2)	Appropriate (3)	Professional (4)	Notes
Instructional Objectives	Not clear	Clear but don't make effectively	Clear and make effectively	Clear and make particularly professional	
Instructional contents	Too easy	There is a big gap for the whole contents	Competent content	Deep understanding and further study	
Instructional assessment	Teacher doesn't use assessments for objectives	Teacher assesses some of objectives	Teacher assesses objectives and know students' learning situation well	Teacher uses well-designed assessments and connects with further lessons	
Instructional materials and technologies	Teacher doesn't use materials and technologies	Teacher uses materials and technologies, but doesn't support lesson	Teacher uses materials and technologies, and support lesson	Teacher uses creative materials and technologies, and make further learning for this and further lesson	
Instructions	Teacher's instructions don't use for all students	Diversity instructions, but fail to work for all students	Diversity instructions work for all students' needs.	Instructions are particular well-designed and work effectively.	
Instruction engagement	No purposeful engagement	Purposeful engagement, but fail to capture students attention	Purposeful engagement, and capture students attention with related	Creative designed engagement, and effectively capture students' attention	

			lesson's objectives		
Distribution of instructional time	Teacher has problems in pacing instructional time	Teacher is able to pace instructional time, but still has problems	Teacher is good at pacing instructional time	Teacher takes great advantages of pacing instructional time	
Instructional transition	Awkward transition	Instructional transitions are planned, but are somewhat rough.	Smooth and logic; teacher use transitions in the lesson	Particularly smooth and logic; teacher make effective transitions	
Instructional question	Teacher doesn't use questioning for students' deep understanding	Teacher uses questioning for students' deep understanding, but still need to develop	Teacher is good at using questioning for students' deep understanding	Teacher is professional for using questioning for students' deep understanding	
Instructional feedback	Teacher doesn't response students well	Teacher attempt response as a good listener, but still develop	Teacher responses students with creative, reflective and humors feedback; effective listening happens among students	Teacher responses students with creative, reflective and humors feedback; and leads to class discussion and student communication	
Teachers awareness with students' diversity	Teacher is not aware of students' diversity	Teacher is aware of student' diversity and attempt to give different responses, but still need to develop	Teacher is aware of students' diversity with respect	Teacher is adapted in students' diversity and responses professionally.	
Instructional closure	Teacher doesn't make a class closure	Teacher makes the class closure but doesn't connect with next lesson	Teacher guides to the degree of students' understanding, effective close the lesson and connects with next lesson	Teacher's closure is effectively encouraging students' own summary.	
Instructional control	Teacher fails to control the class	Teacher to some degree control the whole class	Teacher effectively control the whole class	Teacher is adapted in professional controlling the whole class	

Note: Adapted from “Lesson observation rubric,” by School of Education Dean’s Office, The College of New Jersey, 2007, *Teacher candidate assessment program, New Jersey, Spring 2007*.

### Appendix M: Classroom Observation Guide for Classroom

Teaching Date:		Class Number:	Teacher’s name:	Lesson topic:
Time (60mins)	Steps	Teaching contents		Observer’s notes
	Step 1: Elucidation & clarification			
	Step 2: Prediction & implication			
	Step 3: Testing prediction			

Teaching Date:		Class Number:	Teacher’s name:	Lesson topic:
Time (60mins)	Teaching steps	Instructional activities		Notes
	Review			
	Step 4: Elucidation & linking			
	Step 5: Metacognitive evaluation and further-test			

## Appendix N: Interview Guide for Teachers

Step		Tasks/questions	Probes
Opening		<ul style="list-style-type: none"> <li>♦ Self-introduction of interviewer</li> <li>♦ Questions:               <ul style="list-style-type: none"> <li>- Please tell something about yourself.</li> <li>- How long have you taught physics?</li> <li>- Please tell more about your study experience and work experience.</li> <li>- What is your daily schedule?</li> <li>- What is your strength as a teacher?</li> <li>- What aspect do you want to improve?</li> <li>- Why do you want to participate in the project?</li> </ul> </li> </ul>	
Content	1. Conceptual understanding in physics and instructional approaches	1) Do you think conceptual understanding is important in physics?	- Why...
		2) Do you think there are different understandings between common sense, intuition, alternative conceptions, and canonical conceptions when students enter class?	- Can you give some examples about that?
		3) Do you think it is difficult to change students' alternative conceptions?	- Can you explain more about that?
		4) What kind of instructional approach is the best effective way to help students' conceptual understanding/change?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		5) What kind of instructional approach do you usually use in your class?	<ul style="list-style-type: none"> <li>- Do you have fixed procedure?</li> <li>- Can you give some examples about that?</li> </ul>
		6) What do you think of your instructional approach?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Tell me more about the traditional approach.</li> </ul>
	2. Inquiry-based learning approach	1) Before this project, do you know inquiry-based learning?	
		2) What do you understand the inquiry-based learning?	- Can you explain more about that?
		3) Before this project, have you used inquiry instructional approach in your class?	<ul style="list-style-type: none"> <li>- How did you use it?</li> <li>- Tell me more...</li> <li>- Can you give me an example?</li> </ul>
	3. The ILIS approach and conceptual understanding	1) What do you think of the ILIS approach? And what do you think of conventional instruction?	<ul style="list-style-type: none"> <li>- Tell me more about that...</li> <li>- Can you explain why...</li> <li>- What's the difference?</li> </ul>
		2) Do you think the ILIS approach can support students' conceptual understanding?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> </ul>

