

Design and Evaluation of a Collaborative Inquiry Environment to Enhance Science Learning

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Abstract: The CSI (Collaborative Science Inquiry) learning environment is designed to help secondary school students understand scientific concepts, and develop scientific inquiry knowledge and skills through collaborative inquiry-based learning activities. This paper presents the design rationale and architecture of the system to support the shape of CSI learning environment. A pilot study that evaluates the effectiveness of the learning design is then reported. The findings attest to the positive role that CSI plays in enhancing students' conceptual understanding, learning interest and engagement in collaborative inquiry activities.

Keywords: CSI system; science learning; collaborative learning; inquiry; pilot study

1. Introduction

Inquiry-based learning supported by Information and Communication Technologies (ICTs) has long been recognized as an effective pedagogical approach in science learning. In recent years, a number of computer-supported inquiry-based science learning environments (e.g. WISE, Co-Lab, Inquiry Island, and nQuire) have been created and studied. Research-based evidence has confirmed that such learning environments could facilitate the development of cognitive and metacognitive strategies in pupils (Goldsmith, 2007; Minocha & Thomas, 2007; Schwarz & White, 2005). Encouraged by such research outcomes, we endeavour to develop a web-based science learning environment — CSI (Collaborative Science Inquiry) learning environment to enhance science learning for secondary school students. The uniqueness of CSI lies in its integration of modelling, visualization, inquiry and social interactions, a feature that is not common in most of established applications. With multiple functions, the system is targeted to support secondary school student to develop scientific conceptual knowledge and learning skills (e.g. inquiry skills, modelling skills, collaborative learning skills), as well as reflective thinking skills. To date, a series of usability tests and pilot studies have been conducted for improving and validating the system. In this paper, we document the development of the CSI system and the implementation of CSI-supported science inquiry to enhance the learning of a biology topic in a secondary science classroom. We hope this study can help teachers better comprehend the needs and approaches to integrate ICT-supported collaborative inquiry to induce enhanced learning outcomes.

2. Design rationale

Pedagogical principles for model-based inquiry learning attained in existing studies have been mined and translated into the design of CSI system. White and Frederiksen (2002) held that an inquiry cycle consists of iterative activity sequences such as “question-predict-experiment-model-apply”. And the application of this inquiry model produced positive learning outcomes for both high and low achieving students. The inquiry process designed in Inquiry Island is composed of similar sequence of activities including questions, hypothesis, investigation, data record and analysis, model creation and evaluation. Empirical data gained had proved it as facilitating students' socio-cognitive and meta-cognitive development. The inquiry process embedded in EIMA (Engage-Inquiry-Model-Apply), the teaching framework developed to improve students' engagement in the guided scientific inquiries is consistent with the ones mentioned above as well (Schwarz & Gwekwerer, 2007). Through literature

review, it is affirmed that a model-based inquiry process mainly includes orientation or question, hypothesis, plan, investigation, model, and conclusion (Bell, et al., 2010), and that modeling being an integral component in science inquiry deserves attending. In the design of CSI learning environment, modeling approach is highlighted as it can help visualize the comprehension and transformation of scientific concepts occurred in the learning process. To better support modeling, the pre-model and model phases, building on the design principle of “Predict-Observe-Explain (POE)” (White & Gunstone, 1992), are embedded in CSI inquiry cycle. The model-based CSI inquiry cycle finally developed encompasses eight phases: Contextualize, Question & Hypothesize (Q&H), Pre-model, Plan, Investigate, Model, Reflect, and Apply. The CSI inquiry phases are proposed to guide teachers’ design of inquiry activities and students’ exploration in inquiry activities.

CSI learning environment is a complicated system, so we employ a standard approach the Rapid Application Development (RAD) for system development in the consideration of the research condition (fund, manpower and the expected duration). RAD focuses on the short development cycles, limit features development in each cycle and strong end user involvement. It is appropriate for CSI development. The development of the whole system is classified into several stages as Figure 1 shows. The stages which have been complete are described in solid boxes; stages presented in dashed boxes are still under the development. The development process consists of five short development cycles which mostly involve: design → discuss → adopted features development → discuss & usability test → redesign. The participants who take part into different stages include designers, programmers, researchers and teachers.

