A Novel Instructional Sequence for Interactive Simulations (ISIS): Developing Conceptual Understanding in Physics Education in China within a Context of Curricular Reform

Author

Geelan, DR, Fan, X

Published

2014

Conference Title

Proceedings - 2014 International Conference of Educational Innovation Through Technology, EITT 2014

Version

Accepted Manuscript (AM)

DOI

10.1109/EITT.2014.41

A Novel Instructional Sequence for Interactive Simulations (ISIS)

Developing Conceptual Understanding in Physics Education in China within a Context of Curricular Reform

Xinxin Fan
School of Education
The University of Queensland
Brisbane, Australia
xinxin.fan@uq.net.au

David R Geelan
School of Education and Professional Studies
Griffith University
Gold Coast, Australia
d.geelan@griffith.edu.au

Abstract

China has implemented curricular reforms with a focus on inquiry learning in physics education. As has been the case in other countries around the world, teachers have generally supported the intentions of the curriculum in relation to inquiry pedagogy but, in the face of high stakes assessment and other issues, have struggled to implement it appropriately in classroom teaching. Interactive simulations – computer-based 'virtual experiments' in which students can enter values and both observe and record the results – have considerable potential for supporting teachers' use of inquiry approaches to the development of concepts in physics. This paper outlines the Chinese context of the study along with a novel instructional sequence developed and tested by the authors for the purpose of scaffolding inquiry instruction using interactive simulations. The paper describes a pilot study of the classroom use of the ISIS instructional sequence, including measurement of students' development of physics concepts, their confidence in their own understanding and their development of the skills of scientific inquiry. The sequence was found to be effective for conceptual development.

Keywords: physics, interactive simulations, inquiry learning, conceptual development

I. INTRODUCTION

The authors [1] recently outlined a novel Instructional Sequence for Interactive Simulations (ISIS) to support students and teachers in the inquiry learning of physics concepts. This sequence drew on both the relevant literature – particularly the 'conceptual change' model of Posner, Strike, Hewson, and Gertzog [2] and Vygotsky's Zone of Proximal Development (ZPD) theory [3] – and the authors' experience of teaching physics in classrooms and researching the physics teaching of others [4, 6]. ISIS involves five steps, passing through the processes of conceptual change for students, drawing on the special affordances of interactive simulations, with the intention of enhancing students' conceptual understanding and the development of confidence and skills in inquiry learning as clear ends-in-view at all times.

Step 1 – Elicitation and clarification of existing concepts and the 'target' scientific conception;
Step 2 – Outlining the predictions and implications of students' existing conceptions and the scientific conception;
Step 3 – Testing predictions of competing conceptions using interactive simulations;
Step 4 – Clarification of findings and linking results to the scientific conception;
Step 5 – Further testing to develop and deepen understanding of the scientific conception.

Numerous studies have advocated inquiry instruction, an approach that emerged from science education reform [7, 8]. Inquiry instruction can be described as 'constructivist-referenced', rather than explicitly constructivist [6]. In the United States, inquiry is considered to be a means as well as an end in learning science [9]. Inquiry instruction shows promise as a means to bridge the gap between teaching and scientific practice [10].

As educational technology tools, interactive simulations offer new affordances for facilitating inquiry learning and supporting the achievement of inquiry instruction [11]. Studies have found that interactive simulations, used as cognitive scaffolds, provide support for a series of inquiry processes and scaffold the tasks of inquiry [12]. Songer [13] argued that the use of interactive simulations facilitated greater understanding of scientific concepts than inquiry sequences involving textbook pictures or models.

This study is not focused on either the design of interactive simulations or inquiry instruction per se. It is focused on conducting inquiry instruction using interactive simulations for conceptual development and enhancing students' understanding of inquiry processes in the context of classroom teaching, and evaluating the effectiveness of that teaching approach. Our view is that inquiry instruction requires cognitive and social scaffolding when learning happens in the social plane of the classroom. Inquiry instruction should be implemented in ways that are consistent with the requirements for conceptual change. Inquiry instruction using interactive simulations can create a constructivist-referenced environment for learning in which students can develop new knowledge with the assistance of scaffolds including knowledgeable teachers, capable peers and cognitive tools. In the context of the classroom this kind of inquiry instruction offers many cognitive and social scaffolds to maximize learning.

