A Mixed Method Study of Promoting Student Conceptual Understanding through Simulation-supported Inquiry Instruction

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Abstract: *This research project is indented to develop and explore the effectiveness of inquiry instruction when combined with interactive simulation technology to help students address their misconceptions and come to deeper conceptual understandings about force and motion in Physics. Inquiry instruction is an operational iterative process in the nature of science. It in this study will be implemented through four steps involving Engagement, Experiment, Discourse-sharing and Evaluation (EEDE). Interactive simulation plays the educational scaffolding role in the process of inquiry instruction. Working from a constructivist perspective, the concepts of inquiring instruction, interactive simulations and students' achievement in dispelling their misconceptions as well as empirical studies of inquiry instruction with interactive simulations will be examined. A quasi-experimental mixed method will be used. The Force Concept Inventory (FCI) will be applied in pre- and post-tests to measure students' achievement in addressing misconceptions; classroom observations and semi-structured-interviews will be conducted to complement the quantitative data. The data will be analyzed using Spearman's correlation and simple linear regression; Hake gain method and NVivo software for qualitative analysis. The results will compare two instructional approaches and provide evidence about promoting student conceptual understanding through technology-supported inquiry instruction.*

Keywords: inquiry instruction, interactive simulation, misconception, Physics

1. Introduction

Inquiry instruction which emerged from science education reform has been contended by numbers of researchers over a century (Deanna Kuhn, Black, Keselman, & Kaplan, 2000; D. Kuhn, Katz, & Dean, 2004; Reid, Zhang, & Chen, 2003). However, teachers found that inquiry curricula are time consuming, difficult to teach, hard to track, and lack of support in practice. Moreover, some inquiry experiments are risky and expensive (Welch, Klopfer, Aikenhead, & Robinson, 1981). Teachers prefer using easily operational traditional instructional methods such as teacher-centered lectures, discrete science facts rote memorization, "cookbook" laboratory activities and summative tests. Studies have proven that traditional instructions not only make little effect on students' misconception change (Bryce & MacMillan, 2005; Hake, 1998; Kloos, Fisher, & Van Orden, 2010; Knight, 2004; McDermott, 1984; Redish, 1999, 2000; Redish, Saul, & Steinberg, 2000; Zavala, Alarcón, & Benegas, 2007), and ironically serve to destroy students' innate curiosity about the world of science. Typically students come to the science classroom with a number of alternative conceptual frameworks which are not inconsistent with scientific concepts but provide students to explain the basic knowledge for how and why things behave as they do. These alternative conceptual frameworks are commonly called misconceptions and inhibit the further learning and understanding of certain concepts (Driver & Easley, 1978; Driver & Erickson, 1983; McCloskey, 1983). Furthermore, students use the well-documented misconceptions quite happily as they explain phenomena in daily life even if finishing their physics classes (Bryce & MacMillan, 2005; Geddis, 1991; McDermott, 1984). With the development of educational technology, interactive simulations offer new affordances for facilitating inquiry instruction to promote students' science inquiry (Clark, Nelson, Sengupta, & D' Angelo, 2009; Jacobson, 2004). In order to facilitate the use of inquiry instruction for learning science and enhance students' achievement in addressing their physics misconceptions and supporting deeper conceptual understandings, the project links inquiry instruction with computer-based interactive simulations to support conceptual change in the context of Mainland China.