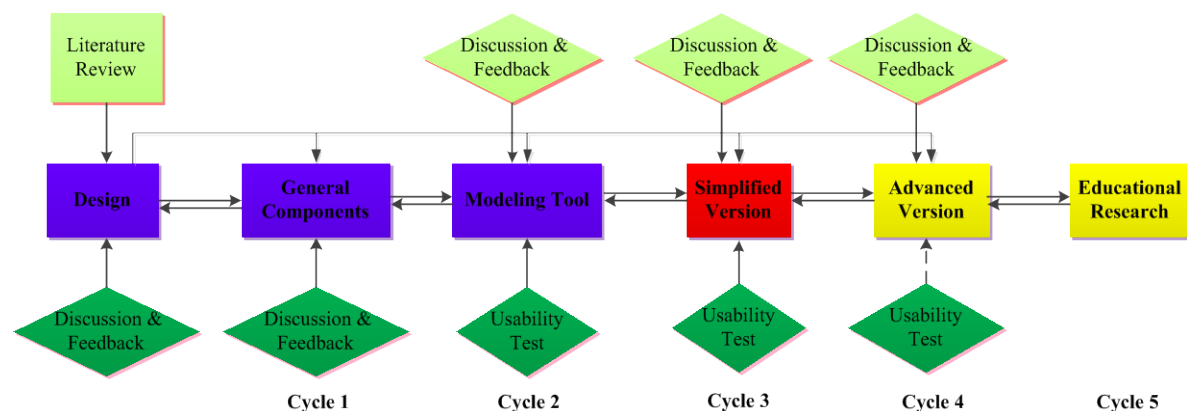


Figure 1. The Development Process of CSI Learning Environment

At each stage, consultants and collaborators from different research including science education, computer technology, and educational technology areas are invited to give feedback and comments on the design of the system. Subsequent revisions are made based on the feedback and comments. During the whole process, to verify the validity of the system at each stage, usability testing is proposed to conduct to collect data for revising and improving the design and development. This approach helps to develop complicated system in effective way. Up to date, we have finished several usability tests and three pilot studies. The existing CSI system has been revised and improved based on the usability report and feedback from trial implementation in the pilot school.

3. Architecture of the System

As a web-based learning environment, the CSI system can be accessed via general browsers (e.g. Firefox, Google Chrome, IE). The system includes two major functional modules: teacher module and student module. Table 1 describes the main functionalities of each component in the two modules. With CSI system, teachers are allowed to design, import and edit the learning content in Project Management and they can review and comment on students’ artefacts through Solutions Review. Students focus on their inquiry activities and construct their learning artefacts individually or collaboratively in My Project. For a detailed introduction of the system, please refer to Sun & Looi (2013).

Table 1: Description of teachers' module and students' module

User	Component	Functionality
Teacher	Profile	Identifies users based on photos, name, nationality and profile description.
	Subject Management	Allows defining subjects and grades for projects.
	Project Management	Allows editing content, attaching guided questions, inserting images, videos and simulations, and establishing and managing groups for students.
	Solutions Review	Allows viewing and examining students' artefacts (e.g. written information, pre-models and models); providing feedback through a comment box.
	Simulation Library	Allows uploading and executing simulations for the projects.
	Mail Box	Used to send message to exchange ideas, written materials or other information.
Student	Profile	Identifies users based on photos, name, nationality and profile description.
	My Project	Allows students to go through inquiry phases to conduct learning activities and complete series of learning tasks.
	My Group	Enables students to manage the access to the system and create or find an available group to join.
	Mail Box	Used to send message to exchange ideas, written materials or other information.

