

Learning with Collaborative Inquiry: a Science Learning Environment for Secondary School Students

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Abstract: The paper presents a study of science instruction using collaborative inquiry with the CSI (Collaborative Science Inquiry) system which combines multiple learning design features with CSCL design elements. The study reported here explores the educational value of the system on students' conceptual understanding, performance on inquiry phases and collaborative work. Promising results have been received from the comparison of pre-test and post-test achievements, the examination of artefacts, peer discussions, and interview transcripts. The results indicate that the collaborative inquiry facilitated by the CSI system can engage students in activities and promote their conceptual understanding in a progressive way.

Introduction

Computer Supported Collaborative Learning (CSCL) applications incorporating design elements such as shared (work) space, chat tools, collaborative text editor, and argumentative editor, have been identified as being capable of facilitating collaborative learning in pupils (Bouyias & Demetriadis, 2012; Gogoulou, et al., 2008). Concerning the benefits addressed with the use of CSCL approach, the study reported here aims to implement a web-based science-learning environment employing collaborative inquiry approach to facilitate science instruction and learning at secondary schools in Singapore. The system, known as Collaborative Science Inquiry (CSI) science learning environment, leverages both guided inquiry and modelling with multiple CSCL components. The conceptualization of the learning design for the system is influenced by existing design principles and relevant applications, such as WISE, CMapTools, Co-Lab, and ModelingSpace, which seek to integrate appropriate pedagogies with appropriate CSCL design elements.

In the CSI system, learning designs included guided inquiry, modelling and visualization, have been proved to be contributing positively to science learning (Buckley et al., 2004; Jackson, et al., 2008). The guided inquiry process is developed and modified from dominant model-based inquiry principles (Bell et al. 2010; White et al. 2002). It consists of eight phases: Contextualize, Questions and Hypothesis (Q&H), Pre-model, Plan, Investigate, Model, Reflect, and Apply. Modelling pertains to the construction of scientific models by the use of drawing-based, qualitative and quantitative modelling tools (Lerner, 2007). These modelling tools are embedded in both the Pre-model and Model phases. The system allows the display of various visualizations, such as images, videos, and dynamic simulations, to support virtual inquiry. Multiple CSCL design elements, including synchronous modelling and editing, shared workspace, peer review, chat tool, and social presence, are also integrated in each inquiry phase as required. Thus, the unique feature of the system is the tight coupling of relevant CSCL design at each inquiry phase, such that each phase can be utilised in a flexible way towards inquiry learning through modelling and visualization.

To validate the educational value of the system, a series of pilot studies, each with different educational aims, have been conducted (Sun & Looi, 2013). Due to the continuous efforts made in system development, we have further continued the exploration of the deployment methods of the system in various classroom settings. Hence in this study, we interpret a study of trial instruction of the CSI system in a biology class at Secondary 1 (Grade 7) level. The aims of the study are: 1) Demonstrating the effect on promoting conceptual understanding of abstract concepts associated with the system. 2) Exploring the progressive process of students' conceptual changes at every stage of the inquiry process. 3) Summarizing students' performance on peer discussion which contributes to the accomplishment of collaborative artefacts.

System Overview

General Structure

There are two major functional modules in the system: teacher module and student module. The teacher module consists of six sections: Profile, Subject Management, Project Management, Simulation Library, Solutions Review, and Mailbox. An authoring tool is available for teachers to design lessons when they enter the various sections. Project Management enables teachers to set up the inquiry project, and the stages by creating the project and 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' artefacts (e.g. answers, models, reflections) and their chat logs. 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, proposing and negotiating solutions, manipulating and observing simulations, responding to guiding questions, constructing models, and writing reflections at the assigned inquiry phases. 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 1. The CSCL design elements are annotated (see the following introduction of CSCL design features).