2. Inquiry Instruction with Interactive Simulation

To help clarify 'inquiry instruction', the National Academy of Sciences of National Research Council of the US released the *National Science Education Standards* and identified five essential features of inquiry (2000, p. 25), regardless of the grade level including 1) scientifically oriented questions that engage the students; 2) evidence collected by students that allows them to develop and evaluate their explanations to the scientifically oriented questions; 3) explanations developed by students from their evidence to address the scientifically oriented questions; 4) evaluation of their explanations, which can include alternative explanations that reflect scientific understanding; and 5) communication and justification of their proposed explanations. The Ministry of Education of the PRC issued the *Guidelines on the Curriculum Reform of Basic Education (Trial version)* (2001a) which marked the launch of the biggest curriculum reform in the PRC. The *Physics Curriculum Standards for Compulsory Education in Fulltime Senior Middle Schools (Trial version)* (2001b) followed up the Guidelines. It is to achieve scientific literacy of student (ages 15–18). Six steps of inquiry instruction was promoted: 1) conducting experiment design, 2) collecting and analyzing data, 3) evaluating, 4) making conclusions through discussing with others after 5) teachers propose questions and 6) students make assumptions and hypothesis. In the Physics Curriculum Standards 'inquiry process and physics method' is included in the objectives of the curriculum for the first time.

Adopted from the explanations of inquiry in national and international education reforms, four steps of inquiry instruction in this study will be involved: Engagement, Experiment, Discourse-sharing and Evaluation (EEDE). Studies reported that science teachers have a positive attitude toward the importance of inquiry instruction. However, little evidence exists that inquiry instruction is being used (Hurd, Bybee, Kahle, & Yager, 1980). In order to achieve inquiry processes in real science classroom, studies argued that leveraging interactive simulations are a promising educational technology tool (Geban, Askar, & Ozkan, 1992; Kinzie, Strauss, & Foss, 1993). Interactive simulations, as scaffolding instructional technologies, play an important role in the whole inquiry instructional process. When engaging in this scaffolding inquiry, students identify their assumptions, ask questions, conduct experiments, collect data, construct explanations, use critical and logical thinking, test those explanations against current scientific knowledge, communicate their ideas to others, as well as evaluate and make conclusions. In this way, students actively achieve deeper understandings of physics conceptions and address misconceptions.

White and Frederiksen (1998) conducted two studies to investigate the impact of Thinkertools on science process skills. Experimental group and control group were randomly selected during the 10.5 experimental weeks. Data from pre- and post- inquiry tests showed that understanding of scientific investigations of experimental and control groups had been improved; and that scores for the group using self-assessment exhibited much greater advancement. Particularly, there was an impressive gain for the lowest-achieving students. These authors also found that Thinkertools advanced students' conceptual understanding of ideas like motion and force in physics. Comparing middle school and high school gains for the middle school students were greater than for those of the 40 students who had graduated from high school. Both levels of students who completed the simulation curriculum unit thought Thinkertools had a positive impact on their learning and conceptual understanding. Cox, Belloni, Dancy and Christian (2003) investigated simulation focused on interactive Physlet-based curricular materials. The simulations allowed students to manipulate the experiment and generate data. They claimed that it is difficult and time-consuming for traditional instructional approaches to facilitate the development of students' conceptual understanding; let alone engage students in the investigative processes of science inquiry. This process of simulation-based inquiry inspires students' innate curiosity about the natural world and develops deep understandings about various. The simulation-based 'Model-Enhanced ThinkerTools' (METT) environment developed by Schwarz and White (2005) was embedded in a 7th grade science curriculum unit for 45 minutes every school day. The goals of the 'Model-Enhanced ThinkerTools' (METT) curriculum unit are to create; evaluate; and discuss understanding of concepts in science. Researchers administered three pre- and post- tests that included a modeling 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.

Scientific inquiry plays a vital role for students’ learning of science (Committee on Science Learning, 2007; National Research Council, 2005). Conceptions as the content and scientific inquiry as the method are two key parts in science. Inquiry instruction could and should be the most effective way to students’ achievement in addressing misconceptions about physical world in real classroom. Although studies show no significant difference between the learning of students engaging in inquiry instruction using technology and without technology(Geelan & Mukherjee, 2011; Gobert & Pallant, 2004; Schwarz, 2005), it remains valuable and important to explore ways to conduct inquiry instruction appropriately in community of classroom. In order to make further exploration about this question, this study derives and extends a theoretical framework from Zone of Proximal Development theory (Vygotsky, 1964) and scaffolding theory (Gobert, 2005) to develop and evaluate an inquiry instruction with interactive simulations in an active environment.