In this paper, we specifically describe the student interface of the topics in “My project”, which is the main venue of students doing inquiry activities. The student interface presents a four paned window: shared workspace, inquiry phases, group member list, and a chat box. See Figure 2. The main component, shared workspace presents the content or tools for each inquiry phase. In a typical learning scenario, the system will guide students to go through the 8-phase inquiry process: Contextualize - Q&H - Pre-model - Plan - Investigate - Model - Reflect - Apply. Considering students may vary in cognition levels and inquiry skills, skipping one or more phases in the inquiry process is acceptable in the CSI instruction (Kilinc, 2007). Inquiry activities of different difficulty levels (Simple vs Complex) are both provided. Teachers and students can choose the appropriate ones based on students' abilities.

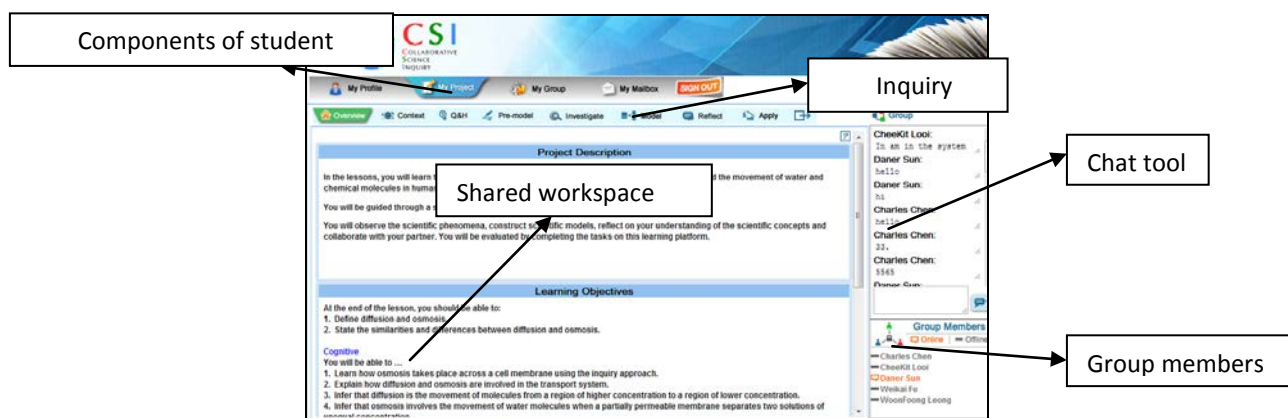


Figure 2. The Interface of Student's Workspace in “My Project”

To facilitate students' mode-based inquiry, the learning scenario of modeling activities in Pre-model can be briefly described as follows: 1) After reviewing the modeling tasks and the procedures in “Instruction” tab⁴, the students draw individual models on the private modeling space (in the “My

⁴ The system employs “Instruction” as a platform for providing scripts about procedures and tasks of the activities in the phases of Pre-model, Investigate, Plan, Model, Reflect (Dillenbourg, 2002).

Work” tab). 2) They shift to review and comment on the model drew by one of their group members through clicking on the relevant tab (group members’ modeling tab), and then seek consensus on a group model through discussing with group members. 3) Finally, they construct and post their collaborative model on the group modeling space (in the “Group” tab) through peer review, discussion and modification. Students can rethink their pre-models after obtaining new understanding of the concepts in Investigate; they are likely to draw another revised/elaborated model collaboratively in the Model phase. Hence, the model construction in CSI lessons can be refined as following steps: constructing initial models→ reviewing models → discussing models → revising models → reflecting and elaborating models. The collaborative modeling approach combining scientific modeling with synchronous construction and communication is proposed to facilitate students’ acquisition of sophisticated understanding of scientific concepts, reasoning skills and reflective learning skills, as well as students’ critical thinking and their collaborative learning skills (Johnson & Johnson, 1999; Koschmann, 1996).