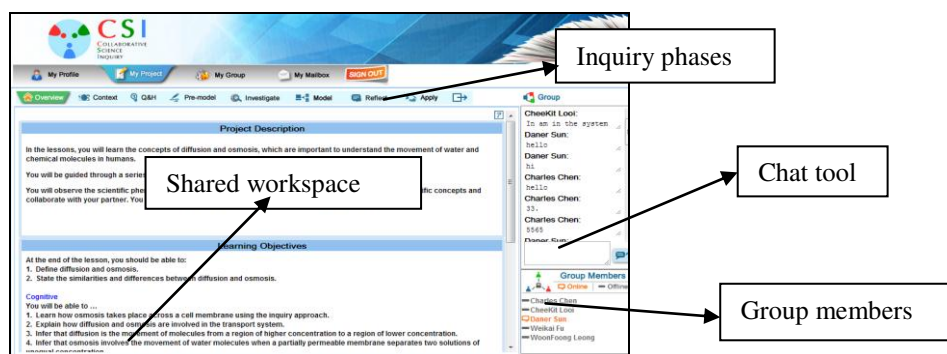


Figure 1. General Interface of the Project Work Session in Student Module

CSCL Design Features

The system employs multiple CSCL design elements in inquiry phases to facilitate students' various forms of collaboration as mentioned above (Pozzi, 2009). Figure 2 depicts a map representing how CSCL design elements are combined and integrated in the system. In Overview and Contextualize, all online members can share the text information. Besides peer review and mutual editing, students are allowed to edit and revise their answers synchronously in the private editing box in Q&H, Plan, and Reflect. Furthermore, the shared workspace in Pre-model and Model is able to receive inputs from multiple devices to permit concurrent multi-user operations (Yang & Lin, 2010), such as co-constructing models, mutually reviewing and revising models in real time. The design intends to encourage students to pursue the common goal of creating joint models through a collaborative and interactional process. The system allows peer review of the individual models within the private modelling space. Coupled with a chat tool, each phase supports students' peer discussion synchronously.

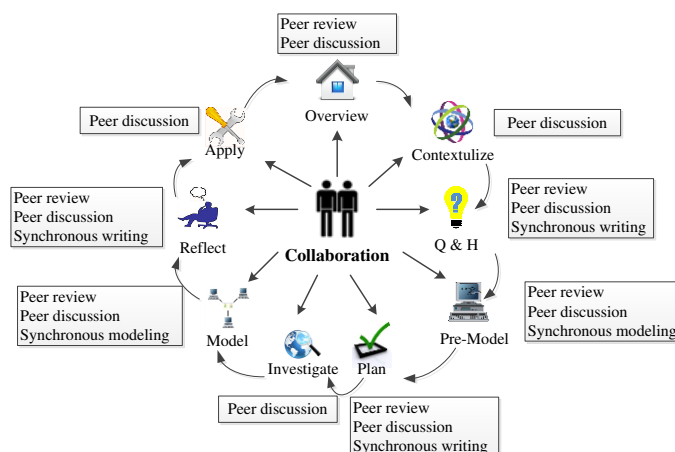


Figure 2. CSCL Design Elements Integrated in the Inquiry Phases within the CSI System

The system also integrates other CSCL design elements to facilitate ease of use. The task checklist in Overview facilitates students within the same group to keep track of their progress in carrying out activities in real time. The online member window can display students' social presence to facilitate coordination and collaboration between students from different spatial locations (Janssen, et al., 2007). An email box available in both the teacher and the student modules is used for exchanging of ideas, written materials and other information.

Methods

Participants

The trial instruction was conducted by four science teachers from a junior secondary school in Singapore. These teachers had rich and extensive teaching experiences and had attended most of regular meetings of CSI project. Hence, they had some understanding of the system development and its underlying pedagogy. A total of 201 secondary 1 (Grade 7) students from 9 classes participated in this study. During the instruction, students were mostly organized in pairs ($N_{\text{pair}}=96$), with only three groups working in triads. The school had excellent computer facilities, with each student owning and utilising a MacBook for daily lessons in the various subjects.

Lesson Design

The class studied the topic of “Diffusion and Osmosis”. Science teachers, researchers and collaborators co-designed and finalized the lessons. The study was conducted as two 50-min consecutive sessions for each class. The lesson sequence was executed in the following order: Overview → Contextualize → Q&H → Pre-model → Investigate → Reflect → Apply. After students reviewed the textual information (e.g. brief description of the project, learning objectives, tasks) in Overview, they were introduced to a story related to the topic in Contextualize. In Q&H, the students were engaged in forming their answers to the questions. In Pre-model, the students performed individual and collaborative modelling after observing two videos (a. the diffusion of red ink in the water; b. the changes of egg in different solutions). In Investigate, students interacted with three simulations and answered guiding questions. The simulations were: a) the diffusion of sugar in the water; b) the movement of water molecules in osmosis; c) a dynamic simulation for observing the results of osmosis. Finally, in Reflect and Apply, the students reflected, refined and validated their conceptual understanding. Except for the Contextualize and Apply, the activities in other phases were conducted in collaboration.