3. Theoretical Framework and Instructional Design

Four steps of inquiry instruction theoretical framework are developed in this study. During the first step - engagement - teachers will introduce discrepant events to invoke students’ disequilibration (Piaget, 1970). The process then moves to the second step - experiment. The purpose of this step is to dig out students’ misconceptions, which will be either discounted or accommodated by a conceptual change at the end (Llewellyn, 2005). Interactive simulations in this step (for the classes studying using inquiry education with interactive simulations) will allow students to conduct experimental designs through operating the simulations, collect experimental data, identify their assumptions through timely feedback and discuss with their group members. Using interactive simulations in the inquiry process is believed to have the potential to make scientific concepts more intelligible and plausible (Posner, Strike, Hewson & Gertzog, 1982). The scaffolding offered by the teacher and the interactive simulations (or by the teacher and experiments or other experiences in the inquiry-without-simulations and traditional-instruction groups) serves to create the ZPD, supporting students to work with concepts in ways they cannot without this scaffolding. Furthermore, working with peers offers students a form of science community, although one conducted partly in informal science language. The key point here is that each student’s learning is connected to, and dependent upon, the scaffolding from teachers, peers and technologies on the social plane of classroom. At the end of this step, the modification and adjustment of cognitive structures to new situations would (it is hoped) occur and a new equilibrium is attained (Llewellyn, 2005, p. 45).

In the third step - discourse-sharing - language plays an important role in learning. The original experimental results from the second step will be discussed, moving from informal expression within groups to discussion in a more formal way beyond groups, in the whole class. Language among learners and teachers becomes of paramount importance in this step. The last one will be the evaluation step in which students present their understanding and apply what they have learned to new situations though presentations, assignments, tests, etc. Teachers will ascertain whether the students have changed their thoughts or behaviors. For students, this step is a time for them to evaluate their own progress and finish the process of internalization (Vygotsky, 1964).

4. Methodology

4.1 Research Questions

In order to explore the effectiveness of inquiry instruction with technology for acquiring a deeper understanding as well as dispelling misconceptions on force and motion in physics, this study will use the quasi-experimental explanatory sequential mixed method. Three main questions with detailed sub-questions will be addressed in this study.

RQ1: What are the relationships between inquiry instruction with and without computer-based interactive simulation and student misconceptions?

RQ2. Why does inquiry instruction with interactive simulations influence (or not) misconception change?

RQ3. How does inquiry instruction with interactive simulations influence misconception change?

4.2 School and Participant

This study will be conducted in a national public senior middle school based on stratified sampling according to the ranking of middle schools in Beijing. This Senior Middle School is the typical public medium-sized school in Beijing. It also has the basic information technology equipments and makes sure every student have their own computer if any needs. As a quasi-experimental research, this study selects the four whole classes to conduct research. Approximately 200 students from Grade-10 will be participated for four months in total. Two researchers will work with two formal teachers who have work experience for more than 5 years. Researchers will assistant two teachers in real classrooms in order to alert and avoid any difference of the implementation of the experimental intervention by different teachers. Besides, teachers and researchers will meet three times a week for sharing teaching experience, discussing students' reflections, creating teaching plan and watching class video. Students will be assigned to two groups based on their academic points and brief questioner survey to guarantee equivalence of student achievement across groups.

4.3 Instruments

This study will use twenty questions selected from the Force Concept Inventory (FCI) *(Chinese Version)* as pre- and post-test instruments (Halloun, Hake, & Hestenes, 1995; Hestenes, Wells, & Swackhamer, 1992). The FCI is a 30-question multiple choice test of "forced choice between Newtonian concepts and commonsense alternatives" (Hestenes et al., 1992, p. 142). It has been recognized as a well validated instrument for checking student conceptual understanding and has been administered to over 200,000 students in many countries and in at least 12 languages (Henderson, 2002).

Adopted classroom observation checklist used in this study not only guarantees each step of inquiry instruction will be conducted as the planned guidelines, but also records the implementation situation of teachers and students in practice for further analysis. Why and how questions will be addressed based on semi-structured face-to-face interview which combines an interview schedule with structured questions and less structured questions to explore issues raised spontaneously by the interviewee.