			<ul style="list-style-type: none"> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		3) Which one provides better conceptual learning during the ILIS approach and conventional instruction?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		4) Do you think there will be gender influence on participants' conceptual learning during the ILIS approach and conventional instruction?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		5) What is your biggest problem when you used the ILIS approach?	<ul style="list-style-type: none"> <li>- What do you mean by...?</li> <li>- Why...</li> </ul>
		6) Which is your favorite step when using the ILIS approach?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Let's talk about that in more details.</li> </ul>
		7) What are the advantages and disadvantages of the ILIS approach and conventional instruction?	<ul style="list-style-type: none"> <li>- What do you mean by...?</li> <li>- Why...</li> </ul>
	4. The ILIS approach and confidence in learning	1) Do you think the ILIS approach can support students' confidence in learning?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		2) What kind of the relationship do you think between conceptual understanding and students' confidence in learning?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
	5. The ILIS approach and inquiry process skills	1) Do you think the ILIS approach can support students' inquiry process skills?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		2) Do you know the inquiry process skills?	<ul style="list-style-type: none"> <li>- What are they?</li> </ul>
		3) What do you think each inquiry process skill for helping students' conceptual understanding?	<ul style="list-style-type: none"> <li>- Why</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
		4) What kind of the relationship do you think between conceptual understanding and students' inquiry process skills?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
		5) Do you think there is a relationship among conceptual understanding, confidence in learning and inquiry process skills?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
	6. Interactive Simulation	1) Do you know physics interactive simulation?	<ul style="list-style-type: none"> <li>- Tell me more...</li> <li>- Can you give me an example?</li> </ul>

		2) Do you like using physics simulations for physics teaching?	- Why? - Can you explain more about that?
		3) Do you think interactive simulation is helpful your and your students' conceptual understanding?	- Why? - Can you explain more about that?
		4) What are the advantages and disadvantages of PhET simulations in teaching?	- Why? - Can you explain more about that?
		5) How to take more advantage of the PhET interactive simulation when integrating it into your class?	- Why? - Can you explain more about that?
	7. Teacher's roles and students' roles	1) Do you think there is difference between student with the ILIS approach and student without?	- Tell me more... - Can you give me an example?
		2) What is the role of teacher in this project?	- Why? - Let's talk about that in more details.
		3) What is the role of student in this project?	- Can you explain more about that?
		4) What kind of influence will this project bring to you?	- Let's talk about that in more details.
Closing		- Do you have anything you want to add that we have not thought about? - Is there anything else you would like to add? - I have no further questions, do you have anything more you want to bring up, or ask about, before we finish the interview?	Thank you for your participant.

### Appendix O: Interview Guide for Students

Step	Tasks/questions	Probes
Opening	<ul style="list-style-type: none"> <li>♦ Self-introduction of interviewer</li> <li>♦ Questions: <ul style="list-style-type: none"> <li>- Please tell something about yourself.</li> <li>- Do you like Physics?</li> <li>- What lesson topics have learned in physics?</li> <li>- Which lesson topic are you interested in?</li> <li>- Who is your physics teacher?</li> </ul> </li> </ul>	
Content	1) Do you think conceptual understanding is important in physics?	- Why...
	2) Do you think there are different understandings between common sense, intuition, alternative conceptions, and canonical conceptions when you enter class?	- Can you give some examples about that?
	3) Do you think it is difficulty to change your alternative conceptions?	- Can you explain more about that?