II. THE CONTEXT OF THE STUDY

Ongoing educational curriculum reform is a critical topic in the context of China. China has undertaken a series of educational curriculum reforms since the early 1950s. The major milestones in this process included the nationwide reform in 1999 when the State Council issued ‘Decision on Promoting Quality-Education in an All-Round Way’. In 2001, the Ministry of Education issued the outline of the basic education curriculum reform (trial version) and curriculum standards of 18 compulsory subjects (trial versions). In 2003, the Ministry of Education launched the program of senior high school curriculum reform and national curriculum standards for senior high physics and 14 other subjects.

According to the national curriculum standards for senior high physics, there are two compulsory modules and three selective series involved in three years of high school. Year 12 students are expected to obtain 1) knowledge and skill, 2) processes and methods, and 3) emotions and attitudes and values after they graduate from high schools. Bloom's taxonomy [14] is the theory behind these three aspects, which were popularly called the ‘Three Dimensions’, in order to operationalize the objectives of the curriculum standards.

The striking dimension in physics in relation to inquiry learning is the second dimension – processes and methods – which requires students to develop the abilities of ‘scientific inquiry’ such as ‘questioning, solving problems and treating data’, ‘application of physics principles and scientific methods’, and ‘independent learning and cooperative learning’. Compared with the previous physics curriculum standards, scientific inquiry is considered for the first time as one of the teaching objectives as well as teaching content. This practice reflects the intention of establishing a balance between knowledge-oriented and practice-oriented education.

The tradition of examination-orientation, however, has greatly influenced the instructional application of scientific inquiry in China. In many cases the implementation of the new curriculum actually didn’t change the old conventional approaches to instruction. Teaching, learning and school activities are still oriented towards exam preparation. Guo, Xing, Xu, and Zheng [15] found that Chinese students are typically well prepared for the examinations, but with low experimental inquiry skill (14.4%) in the investigated four provinces. Scientific inquiry does not receive enough attention to in the practical classroom.

The teachers aspire to promote scientific inquiry instruction, but most of them don’t know how to conduct inquiry instruction in practice. Relevant issues such as inquiry processes, inquiry structure, and organization of required curriculum contents are not involved in the new physics curriculum standards. Researchers cannot help but doubt whether the new physics curriculum standards will be implemented effectively in practice [16].

It is widely accepted that school-based inquiry instruction is cognitively and epistemologically different from authentic scientific inquiry. But few teachers have even had personal experience with conducting an inquiry. Most teachers consider inquiry instruction difficult to implement [17, 18] and too advanced for their students [19]. Lack of knowledge and experience with inquiry on the part of teachers is thought to act as a barrier to teaching science in this way [20]. Despite their aspirations to inquiry teaching, teachers prefer using easily operationalized conventional teaching methods including teacher-centered lectures, rote memorization of discrete science facts, ‘cookbook’ laboratory activities and summative tests, even in the context of findings indicating that conventional science classroom approaches have less than the desired effectiveness for supporting students’ conceptual change [21, 22] and can ironically serve to destroy students’ innate curiosity about the world of science [23].

III. ISIS

In the developed Instructional Sequence for Interactive Simulations (ISIS), there are five steps (elucidation, engagement, experiment, discourse-sharing and evaluation/extension). The cycle is repeated until the problem is solved. Taking Newton’s First Law of Motion as an example, students’ activities and the objectives of each step are shown in the table below. This table describes the actual classroom learning experiences of the students participating in the present study.

TABLE 1 THE IMPLEMENTATION OF ISIS

Teaching steps	Student activities (the Newton’s First Law)	Scaffoldings	Objectives
Step 1: Elucidation (12mins)	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 Newtons’ First Law. And asked students to write down their initial ideas.	Teacher and peers	To elucidate students’ existing concepts and clarify the ‘target’ scientific conception.

Step 2: Engagement (18mins)	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.	Teacher, peers and worksheet	To outline the predictions and engage students in the implications of their prior conceptions on certain topics.
Step 3: Experiment (30mins)	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.	Simulation, peers teacher and worksheet	To test predictions of competing conceptions using interactive simulations.
Step 4: Discourse-sharing (50mins)	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.	Simulation, peers teacher and worksheet	To clarify the findings and link results to the scientific conception through students' presentation and teacher-student's discussion.
Step 5: Evaluation/Extension (10mins)	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."	Peers, teacher and worksheet	To evaluate the whole inquiry sequence in order to develop meta-cognitive inquiry thinking.