4.4 Java Applets Interactive Simulation on Physics

Interactive simulations, as visual representations of dynamic systems of scientific phenomena, are considered to be 'exploratory' applications (Kozma & Russell, 1997, 2005). Interactive simulations not only simulate natural, engineered, and invented phenomena or situations (Committee on Modeling, 2010), but also offer visual explanations of underlying causal mechanisms and scientific phenomena that are not directly observable because of their scale (Gobert, 2000). In addition, they typically allow users to manipulate experimental sets and then observe the results in 'virtual laboratories' (Gilbert & Boulter, 1998). Java Applets on Physics designed by Walter Fendt as high quality interactive simulation will be applied in this study. Using the interactive simulation, students can do a variety of experiments in order to discover the laws of physical concepts. One example is the activity about the Newton's Second Law in which students can change the initial Mass of the wagon, Hanging mass and Coefficient of friction in order to evaluate whether the results are the same to their predictions and figure out what will happen between these three parameters. Their experiments could counteract the common misconception that motion requires a force and to replace it with the Newtonian conception that motion does not require a force and force cause accelerations. The operation of this interactive simulation can not only facilitate students the law of the effects between friction and gravity, but also support students to finish other steps in this study.

4.5 Data Collection and Analysis

Data will be collected through pre- and post-tests in quantitative phase and following interviews in qualitative phase. Classroom observations will be videoed the whole process of experimental intervention.

The Force Concept Inventory (FCI) will be used to measure approximately 200 students' achievements in reducing their misconceptions before and after they finish Newton Laws classes in different groups. Group A has the inquiry instruction with technology curricula (both teacher and students will use interactive simulation during the implementation of inquiry instruction); Group B as control group has the traditional instruction (teacher will use interactive simulation but students don't). All groups conduct four steps of inquiry instruction discussed before. The raw data will be transferred into SPSS to produce a data set. Pre-test will answer the size of misconceptions students hold; Spearman's correlation test and simple linear regression will tell the results of inquiry instruction with technology for addressing students' misconceptions. Hake gains method will be applied to address the relative sizes of the gains in students' achievement in reducing misconceptions. Classroom observations and semi-structured interviews also will be used for further data collection to complement and support the quantitative findings.

Based on the quantitative data, two teachers and six students whose scores fall in the upper, middle and lower quartiles of the distribution are selected for interview in qualitative phase. Each interview will last for 60-90 minutes. Semi-structured interviews will be recorded digitally using a voice recorder to capture all discussions, and brief notes will be taken by the interviewer for further analysis after the interview. Two rounds of interviews will be conducted through six participants. NVivo software will be used to assist with the systematic analysis of interview recordings. Data analysis will consist of an interpretative analysis technique to explore why- and how-questions.

4.6 Result

This project builds on the study on the educational effectiveness of using interactive simulations in Physics (Fan & Geelan, 2012). We are now working on the ways to explore the effective means of reducing the number of misconceptions students hold about force and motion through inquiry instruction with interactive simulation. The project results from comparing (1) the effects of inquiry instruction using interactive simulation with (2) inquiry instruction without the use of interactive simulation will help to answer relative questions and lead to more research.

5. Conclusion

Inquiry instruction with interactive simulations-a necessity for student success in a highly competitive, twenty-first century, technological world-is still prevalent in science education. The objectives of this study are to address students' misconceptions about force and motion and promote deeper understandings of physical conceptions. Meanwhile, it is to engage students in taking ownership of learning, develops process skills in the areas of learning, increases student-student and student-instructor interactions, improves attitudes toward physics and science, enhances learning with information technology, develops supporting process skills in teamwork, communication, management, and assessment.

This study will provide evidence about the effectiveness of particular approaches for physics teachers to effectively deal with students' difficulties in physics. It also offers methodological innovations in the under-researched area of linking particular technological tools for learning with particular pedagogical approaches.

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