Data Sources and Data Analysis

The data sources included pre- and post-tests, field notes, observation sheets, interview transcripts, on-site videos and audio transcripts, learning artefacts, and chatting information (system log). The use of different data sources provided complementary information and enabled a more thorough and reliable understanding of students’ performance observed in CSI lessons. In data analysis, a paired-samples t-test was conducted to identify the difference between pre-test and post-test scores; an item-by-item analysis of the test responses was carried out to further expose misconceptions amongst students. Furthermore, students’ responses to Q&H and Apply, pre-models, and reflections were scrutinized to uncover the conceptual transformation process by the use of coding methods. The chatting were further analysed to probe students’ performance on collaborative work. Only data from the participating students in all sessions and activities was used in the analysis.

Pre-test and post-test

In the study, identical pre- and post-test instruments were used at the beginning and concluding stages of the lessons (10 minutes for each). The 10-paired questions in tests were built on the previously validated two-tier “Diffusion and Osmosis Diagnostic Test” (Odom & Barrow, 1995). In all question sets, the A questions asked for students’ direct answers to a given scenario (the “what” questions), while the B questions focused on students’ explanations to the answer in A question (the “why” questions). The questions covered all the content at the appropriate difficulty levels that the teachers expected the students to learn in the topic of “diffusion and osmosis”. The tests can be retrieved from: <https://sites.google.com/a/wimvt.info/wimvt/teacher-pedagogical-resources/Diffusion-and-Osmosis-Test>.

Q&H and Apply answers

A coding method was employed to assess the understanding levels of conceptions through categorizing answers in Q&H and Apply into five categories. The categorization was built on the knowledge integration scoring rubric (Linn & Eylon, 2011), which is an appropriate and effective way to obtain how students developed the existing ideas to more normative and coherent understanding (Liu et al., 2008). The categories were refined and modified as follows: L_1 : students have irrelevant ideas and make incorrect links between context and their explanations (incorrect answers); L_2 : students have relevant ideas and make partial correct links between context and their simple explanations (partial correct answers with simple explanations); L_3 : students have relevant ideas and make correct links between context and their simple explanations (correct answers with simple explanations); L_4 : students have relevant ideas and make links between context and their elaborated explanations (correct answers with elaborated explanations); L_5 : students have complete relevant ideas and make links between context and their elaborated explanations, as well as related contexts (correct answers with extended elaborated explanations). Frequency of each category were calculated and analysed through this coding approach.

Pre – models

To evaluate students’ modelling performance, we classified the quality of models into three levels based on a literature review (Ergazaki, et al., 2005; Grosslight, et al., 1991; Halloun, 1997): A. High Quality Models (H) refers to models containing accurate description of science concepts that involve objects with basic properties, and reflect interaction between objects; B. Medium Quality Models (M) refers to models with partially exact description of science concepts, which represent some of model components and the possible relations. C. Low

Quality Models (L) refers to models containing inaccurate description of all model components. If the models are built at the macroscopic level, they are marked as sublevel “1”, while models built at the particulate level are marked as sublevel “2”. For example, if the students draw high quality models at the particulate level, the models are coded as H₂. Furthermore, work completion is considered as another indicator for assessing students’ modelling performance.

Reflections

We coded the responses to Reflect into four categories: verification, explanation, improvement and critical reflection. The method was modified from the principle of reflective thinking (Kember, et al., 2000). “Verification” refers to the reflection with simple confirmation of the artefacts. “Explanation” focused 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 enabled researchers to probe the degree of students’ thinking and understanding of their work in the inquiry.

