

DESIGNING FOR MODEL PROGRESSION TO FACILITATE STUDENTS' SCIENCE LEARNING

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The CSI (Collaborative Science Inquiry) learning environment is designed as a science learning environment integrating guided inquiry, modeling and visualization, and social interaction. Model progression is a key component and feature in the CSI system, but few studies examine the value of model progression in the ICT-facilitated science learning. To demonstrate the educational value of model progression in the CSI system, a trial instruction was conducted in this study. In this paper, we first review the relevant literature on the model-based science learning environment, model-based inquiry, and model progression to support the form of CSI learning environment, and its underlying pedagogy. Then we introduce the CSI system, and the work flow of system implementation in science learning for presenting the features of CSI system. Following it, we describe the study of CSI implementation in the secondary science class to investigate the value of model progression with CSI system. By examining students' modeling performance, their peer discussion and self-reflections generated in the activities, positive results were received that CSI learning environment has the pedagogical value on improving students' conceptual understanding through model progression approach. And with the use of appropriate peer feedback, students' models could be improved and elaborated in the learning activities. Implications were discussed to inform science instruction and research.

Keywords: CSI learning environment; model progression; collaboration; peer feedback.

1. Introduction

Over the past two decades, researchers have devoted great efforts to improving the development of model-based learning environment. With the rapid evolution of computer technologies, various types of computer-supported visual representations of models are used to support cognitive processes in learning, especially in science education (Buckley et al., 2004; Wu, 2010). The web-based platform or software that involves components of models or modeling tools for science education can be defined as the computer-supported Model-based Science Learning Environment (MbSLE). The dominant applications, for example, Model-it, ModelingSpace, NetLogo, Co-Lab, and WISE are implemented and

demonstrated to be effective for students' science learning (Avouris, Margaritis, Komis, Saez, & Meléndez, 2005; Jackson, Stratford, Krajcik, & Soloway, 1996; Linn & Eylon, 2011; van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005). Besides incorporating modeling tools, these applications may integrate design elements such as curriculum materials using pedagogical principles (e.g. inquiry-based learning, CSCL, model progression) and communicative tools (e.g. forum, chat tool).

However, few of these existing applications have been designed with the integration of all these design elements. For example, most of them are unable to support online collaborative modeling, especially for synchronous modeling (Avouris, Dimitracopoulou, & Komis, 2003). With synchronous modeling, students can co-construct models in real time when doing the complex modeling activities. Some of them are not allowed for importing and presenting of multiple visual representations, which have been demonstrated to active students' motivation and improve the understanding in abstract concepts (Ainsworth, 1999); and some of them do not facilitate students' modeling with different modeling tools, such as the progressive modeling approach. With the intention of creating an innovative learning environment for secondary school students to acquire sophisticated understanding of scientific conceptions, and develop critical learning skills (e.g. inquiry skills, modeling skills, collaborative learning skills), we have developed a web-based science learning environment named CSI (Collaborative Science Inquiry) with the consideration of the design deficiency in the current learning environments. CSI learning environment is designed as a system in which guided inquiry (laying out the inquiry phases), modeling (providing three modeling tools) and visualizations (importing images, simulations and videos), and social interaction (integrating chat tool, social presence, synchronous editing and modeling, shared workspace), are integrated - which is unique among existing science learning environments (Sun & Looi, 2013). With this comprehensive feature, it will be interesting to explore the potential educational value of the CSI system in science learning. Considering limited evidence showed the effectiveness of models or modeling in the CSCL context, especially for the model progression, in this study, we focus on investigating the design of model progression in the CSCL learning setting with the CSI system, with aims to observe how students' model progression take place, and whether they benefit on conceptual understanding from model progression in the CSI lessons.

2. Literature Review

2.1. Comparisons of the MbSLE

To design and develop the CSI system, we conduct a comparison of design features of the well-established learning environments. We identify the main components (i.e. inquiry, modeling and visualization, CSCL) of these systems as the dimensions for comparing and distinguishing the ways in which different combinations of CSCL design elements work together. The learning environments include WISE, CmapTool, Co-Lab and ModelingSpace (Table 1), which have been demonstrated to be effective for improving

Table 1. A comparison of the design components in the established applications.

Component	WISE	CmapTool	Co-Lab	ModellingSpace
Inquiry	√	×	×	×
Modeling	√	√	√	√
Visualization	√	√	√	√
Chat tool	√	√	√	√
Shared workspace	×	√ (synchronous)	√ (asynchronous)	√ (asynchronous)
C_SCL				
Peer review	√	√	√	√
Coordination tool	×	√	√	√
Social presence	×	×	√	×

students' conceptual understanding, reasoning skills, critical thinking skills and modeling skills (Cañas, Novak, & González, 2004; Ergazaki, Komis, & Zogza, 2005; Linn, Clark, & Slotta, 2003; van Joolingen et al., 2005). Thus, a system integrating the common features of these learning environments is expected for supporting students' development of the above learning skills. On the other hand, if the system can have other features to compensate for the design deficiency of learning environments, students will be proposed to benefit more from the learning with the system.