IV. THEORIES BEHIND ISIS

This study is underpinned by perspectives grounded in (a) cognitive theories of conceptual change [2] and (b) Vygotsky's socio-cultural theories of teaching and learning [3]. We argue that learning – which particularly refers to conceptual change in this study – takes place in the context of both cognitive and social planes, in which a variety of scaffolds potentially support students to internalize and construct new knowledge.

Posner, Strike, Hewson, and Gertzog [2] proposed four conditions for conceptual change: 1) dissatisfaction with existing knowledge, followed by evidence that allows students to find the scientific conception 2) intelligible, 3) plausible, and 4) fruitful [2]. Conceptual change theory supported the implementation of ISIS in inquiry-based instruction. The first two steps of ISIS are designed to stimulate students' cognitive conflicts in contexts where students already hold concepts about the phenomena of interest that are not scientifically accurate or powerful. The other three steps provide opportunities for students to develop satisfactory scientific conceptions. Various forms of scaffolding (e.g. guided inquiry model, interactive simulations, knowledgeable teachers and peers, mandatory worksheets and planned activities) contribute to making the new concepts intelligible, plausible and fruitful. The ISIS approach supports students to achieve understanding that they cannot when working alone. Learning – in Vygotsky's [3] terms – takes place between the things students can already do unaided (these have already been learned), and the things they cannot do, even with assistance (which are beyond their current developmental capabilities). Between these situations lies the 'Zone of Proximal Development', in which learning takes place.

In the context of classroom communities, individual learning takes place during the ISIS process. Knowledge is obtained with scaffolding from both the cognitive plane (e.g. interactive simulation, five-step inquiry guide, and worksheet) and the social plane (knowledgeable teachers, capable peers, communication and discussion). The implementation of ISIS involves students actively, collaboratively constructing new knowledge, rather than passively absorbing it from an external source.

ISIS seeks to bridge the gap between inquiry-based instructional approaches and authentic scientific practices. The confluence of social and cognitive psychology with philosophy and epistemology is focused on the growth and development of scientific knowledge. The theories behind ISIS contribute to the theoretical framework that supports the efficacy of this approach to inquiry instruction using interactive simulations established by the classroom community.

V. METHODOLOGY

A. Purposes of the Study

This study used an intervention to explore the effectiveness and impact of ISIS on students' conceptual change in relation to concepts about forces and motion in the physics classroom. There are three dependent variables: students' conceptual understanding, confidence and inquiry skills. The independent variable is a comparison between the ISIS sequence and 'conventional' physics instruction. Qualitative and quantitative data were analysed to address the following two sub-questions: 1) What is the difference in effectiveness between ISIS inquiry-based instruction and conventional instruction in relation to students' conceptual change? It is hypothesized that students exposed to the intervention would report a higher level of conceptual understanding, inquiry skills and confidence compared to those undergoing conventional instruction. 2) What is the relationship between conceptual understanding, inquiry skills, and confidence in two different instructional approaches? It is hypothesized that the three dependent variables are positively correlated and that inquiry skills and confidence together contribute to conceptual understanding.

B. Subjects

This paper reports the results of a pilot study. Thirty-eight tenth-grade students, one teacher and one researcher participated in the pilot study. Twenty-two students were included in the experimental group for a 7-week instructional sequence of inquiry-based instruction using interactive simulations in physics. Sixteen students were involved in the control group and received conventional instruction for the same period. The selection of subjects was based on students being interested in this educational trail and obtaining a proper academic grade on the pre-tests. The researcher taught the students in the experimental group. The teacher used his regular approaches to instruction for students in the control group. Differences observed will combine influences from the teacher (the researcher for the experimental group and the classroom teacher for the control group) with the influence of the different instructional approaches. That means the findings of this pilot study are somewhat preliminary and tentative. Later the research team will conduct studies in which the same teacher teaches both an experimental and a control group, eliminating teacher differences as a source of difference and focusing the study on the instructional models. Students were not randomly assigned to groups because of their assigned classes, however the conceptual understanding pre-test did not show significant differences between the two groups. The physics content taught was new to all students participating in the study.