Peer discussions

We had extracted and analysed available peer discussions (taking one sentence as a unit) generated in the chat box to explore students’ performance on involvement and collaboration in each phase and to observe the process of conceptual understanding transformation. The method was developed and refined based on the principles of good feedback (Nicol & Macfarlane-Dick, 2006). Aligning with these principles, the peer discussions were classified into A. task-oriented, B. knowledge-oriented, C. strategy-oriented, D. assessment-oriented discourse and E. affection-oriented discourse. 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 definition, explanations, and reasoning. Category C provides strategic methods to complete the task. Category D provides constructive comments on the work. Category E provides comments with intentions to improve motivation of group members.

Video and audio data were transcript and analysed to reveal students’ interactions in the class, as well as their learning performances in the activities. Furthermore, interviews with the teachers (n=4) and randomly selected students (n=16) were administrated to collect feedback on the system implementation. The data were coded and analysed independently by the first author and another researcher. The inter-rater reliability coefficient for these coding was $r = 0.93$.

Findings and Discussions

Pre-test and post-test achievements

In this section, 139 valid tests were received. A one-way ANOVA was conducted to compare the initial levels of the classes. The results indicates that students’ prior knowledge varied very little among the classes, as $F(7, 132) = 2.773$, $p = 0.01$ (the priori alpha level was set at .01). This implies that the students started the lessons with the equivalent cognition levels. Paired-samples t-test analysis indicates that the post-test scores were significantly higher than the pre-test, which received $M = 12.97$, $SD = 2.774$; $t(36) = -4.299$, $p = 0.000$, compared to the pre-test ($M = 10.62$, $SD = 2.792$). It suggests, in general, CSI lessons enhanced the understanding of diffusion and osmosis in most of the pupils.

The Item-by-item analysis shows major conceptual changes concentrated on responses on the reasoning of diffusion, the judgment of solution’s concentration, the identification of osmosis and the effect of osmosis (item 2B, 4A, 5B, 7A, 9A, and 9B). Specifically, a significant finding is that students attained great understanding of the mechanisms of the scientific phenomena after the lessons. In the pre-test, we found that approximately 40.8% of students failed to answer correctly the “why” questions while they succeeded in answering the “what” questions. It suggests that students often could predict the correct outcome but had relatively little understanding about the underlying mechanisms. This may further demonstrates that students’ knowledge on the key conceptions remained at the superficial level before the lessons. After the lessons, only 15.3% of the students continued to have difficulties in responding to “why” questions.

The high rate of failures to answer the questions on most distracters exposes the prevalent misconceptions in both pre-and post-tests. Before the lessons, the high rate of failures was caused by distracters distributed on most of the items (14 misconceptions were identified). After the lessons, the rate of failures due to distractors reduced dramatically, with only two items (item 3B and 4B) continuing to receive high rate of failure due to present distracters. Most of the students wrongly believed that the particles would cease moving when equilibrium concentrations had been reached. Hence, it reveals that students still had some degree of confusion of how the process of diffusion influences the particles’ movement, and vice versa.

Students’ performance on the inquiry

Q & H

In Q&H, Question 1 (Q_1) asked students to propose a reason for the smell of the cooked fishes from a distance (diffusion). Question 2 (Q_2) asked students to propose a reason on why drinking seawater killed the sailors faster than expected compared to not drinking any water at all (osmosis). In sum, the responses to Q_1 were usually more correct and more complete compared to responses to Q_2 . Q_1 received 38.6% of L_2 response and 33.3% of L_3 response, compared to Q_2 which received 56.1% of L_1 responses. The results seem to confirm our findings in pre-test that students had difficulty in reasoning scientifically and deeply about the basic processes of diffusion, because they provided (partially) relevant answers with simple explanations on the reasons for Q_1 . On the other, the result is also consistent with the initial findings which had already suggested that a large percentage of students struggled to comprehend osmosis and its mechanism. As osmosis contained more invisible attributes and processes, students failed to connect the macroscopic observations with the mechanism of osmosis at the microscopic level. Only a fraction of students (Q_1 with 14% of L_4 and Q_2 with 3.5% of L_4) managed to answer them correctly with elaborated explanations. An interesting finding was observed that although the general performance on responses to Q_1 was better than Q_2 , a fraction of students (3.5%) performed better in Q_2 compared to Q_1 . These cases mostly existed among groups in which the pairs interacted with each other frequently as we observed.