As Table 1 shows, guided inquiry is not embedded in most of applications, except for WISE. The design of neglecting guided inquiry may not be appropriate for students in lower secondary levels to execute the inquiry step-by-step by themselves, as well as for teachers to design the inquiry-based lessons. Therefore, inquiry phases being laid out at students' side and teachers' side is proposed to supplement this design deficiency of an application. The modeling tools and visualizations are integrated into all applications to serve to help students build subject matter knowledge, epistemological understanding, and expertise in the practices of building and evaluating scientific knowledge (Baek, Schwarz, Chen, Hokayem, & Zhan, 2011). The design has become the most common features of science learning environments. Particularly, model progression approach has been integrated into the design of modeling tools in the Co-lab and ModellingSpace. The model progression is formed as the way of simple modeling (more qualitative) to complex modeling (more quantitative).

As we found that not all applications support synchronous collaborative evaluation and editing of group work without integrating synchronous shared workspace, students may not be easy to review, post, modify and elaborate the joint artifacts at the same time from different places (Gutwin & Greenberg, 2002). Moreover, the applications (except for Co-Lab) lacking group management tools that are unable to track students' presence at and absence from the group work. The design of social presence supports students' sense of being together, and monitoring of their group members' status and progress according to their progress or inquiry phases. Hence, we seek to adopt the effective learning design components and address the above mentioned issues concerning C_SCL design in the design of the CSI system.

2.2. Model-based inquiry

The value of the model-based inquiry in science education has been verified in many studies. White and Frederiksen (1998) designed ThinkerTools curriculum that consisted of an iterative activity sequence “question-predict-experiment-model-apply” for the teaching of physics topics. The results suggested that the ThinkerTools curriculum facilitated students’ learning in both of inquiry and content, and was particularly beneficial for the low-achieving students. The teaching pattern employed in Inquiry Island involved developing questions, generating hypothesis, designing an investigation, recording and analyzing data, creating models, and the evaluation of models. This approach was proposed to promote students’ cognitive, socio-cognitive and metacognitive development (White, Frederiksen, Frederiksen, Eslinger, Loper, & Collins, 2002). An inquiry framework EIMA (Engage-Investigate-Model-Apply) was developed by Schwarz and Gwekwerer (2007), which encouraged students to engage in the inquiry with a focus on creating, using and revising scientific models to improve their scientific reasoning skills. In summary, these studies pointed to the necessity of having scientific modeling as an important component of science inquiry.

The generic learning pattern of model-based inquiry can be mainly summarized as question, hypothesis, plan, investigation, model, and conclusion (Bell, Urhahne, Schanze, & Ploetzner, 2009). The pattern serves as the guide for the form of CSI inquiry framework. Moreover, informed by the principle of POE (Predict-Observe-Explain) (White & Gunstone, 1992), we propose a phase called Pre-model (to explicate or externalize students’ initial ideas) with the corresponding phase: Model (to explicate students’ post ideas after some experimentations) in the inquiry. POE guides students to present their predictions of the science phenomena before investigation, and then to verify their predictions through investigation, thus ultimately improving their understanding of the science phenomena. Hence, the main purpose of embedding model progression by including Pre-model and Model into guided inquiry is to help students elicit their prior knowledge through constructing pre-models before investigation and to elaborate their models in the Model phase after a series of inquiry-based learning activities. Students will refine their understanding and seek validation of their conceptual understanding in the Reflect and Apply phrases (Bybee et al., 2006). Finally, a revised model-based inquiry framework (CSI inquiry framework) incorporating eight phases is created: Contextualize, Question & Hypothesize (Q&H), Pre-model, Plan, Investigate, Model, Reflect, and Apply. As the core component of the system, CSI inquiry framework helps to build the foundation of the system; students’ activities in the system will be guided by this inquiry framework.

To better support students’ model-based inquiry, multiple CSCL design elements, including synchronous modeling and editing, shared workspace, peer review, chat tool and social presence, are integrated in each inquiry phase (Dillenbourg, 2005; Lingnau, Hoppe, & Mannhaupt, 2003; Mühlpfordt & Wessner, 2009). A key salient feature of the system is the tight coupling of relevant CSCL design elements to each inquiry phase, so

that each phase can be enacted in a flexible way for inquiry learning through modeling and visualization.

2.3. Model progression

The model progression is a way to present models in increasing complexity gradually through expanding the number of components or the levels of relations among variables of models (Mulder, Lazonder, & de Jong, 2011; Swaak, Joolingen, & de Jong, 1998). Using this approach in students' modeling activities, students will benefit gradually via constructing their understanding models from the low level to high level, especially for the low ability students (de Jong, 2005; White & Frederiksen, 1998). As indicated above section, the design of the system supports model progression through the incorporation of Pre-model and Model phases. In the CSI system, a sketch tool serves as a drawing-based modeling tool and is designed to assist low-ability students' construction of scientific models (Lerner, 2007). Compared to the drawing-based tool, the concept map tool and quantitative modeling tools in Model tab provide more opportunities for students to construct high level scientific models. Specifically, when students define objects and establish relations between variables with the use of concept map tool, they allow for organizing and representing their knowledge via a graphical tool, which uses shapes, images, texts and lines to describe the understanding of concepts. In constructing concept map, students may put words on the line to describe the relationship between the two concepts (Novak & Cañas, 2008). In the quantitative modeling scenario, the relations are established via precise mathematical forms involving variables. The model can only be simulated when a syntactically correct mathematical description is entered (Avoiris et al., 2005). In this way, modeling thereby can be progressive because the students can start from simple (novice) models to complex (expert) models using the sketch tool. Otherwise, they can work from more qualitative modeling without defining formulas and then get into the stage of more quantitative modeling when figuring out the formulas finally. Reviewing the literature, few studies focus on observing the model progression in the CSCL learning setting (Darabi, Nelson, Meeker, Liang, & Boulware, 2010; Mulder et al., 2011; Swaak et al., 1998). Thus, the hypothesis is posed here that if students' model progression takes place in the collaborative learning activities, how the modeling performance will be affected by students' collaboration (i.e. peer discussion). This will be explored in our study.