C. Instruments

In this study, the Force Concept Inventory (FCI) [24], an inquiry skills survey and a confidence survey (added to the FCI) were used as pre- and post- tests. The FCI typically includes only multiple-choice items that are marked as incorrect. For the present study a three-tier modified FCI test for conceptual understanding was developed. The first tier is the 30 multiple force concept questions, the second tier asks students for their own explanations of why they choose the answers they did, and the third tier is a Likert 5-point scale confidence survey which asks the student to measure their confidence levels in their answers. The inquiry skills survey is also a Likert 5-scale survey. Questions were drawn from a study by White and Frederiksen [25].

An example of a question about conceptual understanding and confidence in learning: A ball is fired by a cannon from the top of a cliff as shown in the Figure 1 below. Which of the paths would the cannonball most closely follow?

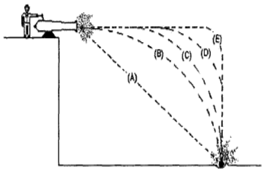

Figure 1 The question of conceptual understanding test

☺: 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

An example item from the inquiry skill test – in this case in relation to cooperative inquiry:
In the group experiment, I was not able to work together properly with team members to smoothly develop the results.
5 = strongly agree; 4 = Agree; 3 = no opinion; 2 = disagree; 1 = strongly disagree

D. Simulations

The simulations selected for scaffolding inquiry instruction in this current study are provided by the physics education technology (PhET) project. This project is designed by the Interactive Simulations Project at Colorado University. The central intention of the PhET project is to support the implementation of inquiry learning. A Chinese translated version of the force and motion simulation was used in this current study.

The simulation enables students to interact with Newtonian laws (see Figure 2). Students can run computer interactive simulations with mouse and keyboard. The simulation includes an introduction, a topic on friction, force graphs and relevant game interfaces. The interactive simulations allow students to choose frictionless and frictional surfaces that are impossible or difficult to create in the classroom. Students can define and change the properties of objects such as mass, applied force, position, friction, and also can see the results in tables and visual cartoons. Students can also create and experience different type of experiments though record and playback their experiments. There is also a force graph interface that provides students with accurate information about position, time, velocities, acceleration, vectors and different forces.

Free Body Diagram: ○ Show ● Hide
Friction: ○ Ice (no friction) ● Wood
Vectors: ☑ Force Vectors ☐ Sum of Forces F_{sum}
Walls: ● Brick ○ Bouncy
Position: Object Position -6.0 meters (-10.0 to 10.0)
Sound: ● on ○ off
● Record ○ Playback

Figure 2 Force and Motion simulation interface

Studies have shown that the PhET simulations can challenge, improve, correct and reinforce conceptual understanding through self-driven exploration [26, 27]. The results of the research [28] strongly supported the application of the PhET simulations. PhET quantum simulations addressed many new student difficulties in quantum mechanics. The researchers concluded that it is the features of PhET that are effective for helping students understand the abstract concepts of quantum mechanics. They also found that utilizing simulations enhanced the teaching of limits and helped students become immersed in the virtual physical world model and the inquiry processes. The study of Moore, Herzog, and Perkins [29] showed that PhET simulations were used to large classrooms because of its implicitly scaffolded quality. They found students engaged in discussions about experimental content when they were supported by the simulation implicitly.

VI. DATA COLLECTION AND ANALYSIS

There was a 7-week ISIS intervention in two groups for learning Newton's laws. Classroom observers (the researcher and the participating teacher) were at the back of each classroom and completed classroom observation guides on the implementation of inquiry instruction. All student groups finished the student worksheet during the class.

One class was taught using the ISIS sequence, as described in Table One. The other was taught using the 'usual' or 'conventional' approach of the classroom teacher, who is an experienced teacher. This involved teacher explanations delivered in a lecture approach, along with questions to students, working of set problems and other teaching activities typical of physics instruction world-wide.