4. Methods

4.1 Participants

46 students in two secondary 1 classes from a local future school participated in this pilot study. The school provides one to one computing environment. As a future school, the computer facilities are excellent and the school had full-time ICT coordinators who assist teachers in the technical aspects of the use of ICT in their teaching. The students each is equipped with a Macbook and has developed good competence and familiarity in ICT-supported learning. A biology teacher with rich teaching experiences taught both classes.

4.2 Procedures and Lesson Design

Researchers, collaborators and science teachers worked in close collaboration to design the CSI lessons. “Diffusion and Osmosis” in the domain of biology subject from year-1 science curriculum was selected as the topic for this study. Two 50-min lessons incorporating the CSI system were designed and delivered under this topic. In the CSI lessons, altogether six inquiry phases were included: (Overview) → Contextualize → Q&H → Pre-model → Investigate → Reflect → Apply. In the Overview tab, there were brief descriptions of the project, learning objectives and tasks. After reviewing the Overview information, the students proceeded to read the story in the Contextualize tab. In the following, the teacher guided the students to formalize and edit their collaborative hypothesis according to the questions posed in the Q&H phase. Then the students were engaged in the Pre-model phase (build individual models → peer review and discussion→ build group models⁵) based on the information gained in “Instruction”. During this process, the teacher was responsible for supervising, managing and scaffolding students’ learning activities. Before investigation, the teacher concluded the work done by students and presented some selected hypotheses and models generated by the students. This was intended to visualize and expose students’ misconceptions of Diffusion and Osmosis. Then students were presented with two videos and one dynamic simulation to make further investigation of the scientific phenomena, especially for the mechanism of diffusion and osmosis in particular level. In this phase, they manipulated visualizations, conducted observations, and discussed with their peers the evidence attained in Investigate. A series of questions were raised for the students to guide them to observe the simulation in a deep and purposeful way. Afterwards, students reflected upon on their hypothesis, pre-models and conceptual understanding obtained in Reflect. The reflections could be shared within group members. Students were also required to apply their new understanding in the new context designed in the Apply tab.

Before the CSI class, students were asked to try the system at home to get themselves familiarized with the basic manipulations and navigations in the system. The teachers integrated the

⁵ The system provides two modeling spaces, namely, individual modeling space and group modeling space for students’ building/drawing by modeling tools in the system or inserting images drawn by other tools. The group modeling space with its sketch tool enables students to do synchronous collaboration of modeling activities.

instructional content in the system and managed groups. Students were divided into 11-12 heterogeneous dyads (in terms of students' science abilities, gender, and ethnicity). Pre-and post-tests using identical test items (the test was built on the "Diffusion and Osmosis Diagnostic Test")(Odom & Barrow, 1995) were conducted at the beginning and concluding stages of the lessons.

4.3 Data Source and Analysis

The study focuses on examining students' conceptual change and their performances at the specific inquiry phases in the CSI system. Multiple sources of data including pre-and post-test scores, field notes, observation sheets, interview transcripts, target group video and audio transcripts (a voice recorder were set up in each of the 4 target groups and a video camera was set up at the back of classroom to record teacher and student actions), and learning artefacts (pre-models and reflection) were mined.

In test employed was made up of 10 paired two-tier multiple choice questions (altogether 20 questions) covering: 1) the identification of diffusion; 2) the movement of particles in diffusion; 3) the rate of diffusion; 4) dissolve and solutions; 5) the identification of osmosis; 6) the water movement in osmosis; 7) the effects of osmosis. The first tier were content (what) questions with two, three, or four choices; the second tier were of why questions with four choices (among the four, there was only one desired reason, the other three were alternatives derived from misconceptions detected during the multiple choice test with free response reasons and the interview sessions). One item was scored 1 point, the total score was 20. In data analysis, the difference between pre-and post-test was examined to identify students' conceptual changes. Video and audio data were analyzed to reveal teacher-student and student-student interactions in the class, as well as student learning performances in CSI learning activities. In particular, students' modeling performances and their self-reflections were scrutinized to uncover the conceptual transformation process. Teacher and student feedback on CSI-supported collaborative inquiry were also collected and studied for supporting the continuing implementation of the CSI system. The results were subsequently verified by cross-referencing multiple sources data.