Pre-model

In this section, students generally responded to the individual modelling tasks positively with the high percentage of work completion (80%). However, 70% of the students failed to finish the collaborative models. Meanwhile, the division of labour on collaborative modelling was not equally distributed between group members. There are three possible reasons to these observations: 1) limited class time affected students' group modelling. 2) few opportunities were offered for students to participate in synchronously collaborative activities in previous lessons. 3) collaborative scripts were not provided in time by the teacher to guide and structure students' collaboration.

Data analysis of their resultant models suggests that most students constructed the individual models at the particulate level but varied on the model quality. It reveals the different representations that individual students had about the concept of diffusion and osmosis as found in Q&H. Positively, more than half of the students drew the middle quality of diffusion models ($M_2=54.8\%$). However, some issues were found: 1) the models lacked the necessary annotations of each model component; 2) most of the models described the result of diffusion with water and ink particles in a container, but 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.

Variation of model quality also existed among the osmosis models, with M_1 and M_2 , taking up 40%, and L_2 taking up 35%. The significant proportion of M_1 and M_2 models may indicate that a significant part of students, who had viewed and observed the videos, had acquired a more appropriate perception of the process of osmosis and developed more accurate knowledge about osmosis. However, some students failed to distinguish the functions of model components (e.g. the egg yolk membrane as the partially permeable membrane, and the net movement of water molecules through the partially permeable membrane) although they knew that osmosis would happen when the egg was immersed in the corn syrup, as inferred from the significant proportion of L_2 models. We also notice that students' active engagement in peer review and discussion of models resulted in the improvement of their prior knowledge of osmosis.

Reflect

Responses in the Reflect varied, consisting 30.28% of "verification", 23.33% of "explanation", 18.33% of "improvement" and 28.06% of "critical reflection". Although 30.28% of students reflected upon their artifacts through "verification", the rest of the reflections indicated some deep thinking of the artifacts. Students' "explanations" were mainly concentrated on: 1) providing supplementary comments on interpreting the process of diffusion and osmosis at particulate level. 2) writing the definition of diffusion and osmosis, in order to show their current understanding. 3) explaining the effects of diffusion and osmosis correctly. Students that gave the "explanation" reflections achieved better understanding of diffusion and osmosis, especially with respect to the understanding of the definitions, the movement of the particles as the physical basis, and the results of diffusion and osmosis. They could link the key concepts or terminologies with the context after receiving more knowledge from Investigate. Students that gave "improvement" reflection generally thought that they should revise and improve their artefacts, it means they realised the misconceptions they held in their prior knowledge. Students that gave "critical reflection" indicated that they succeeded in developing a more sophisticated understanding and presentation of the target concepts.

Apply

Three questions, Q_1 , Q_2 , and Q_3 , were provided for students to answer in the Apply phase. Q_1 concerned the possible outcome of placing the microorganism *Elodea* into the ocean. Q_2 was about the reasons on vegetables becoming soggy when salad dressing was applied. Q_3 asked for the explanations on killing weeds using salt

water. The results show that Q_1 and Q_3 received more L_2 (Q_1 : 30.3%, Q_3 : 30.5%) and L_3 answers (Q_1 : 40.5%, Q_3 : 34.6%), than L_1 answers (Q_1 : 8.9%, Q_3 : 15.3%). Furthermore, a number of students attained L_4 (Q_1 : 20.3%, Q_3 : 19.6%). The presence of L_4 answers means that these students managed to apply their knowledge learnt from the lessons in the new context. However, students seemed to have difficulties in understanding the nature of the dressing relative to the vegetables in Q_2 , as most of the students defined the dressing as the hypotonic solution compared to the cellular content in the vegetables (56.3% L_1 , 12.5% L_2 , 18.8% L_3 , 12.5% L_4). This issue indicates that it may not be advisable to assess students' new acquired understanding within a new context that has little connection with the information in Investigate. In this case, it is easier for students to compare between liquid solutions (e.g. ocean, salt water) with hypotonic, isotonic or hypertonic relationships. However, students were hesitant in linking their new knowledge between salad dressing (colloidal mixture), and vegetables (cellular matrix).

Students' performance on the collaborative work

Peer discussions by students were mainly categorised as task-oriented, knowledge-oriented, strategy-oriented, and assessment-related discourse based on our data analysis. The distribution in these categories in the specific inquiry phases depicted in Table 1.