After the trial intervention, post-tests were conducted. Two students and the teacher were selected for 30-60 minute face-to-face semi-structured interviews. Prepared questions on predetermined topics provided a starting structure followed by open-ended questions. An interview protocol was prepared for asking questions and recording key points during the interview. These interview questions were based on the research questions.

In this study, a Mann-Whitney and Wilcoxon signed-rank test was conducted to analyze the data between the subject groups and within each group to address the first research question. Non-parametric tests were employed because the requirements for ANOVA were not met. This technique is frequently used with studies with a small number of subjects conducted in social science [30]. Multi-regression analysis was used for the second question. The interviews were analyzed using thematic analysis [31].

The Cronbach alpha scores for the conceptual knowledge test, confidence survey and inquiry skills survey were .76, .89 and .80 respectively. These were considered acceptable (above .70) and preferable (above .80) values for the scale with this sample [32]. The translation and interpretation of these themes was conducted by a process of re-reading the list of code words and peer-reviewed for consistency and reliability in the coding procedure.

VII. RESULTS

A. *Quantitative phase*

1) *Between Group Differences*

A Mann-Whitney U test indicated a significant difference in conceptual understanding between the experimental group (Md = 29.5, n = 22) and the control group (Md = 26.5, n = 16), U = 107.00, z = -2.05, p < .041, r = .33[1].

For inquiry skills, a Mann-Whitney U test revealed a significant difference between the experimental group (Md = 27, n = 22) and the control group (Md = 21.5, n = 16), U = 63.5, z = -3.34, p < .001, r = .54.

For confidence in learning, a Mann-Whitney U test indicated no significant difference between the experimental group (Md = 31, n = 22) and the control group (Md = 28, n = 16), U = 161, z = -.45, p = .656.

2) *Within Group Differences*

A series of the Wilcoxon Signed Rank test was performed to explore the effectiveness of the different instructional approaches.

For the experimental group, results indicated statistically significant change in conceptual understanding from pre (Md = 24) to post-test (Md = 29.5) for the ISIS instruction, with z = -3.69, p < 01, r = .72; statistically significant change in inquiry

---

[1] Effect size r is calculated by dividing the Mann-Whitney z-score by the square root of the sample size N. Range values use Cohen's (1988) criteria of .10 = small effect, .30 = medium effect, and .50 = large effect.

skills from pre (*Md* = 21) to post-test (*Md* = 27) for ISIS instruction, with $z = -3.80$, $p < .01$, $r = .75$; and, statistically significant change in confidence in learning from pre (*Md* = 26) to post- (*Md* = 57) test for ISIS instruction, with $z = -4.11$, $p < .1$, $r = .81$.

For the control group, results indicated no statistically significant change in conceptual understanding from pre (*Md* = 24.5) to post-test (*Md* = 26.5) for the conventional instruction, with $z = -.597$, $P = 551$; also no statistically significant change in inquiry skills from pre (*Md* = 21) to post-test (*Md* = 21.5) for the control group, with $z = -.597$, $p = 550$; however, statistically significant change in confidence in learning from pre (*Md* = 24) to post-test (*Md* = 28) for the control group, with $z = -2.83$, $p < .05$, $r = .7$.

3) Relations between conceptual understanding, inquiry skills and confidence in learning

In the experimental group in which students used ISIS inquiry-based instruction, there was a significant correlation between conceptual understanding and inquiry skills, $r = .587$, $p < .001$, and also between inquiry skills and confidence in learning, $r = .47$, $p < .05$. However, there was no significant correlation between conceptual understanding and confidence in learning, $r = .32$, $p = .145$.

In the control group, there was a negative correlation between conceptual understanding and inquiry skills, $r = -.011$, $n = 16$, $p = 0.967$. There also was a negative correlation between inquiry skills and confidence in learning, $r = -.112$, $n = 16$, $p = .68$. However, the correlation between conceptual understanding and confidence in learning was significant, $r = .62$, $p < .05$.

B. Qualitative phase

This paper includes one vignette from classroom observation and three excerpts from the following-up interviews with two students and a teacher. These provided explanations and insights into the employment of different instructional approaches.

1) Classroom vignette:

T: You told us there is an argument between you two. What’s that?

Sgroup2-A: Yes, and I find I am wrong later.

Sgroup2-B: I also found my thought was wrong.

T: What do you think before? And why do you think you are wrong?