2.4. Peer discussion

Embedded with CSCL, model progression is assumed to be more effective for students to learn scientific concepts. In CSCL, students are encouraged to review, assess and negotiate the quality of group models through sharing ideas, knowledge and strategies. In CSCL contexts, peer discussion focusing on the accomplishment of common learning tasks could promote students' deep thinking on the quality of personal contributions and the input of their group members, and to develop awareness of effective and qualitative contributions to the discussions (Freeman & McKenzie, 2002; Sluijsmans, Dochy, &

Moerkerke, 1999). Especially in the complex modeling activities, the interaction process would engage and enable the individual learner to achieve more than what he or she is capable of when a task is done individually, and this is also known as the zone of proximal development (Vygotsky, 1978). According to Kluger and DeNisi (1996), as a form of peer discussion, feedback is any form of information communicated to a person so that improvements can be made. In many aspects, feedback is important and crucial in ensuring that performance is regulated. Helpful and valuable feedback can lead to learning gains. In the meta-analysis paper by Black and William (1998) regarding feedback, it was found that useful feedback led to significant gains in learning and achievements in students. Thus, peer feedback can help an individual to make sense out of compatible or opposing information directed at him or her and leading up to understanding goals and performing tasks more effectively (Nicol & Macfarlane-Dick, 2006). In the study, peer feedback is proposed to examine for exploring the relationship between different categories of peer feedback and the quality of models, this will inform the instruction of model-based science inquiry.

3. Introduction of the CSI System

3.1. General structure

There are two major functional modules in the CSI system: teacher module and student module. The teacher module consists of six sections: Profile, Subject Management, Project Management, Simulation Library, Solutions Review, and Mailbox. A multifunctional authoring tool is available for teachers to design lessons when they enter various sections. More specifically, Project Management enables teachers to set up the inquiry project, and the inquiry stages by creating the tasks, posing guiding questions and configuring student groups. Simulation Library allows for importing visualizations (e.g. Java applets, videos, flash applications) for projects. Solutions Review facilitates reviewing and evaluating students' artifacts (e.g. answers, models, reflections) and their chat logs. Figure 1 illustrates the interface of "Project Management" in the teacher module which is used to establish, modify and delete projects in the form of lesson units. In the "Project Setting" window, basic information of the project (i.e. project name, grade, subject and topic) is provided. The eight inquiry phases of Overview, Contextualize, Question & Hypothesize (Q&H), Pre-model, Investigate, Model, Reflect and Apply are listed at the bottom of the window. The teacher will select the inquiry phases in the list based on her lesson plan and fill in the specific content and instruction in each phase. Therefore, CSI teacher module provides an authoring tool for teachers for designing and modifying the lesson content, uploading visualizations, as well as assessing students' learning artifacts.

The student module consists of four sections: Profile, My Project, Group Management, and Mailbox. As the core component, My Project allows students to access the assigned project to conduct inquiry activities and complete a series of tasks with their group members. The tasks may include reading and discussing textual information or

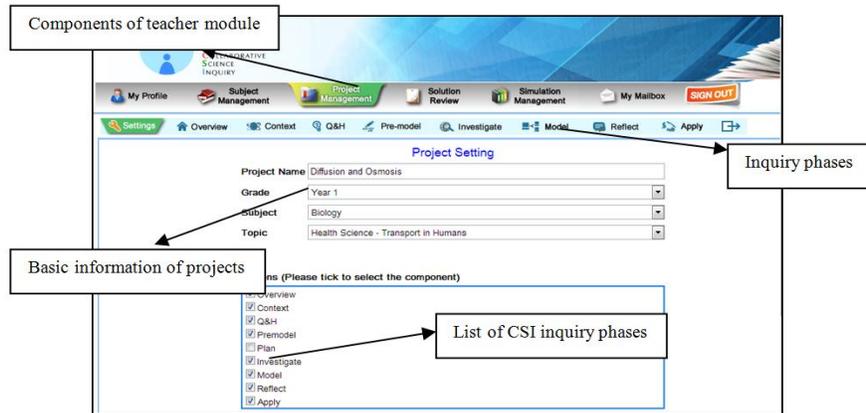


Figure 1. The interface of “Project Management” in teacher module.

watching videos in Contextualize (to attract students to do inquiry); proposing and negotiating solutions in Q&H (to detect students' prior knowledge through examining their answers to the questions); manipulating and observing simulations, and responding to guiding questions in Investigate (to guide the students to learn about new knowledge); constructing models in Pre-model and Model (to visualize students' understanding levels and conceptual changes); and writing reflections in Reflect (to enhance further understanding of the concepts and develop reflective thinking skills); finally verifying their understanding in Apply (to assess students' acquisition of knowledge). Following this inquiry process, students' progression in modeling and in understanding the concepts are likely to be attained. The system supports the inquiry either in a linear or non-linear manner. Students can switch between phases easily by clicking tabs on the tool bar. The project work session at student module is presented in Figure 2. The interface is split into four panes: shared workspace which holds the textual information or tools associated with each phase (supporting students to review, edit and co-construct the learning artifacts), status of group members (online students' usernames are visible at all times), name list of group members, and a chat box (supporting peer discussion on the common tasks).