5. Findings and Discussions

5.1 Conceptual understanding

Paired-samples t-test (valid n=37) administered confirmed significant improvement in students' test scores in the post-test ($M=12.97$, $SD=2.774$; $t(36)=-4.299$, $p = 0.000 < 0.01$) compared to the pre-test ($M=10.62$, $SD=2.792$). This suggests the effectiveness of CSI lessons in helping student develop conceptual understanding. Further analysis shows that students' improved most on item 4 (the correct rate increased from 45.9% to 78.4% in the post-test), item 7 (from 40.5% to 81.1%), item 13 (from 29.7% to 81.1%), item 16 (from 2.7% to 29.7%), and item 18 (from 24.3% to 62.2%). It indicates that students gained better understanding on the reasons of diffusion, the effects of diffusion, and the nature of osmosis at the microscopic level. This further reflects that students could acquire more knowledge on the mechanism of scientific phenomena with CSI system.

5.2 Modeling Performance

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, so building models reifies the conceptual models. To explore how students identified and described key features or attributes of diffusions and osmosis models, and how they related them, we judged the models built in Pre-model by assessing and analysing the model quality. In the Pre-model phase, the students were instructed to build two models to represent diffusion and osmosis at the microscopic level. Students were allowed to use sketch tool in CSI system to construct their models. According to available literature, we classify the quality of models into three levels (Ergazaki, et al., 2005; Harrison & Treagust, 2000): 1) High Quality Models (H), which contain accurate description of science conceptions or phenomena that involve objects (model components) with basic properties, and reflect interaction between objects (model components). 2) Medium Quality Models (M), which feature partially exact description of particular scientific conceptions or phenomena and take into account some of appropriate components

of models. 3) Low Quality Models (L), which contain inaccurate description of all modelling components and are usually at the level of the scribble drawing. Additionally, if the models built were at the macroscopic level, they were marked as 1, the microscopic level as 2. See the exemplars we coded from students' models.

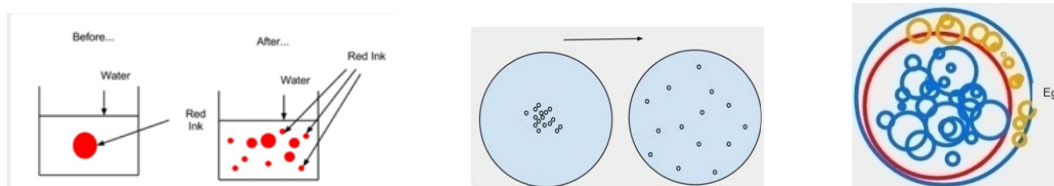


Figure 3a. H₂ Model of Diffusion

Figure 3b. M₂ Model of Diffusion

Figure 3c. L₂ Model of Osmosis

As depicted in Figure 4, most students could only draw individual models at Pre-model stage (80%) and most of them (65%) failed to finish the collaborative models. We inferred that students' inadequate collaborative skills and limited class time caused the failure of co-constructing of models. Compared to the osmosis model, students were found to perform better in the construction of diffusion model. Data analysis of their resultant models suggests that most students constructed the individual models at the particulate level but the model quality varied (12.9% of H₂, 54.8% of M₂, 3.2% of M₁, 27.4% of L₂, 1.6% of L₁). Positively, more than half of the students drew the middle quality of diffusion models at particulate level (M₂ = 54.8%). The deficiencies were: 1) The models lacked the necessary annotations of each model component; 2) The models failed to represent the process of how particles scattered over time; 3) The particles drawn were placed in an orderly arrangement in the container, which should not be the case. For osmosis models, H₂, M₂, M₁, L₂, and L₁ were taking up 2.5%, 40%, 7.5%, 35%, and 15%. The significant proportion of M₂ models may indicate that these students, who had viewed and observed the videos, had acquired a more appropriate perception of the micro- phenomenon of osmosis. However, some students failed to distinguish the model components of osmosis which resulted in a number of L₂ models (e.g. identifying the egg yolk membrane as the partially permeable membrane) although they knew that osmosis would happen when the egg was immersed in the corn syrup. We also notice that students' active engagement in peer review and discussion of models led to the improvement of their prior knowledge of osmosis and diffusion, especially the groups who built H₂ models.