……

Sgroup2: Yes, both of us have changed our thoughts.

T: How did that happen?

……

Then the group 2 demonstrated how they conducted their experiments and what the data they collected from the experiments. They used Force Graphs page to provide data support and graph support.

……

Sgroup2-A: Actually both of us are confused at beginning. But the simulation seems so powerful and unquestionable. We re-thinked about this topic for a while and make the conclusion.

2) Interview excerpts:

“It (the project) helped me learn concepts with a vivid way which make objects move based on computer. I can understand the physics concept deeper instead of the surface understanding through interacting with experiments.” (Lily, a student who is struggling with physics.)

Asked about the ability of what they had learnt, Alan said, “It improved my operation skills. I know the procedure and the details about how to do it with the assistant of the computer,” he said also, “Doing experiment part is my favorite, particularly the time when I fill in the results after I test my guess. I know more physics and like physics more through this study. I can do the experiment which I could not know before. More understanding makes me like physics more.”

Teacher Gao comments, “The enthusiasm of student participants was pretty high. The operation and tasks were not difficult for them. Complementary tasks gave students a sense of achievement.” In addition, the scientific expression of the students’ presentations provided them with opportunities to improve their confidence in learning.

VIII. DISCUSSION

ISIS represents a novel inquiry-based instructional approach for teachers and students. Compared with a conventional teaching environment, well-structured inquiry sequence and activities with the proper scaffolding proved more effective for learning.

First, the inquiry-based teaching method focused on instruction sequence. It is grounded in conceptual change theories and ZPD theory, which provided opportunities for students to experience how to solve problems by themselves, and also supports students to finish the exploration. For instance, during the first step, the teacher stimulated students’ prior knowledge through questions, scenarios, videos etc. Then the teacher introduced the lesson objectives and clarified the instructional sequence. This means teachers lead students to learn and take responsibility for their own learning. Some researchers argue that open inquiry is the only real scientific inquiry model for learning. However, there are normally 45-50 students in Chinese classrooms. It is necessary and efficient for teachers to organize a structured approach to inquiry learning or guided inquiry learning. Chinese students are also used to following teacher’s instruction. It is not educationally appropriate to move immediately to an approach of unscaffolded open inquiry when students are used to a culture of obedience. These two steps are similar to conventional instruction, but only with well-structured elucidation and engagement, can students’ individual exploration be conducted well. Classroom observation showed that during the experiment-conducting step, students hardly sought any help from the teacher. They finished their experiments cooperatively and smoothly with their peers. This situation confirmed the studies that found students in highly-structured classroom conditions seeking less help than their peers who were in the less-structured classrooms [32]. This was attributed to the supportive environment that computer-based technology created. During Step 4, ‘discourse-sharing’, students in groups presented their experimental questions, process of data collection and analysis, and their conclusion. Teachers asked questions if they noticed students have mistaken experimental implementation and language expression. For this step, teachers used questioning techniques for communicating with students, who presented their works and were also involved in discussing with other students who were listening as the audience. As last, students reviewed their inquiry experience and gave a score as the evaluation criteria. Then they evaluated other groups’ performances.

Secondly, the various forms of scaffolding supported students properly in the environment of simulation-based inquiry instruction. Many studies have found that the potential of inquiry-based instruction cannot be realised without proper scaffolding [33, 34]. The analysis of classroom observations and interviews revealed that students engaged in exploring questions by themselves, and felt safe and confident to practice their thoughts, because the simulations provided them with ways to test their ideas as many times as they wanted. Their partners and capable peers were around them when they asked questions. Teachers and students said the worksheet was not too difficult and students were easily involved in it during their experiment. In all, the scaffolding created a new learning environment in which it is not too difficult for teachers to balance freedom with the mandatory curriculum and elements of teaching.

This study is focused on the contribution of interactive simulations for students’ learning. In science education, there are special representations to express the meanings of scientific terms. For instance, vectors, force, velocity, acceleration and friction have their fixed symbols, rather than the text words. Simulations offer representations with the visible figures and dynamic animations in a vivid three-dimension virtual environment. It not only offers more potential resources for students to learn the meaning of scientific terms and symbols, but also supported the students after their presentations. They used simulations to show their data, which provided evidence about how and why they made the conclusion. This further served to facilitate a productive conversation between teachers and students, and students and their peers. According to the analysis of students’ attitude to application of interactive simulations, the results showed that students had highly positive attitudes toward learning with interactive simulations. Only one student out of 22 selected the choice of “very unsatisfied” when answering the question about their satisfaction with this mode of learning.