Figure 3 shows the interface of Pre-model tab. The interface consists of shared workspace, individual workspace, instruction, and the social presence and chat tool for mutual interaction. The shared workspace embedded in the “Group” modeling tab in both Pre-model and Model are designed to receive inputs from multiple logins and to permit concurrent multi-user operations (Yang & Lin, 2010), such as co-constructing models, mutually reviewing and revising models in real time. The system allows for peer review of the individual models within the private/individual modeling space. Coupled with a chat tool, it supports students' peer discussion of their models synchronously. The design

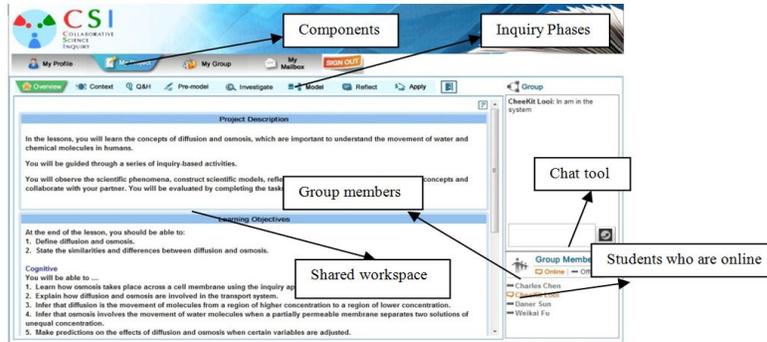


Figure 2. The interface of students' work session.

is intended to encourage students to pursue the common goal of creating joint models through a collaborative, competition-free, and interactional process.

Hence, with various functions in the inquiry phases, students' inquiry activities can be guided by the step-by-step designed by the teacher, and teachers' guide, lectures, scaffolds are provided for students to go through these phases in a meaningful way.

3.2. Work flow of the system implementation

The general work flow of the CSI implementation can be described as follows:

- (1) Establish the project: In designing lessons with the system, the teacher may complete some of the following tasks using the authoring tool in the teacher module:
 - a. Present brief project description, learning objectives, and tasks;
 - b. Edit content accompanying various types of information (e.g. videos, images, simulations) for Contextualize;
 - c. Design questions for Q&H, and tasks for Plan, Pre-model and Model, Reflect, and Apply.
 - d. Insert simulations into the Investigate tab where students are

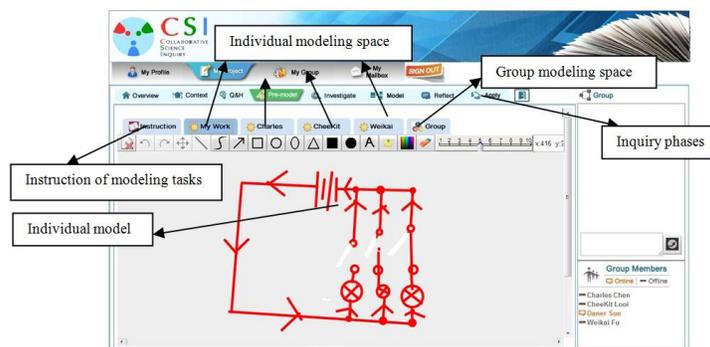


Figure 3. The interface of Pre-model tab.

required to do certain virtual experiments, as well as edit guided questions for each simulation. Finally, the teacher configures the students' groups in the Group Management section and assigns the projects to the students.

(2) Log onto account: After logging into the system with their accounts and passwords, the students can access student module which comprises four functional components: my profile, my project, group management and mailbox. Thus, the general information of the assigned project can be retrieved in My Project section.

(3) Conduct inquiry activities: After accessing the "Overview" tab, the students will be guided to engage in a series of learning activities, such as: students formalize their hypothesis after thinking and chatting over the questions in the Q&H stage; create and negotiate pre-models of scientific concepts they will learn based on their prior knowledge when in the Pre-Model phase; design the plan in the Plan phase and then carry out the investigation in the Investigate phase, and collect and discuss the data. Additionally, they can also engage in the manipulation of several simulations to observe the science phenomena and answer the guided questions. They are then asked to revise their pre-models through peer discussion in the Model phase, and to reflect upon the learning process and artifacts being built when getting into the Reflect phase. Finally, a set of questions will be provided at Apply tab for students, which is used to assess their understanding further.

(4) Review and comment on artifacts: The teacher thereby can access the artifacts and interactions generated by students while navigating in the Solutions Review section, and comment on each student's or each group's hypotheses, plan, investigation report, pre-models and models, reflective content, as well as their responses in the Apply phase if any. Thus, the system supports both formative and summative assessments.

4. Purposes and Research Questions

Considering that various research aspects might be studied within the scopes of inquiry, collaboration, and modeling according to the features of CSI system, we intend to examine the learning efficacy of the CSI system in these scopes stage by stage. Thus, the work reported in this paper focuses on one of the core features: model progression. The study is used to answer the research questions below:

- (1) How to integrate a science learning environment featuring model progression into a real learning context?
- (2) What is the learning effectiveness of the model progression for students' conceptual understanding in science?
- (3) Does the peer discussion promote students' modeling progression in the CSI lessons?