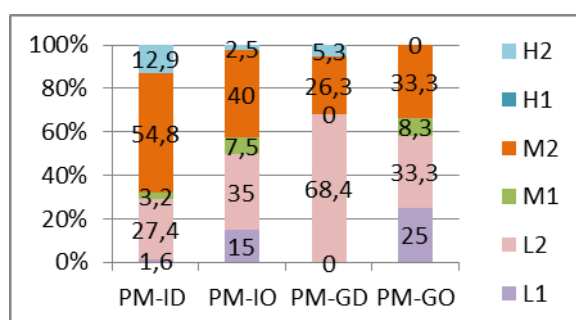


Figure 4. The Percentages of Different Quality of Models

(PM-ID: Pre-Model-Individual model of Diffusion. PM-IO: Pre-Model-Individual model of Osmosis, PM-GD: Pre-Model-Group model of Diffusion, PM-GO: Pre-Model-Group model of Osmosis)

In conclusion, students' modeling performance provides a window into the students' misconceptions and their reasoning of diffusion and osmosis. In Pre-model, a considerable proportion of students established a (partially) correct understanding of the diffusion and osmosis phenomena, and developed a microscopic view for representing the scientific phenomena, with most of ideas residing at the moderate level of the macroscopic view as they were at the beginning of the inquiry.

5.3 Reflections

After observing the three visualizations about diffusion and osmosis, students reflected and improved upon their Q & H answers and pre-models. This, to some extent, shows their progress in understanding the scientific concept. Their responses at the Reflect phase could be mainly classified into four categories: A. verification B. improvement C. explanation D. critical reflection (Kember, et al., 2010). “Verification” refers to the reflection with simple assessment of the artefacts. “Explanation” focuses on interpreting the definitions of the concepts, but without commenting on how to improve the artefacts. “Improvement” means the reflection expressing students’ ideas on how to improve their artefacts. “Critical reflection” pertains to those reflections that involve the critiques, and the proposals of improvement, as well as further explanation of the artefacts. Reflection from low-level to high-level thinking is ranked progressively from “verification” to “critical reflection”. The ranking of students’ reflection responses enables researchers to probe the degree of students’ thinking and understanding of their work in the inquiry. We illustrate some exemplars based on the categorization of reflection mentioned above.

A. Verification: “The models I drew were not animated but still showed how diffusion and osmosis happened.”

B. Explanation: “Diffusion is the movement of particles from a higher concentration to a lower concentration. Osmosis is the movement of water molecules from a higher water potential to a lower water potential.”

C. Improvement: “At first, the pre-model of osmosis was just molecules gathering in the middle of a cell. However, after learning more about the cell membrane, the pre-model was changed to molecules going into the cell through the cell membrane.”

D. Critical reflection: “My pre-model was quite similar to the one in the video clip but that only refers to the diffusion but for the osmosis, I did not draw the process properly as I did not know at first that osmosis involved water molecules (only). I would have changed the picture we drew for the osmosis in the different way like in a beaker separated in half by a partially permeable membrane and place water on both sides but add a solute in one of the side.”

In category A, students assess their models with simple words, and do not describe why they think the models are satisfactory, what their current understanding of diffusion and osmosis are; in category B, students interpret their major understanding of diffusion and osmosis, but without connecting it with the reflection upon their pre-models or answers in Q&H; in category C, students propose the revisions of the osmosis models with a simple explanation; in category D, students evaluate their osmosis models in more deep and comprehensive way, and they point out the defects of the previous models, and interpret how to improve and elaborate them. This indicates these students had attained a profound level of reflective thinking.