Third, this study found a different relation between conceptual understanding, inquiry skills and confidence in the experimental group in which students used ISIS inquiry-based instruction with the researcher compared with the control group in which conventional instruction was conducted by the teacher.

IX. CONCLUSION

The instructional sequence for inquiry instruction (ISIS) developed and evaluated in this pilot study will be further evaluated in a larger study in Beijing, and then tested in Australia. It is made freely available in the authors’ forthcoming chapter [1], and it is hoped that physics education researchers in other countries will be interested in evaluating its effectiveness in a wide variety of contexts. Given that the most usual finding when evaluating the effectiveness of instruction using computer-based scientific visualisations is ‘no significant difference’ [35], the fact that the present study shows conceptual knowledge gains on the part of students is promising. Further research will support this promise… or not.

REFERENCES

[1] Fan, X., & Geelan, D. (2013). Enhancing Students’ Scientific Literacy Using Interactive Simulations: A Critical Literature Review. *Journal of Computers in Science and Mathematics Teaching, 32*(2), 125-171.

[2] G. J. Posner, K. A. Strike, P. W. Hewson, and W. A. Gertzog, "Accommodation of a scientific conception: Toward a theory of conceptual change," *Science Education, 66*, pp. 211-227, 1982.

[3] L. S. Vygotsky, "Thought and Language," *Bulletin of the Orton Society*, vol. 14, pp. 97-98, 1964.

[4] Geelan, D. (2013). Teacher explanation of physics concepts: a video study.*Research in Science Education*, *43*(5), 1751-1762.

[5] MoE, "Physics curriculum standards for senior secondary school *(Trial version)*," Beijing: the Ministry of Education., 2003.

[6] Geelan, D. R. (1997). Weaving narrative nets to capture school science classrooms. *Research in Science Education*, *27*(4), 553-563.

[7] D. Kuhn, J. Black, A. Keselman, and D. Kaplan, "The development of cognitive skills to support inquiry learning," *Cognition and Instruction*, vol. 18, pp. 495-523, 2000.

[8] D. Kuhn, J. B. Katz, and D. Dean, "Developing reason," *Thinking and Reasong*, vol. 10, pp. 197-219, 2004.

[9] F. Abd-El-Khalick, S. BouJaoude, R. Duschl, N. G. Lederman, R. Mamlok ‐ Naaman, A. Hofstein, *et al.*, "Inquiry in science education: International perspectives," *Science Education, 88*, pp. 397-419, 2004.

[10] W. R. van Joolingen and Z. C. Zacharia, "Developments in Inquiry Learning," in *Technology-enhanced Learning*, Balacheff N., Ludvigsen S., Jong T., Lazonder A., and B. S., Eds., ed Dordrecht: Springer, 2009, pp. 21-37.

[11] D. B. Clark, B. Nelson, P. Sengupta, and C. D'Angelo, "Rethinking science learning through digital games and simulations: Genres, examples, and evidence.," presented at the National Research Council Workshop on Gaming and Simulations, Washington, DC., 2009.

[12] T. de Jong, "Scaffolds for computer simulation based scientific discovery learning," in *Dealing with complexity in learning environments* J. E. & R.E.Clark, Ed., ed London, England: Elsevier Science, 2006, pp. 107–128.

[13] N. B. Songer, "Digital resources versus cognitive tools: A discussion of learning science with technology," in *Handbook of research on science education*, S. K. Abell and N. G. Lederman, Eds., ed Mahwah, N.J: Lawrence Erlbaum Associates, 2007, pp. 471-491.

[14] B. S. Bloom and D. R. Krathwohl, *Taxonomy of educational objectives: the classification of educational goals*. New York: McKay, 1956.

[15] Y. Guo, T. Xing, G. Xu, and C. Zheng, "Alignment between physics curriculum standard and high school physics exit examination in China: A comparison among Guangdong , Ningxia, Shandong, and Hainan provinces.," *E-Journal of R.E.A.L.*, vol. 3, pp. 29-40, 2012.