5. Methods

5.1. Participants

In this study, 46 secondary 2 (Grade 8) students from two classes were randomly selected from a junior secondary school in Singapore. A female physics teacher with 9-year

teaching experience conducted the class. She had participated in a series of teacher-researcher working sessions of CSI project for around one year, and thus had good understanding of the system. She also had strong willingness to share the ideas with researchers before and after lessons. The school had good computer facilities, and each student owned and used a Macbook for daily lessons in the various subjects, and they familiarized the ICT-supported science learning more than students at other schools.

5.2. CSI lesson design

The CSI lessons were co-designed by CSI team, science teachers and collaborators. The classes studied “Current Electricity and D.C. Circuit” which was a topic from secondary 2 science curriculum in Singapore. The choice of the topic was: 1) It was one of the most frequent discussed topics in physics; 2) Students had learning difficulties in learning relevant concepts and drawing the circuits. 3) The model progression approach of CSI could fit the instruction of the topic. The lessons was divided into 8 50-minute lessons, among which four lessons were incorporated the use of CSI system. Table 2 summarizes the information of the lessons.

Teaching strategies on the main activities were suggested and discussed based on the relevant pedagogy during the lesson design. For instance, with the system, the first lesson intended to expose students’ possible misconceptions through a pre-lesson quiz and via a collaborative modeling approach. The students at the same group were asked to draw a model of a circuit needed to run a quiz show for three teams of participants, and to point out the direction of the current flow of the circuit. The teacher reviewed the pre-models and identified the major misconceptions among the students. The students’ initial ideas of

Table 2. The basic information of the lesson design.

Lesson sequence	Materials*	Learning activity
1. Pre-lesson quiz, draw pre-models of circuits	CSI: Overview, Contextualize, Pre-model	Review the tasks, and draw collaborative pre-models.
2. Connect single bulb circuit	Worksheet	Do hands-on experiments, and draw possible models of circuits.
3. Learn circuit diagram and explore the simulation	CSI: Investigate	Explore simulations; observe the bulb’s brightness and the current flow.
4. Learn series circuits and parallel circuits	CSI: Investigate	Explore simulations of the series circuit and the parallel circuit.
5. Review and reflect the tasks	CSI: Model, Reflect	Revise models and reflect the previous work.
6. Experiment	Real-lab experiment	Do experiments and train experiment skills.
7-8. Resistance	Worksheet	Observe simulations of circuits with different resistances.

*According to the class time and content of the topic, we adopted Contextualize, Pre-model, Investigate, Model, and Reflect to guide students’ inquiry in “Current Electricity and D.C. Circuit”.

simple circuits were then further explored and elicited in the second lesson through doing hands-on experiments of connecting possible circuits. During the third and fourth lessons, the students interacted with three levels of PhET (Physics · Education · Technology) simulations, as well as answered guided questions individually. After they gained further understanding of circuits through their investigation, they were guided to Model phase to revise and elaborate pre-models drawn in the first lesson, and reflect on their conceptual changes in the Reflect phase. In this pilot study, the concept map tool and quantitative modeling tool are not incorporated into the system. The students mainly worked with the sketch tool to create models. Meanwhile, they were encouraged to do online peer discussion and provide peer feedback for models creation and elaboration within the group members. Before class time, the students were asked to log on to CSI at home to sufficiently familiarize the system. The teachers integrated the instructional content in the system and managed the grouping of the students. As 23 students in each class were divided into 8 heterogeneous groups, they mainly worked in triads (one group worked in dyads each class).

5.3. Data source and data analysis

The study aimed to examine the pedagogical value of model progression of the CSI system in science learning, as well as the impact of peer discussion on students' modeling performance. The data sources included classroom videos and audios, field notes, students' models, reflections and peer discussion logged in the system, as well as the teacher and students post-interview transcripts. During classroom observation, two video cameras were set up at the back and front of the classroom. Videotaped recordings of the teacher and students' interactions were used to identify patterns of change for triangulation purposes. One audio recorder was directed at each of eight groups in both of classes to record students' discussion, and teacher-student verbal interaction. Two researchers filled in the field notes of activities in the classroom. One programmer stood by to provide necessary technical support for the teacher and students with minimum intervention of students' activities. After all sessions, the teacher and 16 students were interviewed using a semi-structured interview protocol for around 20 minutes. The interview was intended to receive the teacher and students' attitude toward on the CSI implementation and their comments on the elaboration of CSI the lessons.

In the data analysis, all videotapes and audios were transcribed to examine students' performance while doing the CSI activities. Students' models logged in the Pre-model and Model phases were retrieved, coded and analyzed to present students' changes of conceptual understanding. To evaluate students' modeling performance, we classified the quality of models into three levels based on a literature review (Ergazak et al., 2005; Grosslight, Unger, Jay, & Smith, 1991; Halloun, 1997; Harrison & Treagust, 2000).

(1) High Quality Models (H) refer to models containing accurate description of science conceptions or phenomena that involve model components with basic properties, and reflect interaction between model components.

(2) Medium Quality Models (M) refer to models with partially accurate description of science concepts or phenomena, which represent parts of model components and describe the possible relations.