		4) What kind of instructional approach is the best effective way to help your conceptual understanding/change?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		5) What kind of instructional approach your physics teacher usually use in your class?	<ul style="list-style-type: none"> <li>- Can you give some examples about that?</li> </ul>
		6) What do think of the instructional approach your physics teacher usually used in your class?	<ul style="list-style-type: none"> <li>- Why</li> <li>- Tell me more...</li> </ul>
	2. Inquiry-based learning approach	1) Before this project, do you know inquiry-based learning?	<ul style="list-style-type: none"> <li>- Tell me more...</li> <li>- Can you give me an example?</li> </ul>
		2) What do you understand the inquiry-based learning?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> </ul>
	3. The ILIS approach and conceptual understanding	1) What do you think of the ILIS approach? And what do you think of conventional instruction?	<ul style="list-style-type: none"> <li>- Tell me more about that...</li> <li>- Can you explain why...</li> <li>- What's the difference?</li> </ul>
		2) Do you think the ILIS approach can support your conceptual understanding?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		3) Which one provides you better conceptual learning during the ILIS approach and conventional instruction?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		4) Do you think there will be gender influence on your classmates' conceptual learning during the ILIS approach and conventional instruction?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		5) What is your biggest problem when you used the ILIS approach?	<ul style="list-style-type: none"> <li>- What do you mean by...?</li> <li>- Why...</li> </ul>
		6) Which is your favorite step when using the ILIS approach?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Let's talk about that in more details.</li> </ul>
		7) What are the advantages and disadvantages of the ILIS approach and conventional instruction?	<ul style="list-style-type: none"> <li>- What do you mean by...?</li> <li>- Why...</li> </ul>
	4. The ILIS approach and confidence in learning	1) Do you think the ILIS approach can support your confidence in learning?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		2) What kind of the relationship do you think between conceptual understanding and students' confidence in learning?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
	5. The ILIS approach and inquiry	1) Do you think the ILIS approach can support your inquiry process skills?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> </ul>

	process skills		<ul style="list-style-type: none"> <li>- Can you give an example about that?</li> <li>- Why...</li> </ul>
		2) Do you know the inquiry process skills?	<ul style="list-style-type: none"> <li>- What are they?</li> </ul>
		3) What do you think each inquiry process skill helpful for your conceptual understanding?	<ul style="list-style-type: none"> <li>- Why</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
		4) What kind of the relationship do you think between conceptual understanding and students' inquiry process skills?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
		5) Do you think there is a relationship among conceptual understanding, confidence in learning and inquiry process skills?	<ul style="list-style-type: none"> <li>- How</li> <li>- Can you explain more about that?</li> <li>- Can you give an example about that?</li> </ul>
	6. Interactive Simulation	1) Do you know physics interactive simulation?	<ul style="list-style-type: none"> <li>- Tell me more...</li> <li>- Can you give me an example?</li> </ul>
		2) Do you like using physics simulations for physics teaching?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Can you explain more about that?</li> </ul>
		3) Do you think interactive simulation is helpful your and your classmates' conceptual understanding?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Can you explain more about that?</li> </ul>
		4) What are the advantages and disadvantages of PhET simulations in teaching?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Can you explain more about that?</li> </ul>
		5) How to take more advantage of the PhET interactive simulation when integrating it into your learning?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Can you explain more about that?</li> </ul>
	7. Teacher's roles and students' roles	1) Do you think there is difference between student with the ILIS approach and student without?	<ul style="list-style-type: none"> <li>- Tell me more...</li> <li>- Can you give me an example?</li> </ul>
		2) What is the role of teacher in this project?	<ul style="list-style-type: none"> <li>- Can you explain more about that?</li> </ul>
		3) What is your role in the project?	<ul style="list-style-type: none"> <li>- Why?</li> <li>- Let's talk about that in more details.</li> </ul>
		4) What kind of influence will this project bring to you?	<ul style="list-style-type: none"> <li>- Let's talk about that in more details.</li> </ul>
	Closing	<ul style="list-style-type: none"> <li>- Do you have anything you want to add that we have not thought about?</li> <li>- Is there anything else you would like to add?</li> <li>- I have no further questions, do you have anything more you want to bring up, or ask about, before we finish the interview?</li> </ul>	Thank you for your participant.



## Appendix P: Ethical Clearance

SCHOOL OF EDUCATION  
Response to Application for Ethical Clearance

<b>Applicant Name: Xinxin Fan</b>
<b>Principal Supervisor: Dr David Geelan and Dr Tony Wright</b>
<b>Applicant email address:</b> <b>Xinxin.fan@uqconnect.edu.au</b>
<b>Participants/Recruitment (Qs 1-3)</b> Clearly explained.
<b>Project Summary/Research Plan (Qs 4-5)</b> Clearly explained.
<b>Ethical Considerations (Qs 6-17)</b> Explained.
<b>Consent Form/Information Sheet</b> All information included.
<b>Questionnaire</b> Good examples provided.
<b>Gatekeepers</b> Yes.
<b>Presentation (correct form, typed, error free)</b> Satisfactory.
<b>Comments &amp; Recommendation</b> The application is approved.
<b>(Signed) Member of the UQSE Research Ethics Committee:</b> <b>Annemaree Carroll</b> <b>Date. 03/12/12</b>