[16] B. Wei, "Science curriculum reform in post-compulsory education in the People's Republic of China: The case of senior secondary school shemistry curriculum," *Science Education International*, vol. 16, pp. 291-303, 2005.

[17] B. Wee, D. Shepardson, J. Fast, and J. Harbor, "Teaching and Learning About Inquiry: Insights and Challenges in Professional Development," *Journal of Science Teacher Education*, vol. 18, pp. 63-89, 2007.

[18] M. Windschitl, "Folk theories of "inquiry:" How preservice teachers reproduce the discourse and practices of an atheoretical scientific method," *Journal of Research in Science Teaching*, vol. 41, pp. 481-512, 2004.

[19] R. Bybee, "Teaching science as inquiry.," in *Inquiring Into Inquiry Learning and Teaching in Science* J. Minstrel and E. H. V. Zee, Eds., ed Wasington, DC: American Association for the Advancement of Science (aaas), 2000, pp. 20-46.

[20] M. R. Blanchard, S. A. Southerland, and E. M. Granger, "No Silver Bullet for Inquiry: Making Sense of Teacher Change Following an Inquiry-Based Research Experience for Teachers," *Science Education*, vol. 93, pp. 322-360, 2009.

[21] R. M. Gillies and M. Boyle, "Teachers' reflections on cooperative learning: Issues of implementation," *Teaching and Teacher Education*, vol. 26, pp. 933-940, 2010.

[22] G. Zavala, H. Alarcón, and J. Benegas, "Innovative training of in-service teachers for active learning: A short teacher development course based on physics education research," *Journal of Science Teacher Education*, vol. 18, pp. 559-572, 2007.

[23] M. A. Honey and M. Hilton, *Learning science through computer games and simulations*. Washington, DC: The National Academies Press, 2010.

[24] D. Hestenes, M. Wells, and G. Swackhamer, "Force Concept Inventory," *Physics Teacher*, vol. 30, pp. 141-58, 1992.

[25] B. Y. White and J. R. Frederiksen, "Inquiry, modeling, and metacognition: Making science accessible to all students," *Cognition and Instruction*, vol. 16, pp. 3-118, 1998.

[26] C. E. Wieman, W. K. Adams, P. Loeblein, and K. K. Perkins, "Teaching Physics Using PhET Simulations," *Physics Teacher*, vol. 48, pp. 225-227, 2010.

[27] C. E. Wieman, K. K. Perkins, and W. K. Adams, "Oersted medal lecture 2007: Interactive simulations for teaching physics: What works, what doesn't, and why," *American Journal of Physics*, vol. 76, pp. 393-399, 2008.

[28] A. Sokolowski and R. Rackley, "Teaching Harmonic Motion in Trigonometry: Inductive Inquiry Supported by Physics Simulations," *Australian Senior Mathematics Journal*, vol. 25, pp. 45-53, 2011.

[29] E. B. Moore, T. A. Herzog, and K. K. Perkins, "Interactive simulations as implicit support for guided-inquiry," *Chemistry Education Research and Practice*, vol. 14, pp. 257-268, 2013.

[30] Büyüköztürk, *Data Analysis Handbook for Social Science*. Pegem Akademi, 11th Edition, Ankara, 2010.

[31] A. Strauss, *Qualitative analysis for social scientists*. Cambridge, UK: Cambridge University Press, 1987.

[32] A.Katie, "Programming Fun Into Science Ed: Video games, simulations cover scientific concepts," Education Week's Digital Directions, vol. 4, p. 18, 2011.

[33] K. Scalise, M. Timms, A. Moorjani, L. Clark, K. Holtermann, and P. S. Irvin, "Student learning in science simulations: Design features that promote learning gains," Journal of Research in Science Teaching, vol. 48, pp. 1050-1078, 2011.

[34] R. E. Mayer, "Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction," The American psychologist, vol. 59, pp. 14-19, 2004.

[35] Geelan, D., & Mukherjee, M. (2011, June). But does it work? Effectiveness of scientific visualisations in high school chemistry and physics instruction. In *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2011. Chesapeake, VA: AACE.* (pp. 2706-2715). AACE.