(3) Low Quality Models (L) refer to the models containing inaccurate description of all model components.

The three levels of model quality usually differ in the number of model components, the use of symbols and the description of the relationship among these components (Eilam & Poyas, 2010).

Students' typical reflections were retrieved and analyzed from Reflect to support analyzing students' progression in understanding further. Content analysis was conducted to analyze students' reflections. The students' peer discussion during the modeling process was also retrieved, transcribed and identified. The peer discussion coding instrument was developed based on the principles of good feedback theory and practice (Nicol & Macfarlane-Dick, 2006). It consists of five categories: A. task-oriented peer feedback; B. knowledge-oriented peer feedback; C. strategy-oriented peer feedback; D. assessment-oriented peer feedback; and E. affection-oriented peer feedback. Category A clarifies the task specificities, such as procedures, duration, and work division; category B provides necessary information relative to the key concepts, such as definitions, explanations, and reasoning; category C provides strategic methods or plans to complete the task; category D provides constructive comments on the work produced and category E provides comments with intentions to improve motivations of group members. The frequency of these categories of peer discussion appeared in the modeling activities was accounted. In the data analysis, the Pearson coefficient was computed to assess the relationship between model scores and students' peer feedback. Thus, we scored 25 models (11 in Pre-model, 14 in Model) from the range of 0-100 according to the components of models and its relations. Each component in the model was received 10 points (1 battery=10, 3 switch=30, 3 bulbs=30, wires (connection)=10, closed circuit=10, direction of current flow=10). Thus, the scoring schema was: a. the model consisted of all components, it would be received 100 points; b. if the model lacked one of components, it would not receive 10 points; c. if the model had wrong labels, the labels would not receive the points. The inter-rater agreement reached 90.23% for the identification of model quality, 94% for the scoring of models, 90% for students' peer discussion. The results were subsequently verified by cross-referencing collected data.

6. Results

6.1. *The progression of the model quality*

A scientific model is defined as a representation that abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena (Schwarz et al., 2009), so building models reifies the conceptual models. To explore how students identified and described key features or attributes of models, and how they related them (Cartier, Rudolph, & Stewart, 1999), we judged the models built in Pre-model and Model

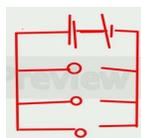


Figure 4a. LQM.

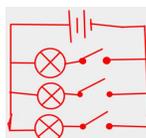


Figure 4b. MQM.

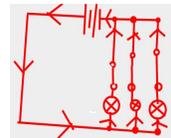


Figure 4c. HQM.

by assessing and analyzing the model quality. In the study, the modeling task was constructing a model of circuit which used in quiz show for three teams of participants, and pointing out the direction of the current flow in the circuit diagram in the Pre-model phase and revising the pre-models in the Model phase. Thus, the students were expected to draw a parallel circuit diagram with batteries, three bulbs and their switches, and annotate the direction of current flow when the switches were closed. Below are the exemplar models of circuits at different quality levels drawn by students in the study, see Figure 4a, 4b and 4c. The LQM presents a model of the parallel circuit using inaccurate symbols of bulbs and batteries. Although the MQM describes a right model of the parallel circuit, but it lacks the label of the direction of the current flow as required. From the HQM, we can see it gives full consideration to the modeling task and presents a right parallel circuit with right current flow.

Among 16 groups, 11 groups constructed 11 models in the Pre-model phase and 14 groups constructed 14 models in the Model phase, this means students' completion rate of modeling tasks increased after manipulating and observing simulations in Investigate. The outcomes of the evaluation of these models in Pre-model and Model phases are depicted in Table 3*.

Overall, the quality of students' pre-models and models were mostly identified the level of MQMs, around 82% (n=9) and 71% (n=10) respectively. Analyzing the details of these models, more differences could be found. In detail, 45% of models (n=5) in the Pre-model phase presented right representations with components of bulbs, switches and batteries, but failed to define the current flow direction. Although the number of models without current flow direction increased to 6, the rate decreased to 42% in the Model phase. This further reflects that students attained more understanding of relevant concepts. More importantly, in comparison with the three groups who drew the incorrect current flow direction in the Pre-model phase, only one group exhibited the same mistake in the Model phase. It indicates that students could provide more correct responses to the concept of direction of current flow in a circuit in the Model phase. In the Model phase, three groups defined the right components of models although they drew the current flow in the broken circuit. The most significant difference was found in the comparison of HQMs, the models of four groups achieved the level of HQM in the Model phase, while only one group's models attained the level of HQM. Moreover, one group drew a model

* As the models were the products of groups' work, the number of models equals the number of groups.

Table 3. The number of different models in the Pre-model and Model phases.

Quality of models	Pre-model stage	Model stage
LQM	1	0
MQM	5 (without current flow direction)	6 (without current flow direction)
	3 (inaccurate current flow direction)	1 (inaccurate current flow direction)
	1 (short circuit)	3 (broken circuit with current flow direction)
HQM	1	4

in the level of LQM in the Pre-model phase, compared to no one constructed the same level of model in the Model phase.

The above data analysis indicates that: 1) After a series of learning activities in the Investigate phase, students could perform modeling better in the completion and quality. With this approach, they attained significant progression in the modeling; 2) With the reduction of LQMs and the increment of HQMs, most of students had improvement in the understanding of core concepts, as well as their modeling skills. 3) The teacher should emphasize the direction of current flow when introducing or interpreting different types of circuits for students in the third and fourth lessons.