Based on our data analysis, although 30.28% of students reflected upon their artifacts through “verification”, the rest of the reflections reveals students’ deep thinking of their artifacts and understanding changes. Among the rest, the “explanation” (23.33%) mainly concentrated on: 1) providing supplementary comments for the Q&H answers and interpreting the process of diffusion and osmosis at the particulate level. 2) presenting the definition of diffusion and osmosis, in order to show their current conceptual understanding. 3) explaining the effects of diffusion and osmosis. This means students that gave the “explanation” reflections had achieved better understanding of the target concepts, especially, the knowledge of the definition, the movement of the particles, and the results of diffusion and osmosis. Students that gave “improvement” reflections (18.33%) generally thought that they should revise and improve their previous work, because they recognized the misconceptions they held in their prior knowledge. Most importantly, 28.06% of students formalized their critical reflection thus suggesting that a group of students succeeded in developing more correct and comprehensive understanding, because they had managed to convey and present their new understanding through critique, and improve their previous ideas and explain the reasons of improvement. This indicates their sophisticated understanding of the concepts. See the excerpts from their critical reflections.

Student A: *My pre-model for osmosis was very different than the video's one. I only drew 1 molecule instead of many and after investigating the animations; my model was more molecules as I need to represent the whole drop of dye instead of just 1 molecule.*

Student B: *My pre-model for diffusion is different as it did not show the membrane and I used a rectangle for the beaker. My pre-model for osmosis was not in detail. I just drew an egg and arrows pointing which direction are water and corn syrup.*

5.4 Teacher and Student Feedbacks

The transcribed interviews were analyzed to mine the teacher and students' perceptions about CSI-supported collaborative inquiry activities. In general, the teacher and students held an overall positive attitude toward the CSI intervention in the science class. Their perceptions can be summarized as the following:

Teacher's feedback:

- Students are given more opportunities to respect and appreciate viewpoints and clarify doubts, because the system allows for sharing and building artefacts through collaboration among peers.
- The system can help teachers to maximize the learning potential for improving students' self-directed learning by initially providing more scaffolding before gradually reducing the amount of information provided. This allows students to think more critically, as well as inquiring and reflecting more.
- Pre-model provides a means for students to explore and discuss in greater depth what they have known; this allows teachers to pick out any potential misconceptions in their prior knowledge. Students are interested in the modelling activities and they become more engaging in the inquiry.
- The system supports students' working from home. Teachers can review their work at any time anywhere.

Students' Feedback:

- The system is different from what they used before and it is more interactive. They become more engaged in the inquiry through real-time chatting, modelling and visualization.
- They paid more attention on the activities with CSI system, because their learning can be guided by the instruction and questions. Meanwhile, peer discussion and review also help them to keep pace with their team members, improving their time management skills and collaborative learning skills.
- They benefit from the Investigation. The simulations in the tab provide important information for them to learn new ideas and when answering the guided questions, they can manipulate the simulations to review the results and then check the answer. The dynamic simulation is specifically useful as it is more interactive and hands on.

6. Conclusion and Further Work

In this paper, we briefly present the theoretical underpinning of the design of CSI and the implementation of CSI supported collaborative inquiry for learning biology in a secondary classroom. Our analysis of data collected from classroom deployment helps us attest to the system providing improvement in students' conceptual understanding, learning interest and engagement. The evaluation of this comprehensive science learning environment is a complex, multifaceted and continuing process. So far, we have conducted pilot studies on the subject domain of physics and biology. In further work, we will conduct a workshop for science teachers from different schools, and use the lesson exemplars to guide the teachers to design and implement lessons with CSI system. More research work will be done concerning science instruction, science learning and CSCL (Computer Supported Collaborative Learning) for science. We will make more efforts to investigate the potential value of CSI system for science instruction and learning, and help teachers to attain further understanding of how to implementing such system in their teaching practices.

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