6.2. Students' reflections

Self-reflections are part of the critical thinking process referring specifically to the processes of analyzing and making judgments about what has happened. They provide students with an opportunity to step back and think about how their previous work should be improved, and how to use their new knowledge to explain their improvement of their previous work. In the Reflect phase, students were required to reflect upon their work in the project. Through examining students' reflections on their previous models and relevant concepts, students' progressions in the conceptual understanding revealed apparently. See the following types of reflections we retrieved and refined from the Reflect phase:

Student A: *In conclusion, I found out more about the different circuits, which are parallel and series, and also the different components in a circuit.*

Student B: *I think that it should be in parallel and switches in each bulb so that the contestants can click on the switch and it will light up.*

Student C: *I feel that our design is correct as it is in parallel connection of the bulbs with a switch connected to it. Closing one switch will cause its corresponding light bulb to light up.*

Student D: *I used to think that short circuits are very complicated, but they are not. In addition, I thought that parallel circuits have different current for each bulb. But now, I think that for parallel circuits, the bulbs have the same brightness as the same amount of current is being flowed through it. Only, when the switch is closed, then the electrons can start flowing. Bulbs in series circuits have lower brightness than bulbs in parallel connection.*

After investigating a series of simulations, students' conceptual understanding on circuits had greatly improved, but varied at the cognitive levels. Most of students reflected their group models through looking back their pre-models and models, and then comparing, assessing and describing their differences. For students whose reflections were similar to student A's (8%), they recognized there were differences in the components between parallel and series circuits, but didn't make further explanation of these components. Students whose reflections were similar to student B's (30%), they proposed the revision of their group model and pointed out it directly, which meant he clearly understood the major concepts. Students whose reflections were similar to student C's (32%), their reflections suggested that they could assess their group model and could explain all of components of the parallel circuit. Students whose reflections were similar to student D's (30%), they interpreted a process of conceptual changes. Their reflections indicted that they not only attained more conceptual understanding, but also became more skillful at critical thinking.

6.3. The correlation of models quality and peer discussion

Online peer feedback is particularly advantageous, due to the possibility of a less stressful and intimidating working environment from the lack of face-to-face interaction, which may promote students to be adventurous and be more involved (Guardado & Shi, 2007). In the study, students were encouraged to build, revise and elaborate their models through receiving peer feedback from their group members both in the Pre-Model and Model phases.

We extracted and analyzed available peer discussions (taking one sentence as a unit) generated in the chat box. The calculation of the frequencies of the peer feedback between group members enables us to recognize students' involvement in the collaborative work, as well as to probe the process of their knowledge building (van Aalst, 2009). Here are some examples of the peer feedback from the transcription of the discourse of a group doing the modeling, with their coding:

Category A + Category B: You press undo and draw the bulb.

Category B: Just put more batteries to make it (electromagnet) stronger.

Category C: Let us first draw and then think it.

Category D: Actually it is possible. But maybe need more batteries.

Category E + Category D: Nice drawing. I will draw the line.

Table 4. The correlations between categories of peer feedback and the model quality.

Measure	A. Task	B. Knowledge	C. Strategy	D. Assessment	E. Affection
Pearson	0.839**	0.280	0.574	0.941**	-0.739
Correlations					
Sig. (2-tailed)	0.000	0.158	0.253	0.000	0.261
N (Model)	25	25	25	25	25

** Correlation is significant at the 0.01 level (2-tailed)

We calculated the quantity of peer feedback that happened at each group, as well as the number of each category of peer feedback. The results indicate that there appeared to be an upward trend, namely, as the amount of peer feedback increases, the higher the scores of the models drawn. For the group which constructed a low score model (40), the number of peer feedback (32) was much less than the group who built the high score model (90), the latter one performed actively in peer discussion (83). The statistical analysis with the Pearson's $r=0.972$, $p=0$ (at the level of 0.01) reflects a strong positive correlations between students' model scores and the quantity of peer feedback. Table 4 presents the respective correlation for the five categories of peer feedback and the model scores.

The findings suggest that category A, B, C, D were positively correlated with the model scores. It reveals that students' frequent peer discussion focusing on task, content knowledge, strategy and assessment improved their models quality. Further, significant correlation exists between category D and model scores, $r=0.941$, $p=0.000$ (the higher the quantity of category D, the higher the models' scores, or vice versa). According to this result, the groups who performed better at assessing group models had received higher score of their models compared to groups who rarely assessed their models through peer discussion. There was also significant correlation between category A and the model scores ($r=0.839$, $p=0.000$). As we observed, the groups discussed more on their tasks, they spent less time on modeling, as well as built model with better quality. As for knowledge and strategy-oriented peer feedback, the correlations ($r=0.28$, $p=0.158$; $r=0.574$, $p=0.253$) for both measures with the model scores were not significant and they were weakly correlated. This could imply that knowledge and strategy-oriented feedback may be less related to the scoring of the model. And students may not focus more on their concepts in modeling, but paid more attention to the modeling tasks and modeling skills, and the assessment of models. Also, the correlation between affection-oriented peer feedback and scores is negative, $r(2)=-0.739$, $p=0.261$. We would like to explore these further in future empirical studies. Thus, when students are working with the modeling tool in the system, it is suggested using more peer discussion, especially more assessment-oriented peer feedback and task-oriented peer feedback should be provided by group members or otherwise, using words like:

Please don't forget that the switch is one of the objects.

There appears to be a problem in that part, do you mind if you check it again?

I think the two objects that you linked up may be incorrect.

6.4. Teacher and students' comments

The teacher and students expressed an overall positive attitude toward the CSI implementation in the science class. In the interview, the teacher was asked about questions like: a. How to integrate CSI system into science curriculum? b. What are the values of CSI curriculum for science learning? c. Which phase (e.g. pre-model, investigate, reflect) benefits your teaching most? After lessons, the teacher had a better understanding of the lessons which could be designed to leverage on the affordances for CSI inquiry. She provided comments and suggestions as follows: 1) Lesson plans should be adopted for best fit with CSI inquiry, and the instruction should optimize the core features of the system; 2) The explicit inquiry mode was a good scaffold to guide students' learning activities; 3) Students were suggested to do individual modeling in the Pre-model phase at first, because they had different initial ideas before investigation; 4) In the Model phase, students were encouraged to converge to a solid understanding whereby they could present in one consensus model through the co-constructive way.

The students were asked questions like: a. Do you like the learning activities (e.g. of CSI system)? b. Do you communicate with your group members about the modeling drawing? c. Which phases do you like most in the learning activities? Why? d. Which phase benefits your learning? How? The students thought that CSI learning activities were more interesting and engaging compared what they had used previously. They pointed out that the system had its unique and attractive features. They preferred the small group's collaboration which provided more opportunities to do tasks in the system, and they appreciated the synchronized collaboration which could help them finish the task faster and better. The modeling process directly within the system could make drawing more convenient and less time consuming. They thought that they enhanced their understanding of electrical circuits taught in the lesson through the comparison of pre-models and models, as well as a reflection phase to concretize the thinking process.

7. Conclusions and Implications

In conclusion, the findings from the pilot study could answer the research questions well. The first research question refers to the way of integrating a science learning environment like CSI system into a real learning context. First, the topic should be fit to the features of the CSI system and the model-based inquiry and CSCL features could be highlighted in the learning activities. In the study, we first adopted a topic which was best fit the features of the system and could highlight the value of the system in its model progression. Second, the proposed teaching strategies were discussed for supporting the lesson implementation. Before the implementation of the lessons, we co-designed the CSI lessons with researchers and science teachers and conducted groups meetings to discuss the proposed teaching strategies of the CSI lessons. Last, during the classroom

observation, data collection focused on both teachers' intervention and students' performance, this was used for evaluating teacher and student performance in the lessons. The data analysis would provide valuable information for teachers for improving their instruction of CSI lessons. Thus, CSI implementation presents a process of incorporating ICT tool which features model progression into science class, and could shed some light on how to use such ICT tool in real class and optimize its value on improving conceptual understanding and developing critical learning skills.

With respect to the second research question, the positive results demonstrate the effectiveness of model progression for students' conceptual understanding in science. Through examining students' modeling performance at Pre-model and Model phases, progression in both task completion and model quality revealed students had acquired better conceptual understanding and developed relevant modeling skills in circuits. Their reflections on models' assessment and elaboration also suggest their progression in conceptual understanding. In summary, the approach using Pre-model and Model in collaborative inquiry activities could facilitate science learning in a progressive way. Teachers are suggested optimizing the value of model progression via designing appropriate modeling tasks for students. For example, scripts on the procedures of modeling tasks and collaborative tasks should be provided in the "Instruction" tab (Onrubia & Engel, 2012); the appropriate modeling tool should be provided based on students' modeling skills and cognitive levels; typical pre-models with misconceptions are proposed to present and discuss in class before investigation; students' individual modeling is required in Pre-model stage to better expose students' prior knowledge, especially for the misconceptions.

In addition, the preliminary finding that the quantity of peer feedback varied with the quality of the models could help inform the design of collaboration into such an environment. Based on our data analysis, students' better performance on modeling benefits from their frequent peer discussion and they were particularly encouraged to heed assessment-oriented feedback in the collaborative activities. In the design of CSI lessons, we suggest that the teachers emphasize the use of peer discussion and guide students to discuss the procedures of tasks, peer review and assess learning artifacts when students involve in collaborative activities.

The teacher and students' voices suggest that more engagement needs more appropriate instructional support such as guiding students' collaboration, scaffolding students' modeling process. On the other hand, teacher's and students' positive comments on the CSI learning activities enable us to investigate CSI lessons further in the future work. In summary, we provide an illustration of the CSI system that supports flexible collaborative students' model-based inquiry. We believe that the inquiry with CSI will create unique educational opportunities for students' science learning.

8. Future Work

In the future work, the investigation of students' conceptual understanding, collaborative skills, inquiry skills and reflective thinking skills will be the main avenues, we will

pursue with longer-term and larger scale use of the CSI system. More importantly, we would like to share our experience on the implementation of CSI in science class through studying teachers' factor (i.e. beliefs, Technological Pedagogical Content Knowledge) (Brownell, Adams, Sindelar, Waldron, & van Hover, 2006; Song & Looi, 2012), this intends to bridge the gap between the designed lessons and actual lessons with ICT implementation.

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