Table 1. The percentage of the peer discussion in the inquiry phase

Category	Q&H /%	Pre-model/%	Investigate/%	Reflect/%
Task	34.2	50.5	41.2	48.3
Knowledge	35.6	9.0	42.0	32.2
Strategy	23.2	33.5	11.9	11.9
Assessment	7.0	7.0	4.9	13.1

Among these discourse, task-oriented discourse was rated highest (42%). This indicates that students were primarily concerned with establishing work procedures to complete different learning related tasks. Furthermore, the proportions of task-oriented discourse were found to be the highest in Pre-model (50.5%), followed by Reflect (48.3%), Investigate (41.2%) and Q&H (34.2%). The discourses were found to focus on managing the division of labour and the procedures to complete the tasks. Students engaged with task-oriented discourses were generally observed to perform better in time management, with most of them posing artefacts of higher quality. Therefore, students' frequent engagement in task-oriented discourse is associated with resultant higher work quality and efficiency.

The proportions of knowledge-oriented discourse were found to be the highest in Investigate (42%), followed by Q&H (35.6%) and Reflect (32.2%). These discourses were mostly associated with knowledge sharing and the construction of the new knowledge between team members (van Aalst, 2009). It was found that students who had limited prior knowledge of diffusion and osmosis tended to discuss and share their existing knowledge with their team members at the initial stage of inquiry. For example, in Q&H phase, students knew the term "Diffusion" but lacked adequate knowledge on its mechanism. Thus, questions were raised, such as "what kind of particles diffused into the air", and "what is the trigger for particles in diffusion". Their knowledge-oriented discourse also concentrated on negotiating the answer to Q_2 . Most students developed their naïve understanding of osmosis based on their prior knowledge. The terms like "saltwater", "organs", "dehydrate", "absorb" appeared in their chatting. In Investigate phase, it was noticed that while most of the students used terminologies to respond to guiding questions, they were generally observed to work together to synthesize the understanding of new abstract concepts. They tend to discuss on the best definition and mechanism of diffusion and osmosis, identification of solution concentrations, movement of particles and the energy associated with the molecules' movements. Hence, the frequent discussions on interpreting new knowledge and extending the prior knowledge have improved their understanding of diffusion, with greater gains in understanding of osmosis. In Reflect phase, the discourses indicated that students started relating their new knowledge with reference to the previous work. Through reflection, they improved their new understanding and they could apply new knowledge in revising the previous work into better quality.

The strategy-oriented discourse took place mostly at the stage of Q&H (23.2%), Pre-model (33.5%) and Investigate (11.9%). The discourse provided partners with resources or the methods to complete the activities. In Q&H, most of the strategy-oriented discourse emphasized the ways to search for relevant information. However, some students were observed to refer either to the textbooks, Internet or the teacher when the team member(s) did not reach a consensus on their ideas. In Pre-model, students discussed with their team member(s) on choosing the appropriate drawing tools, and how to conduct individual drawings and group drawings. Generally, these discourses directed them to find the best way to obtain the answers and to confirm the quality of modelling work. Particularly in Investigate, it was observed that when some of the students did not gain knowledge about the new concepts, the strategy-oriented discourse would focus on obtaining the answers through available resources. This strategy however, resulted in a fraction of students turn to the Internet to get the answers directly rather do any further reasoning and deduction on their own.

Students' assessment-oriented discourses were distributed with the lowest rate at each stage (7.0 % at Q&H, 7.0 % at Pre-model, 4.9% at Investigate and 13.1 % at Reflect). The comparative higher rate appeared in Reflect, as students were allowed to review each other's reflections and the students generally had more confidence of their conceptual understanding. We can conclude that the rate of assessment comments would increase with the improvement of their conceptual understanding. At the beginning of the lesson, students might not have a good understanding of the concepts and concerned about potentially providing incorrect assessments on their partners' work. When they obtaining know knowledge in Investigate, they were observed to be spending most of time to check or revise their prior knowledge. Therefore, students' assessment-oriented discourse received the lowest coding at the stage of Investigate. Another reason we can infer is that the guiding questions came in the form of multiple-choice. Hence, it is neither appropriate nor possible for students to comment on their partners' ideas and reasons of their choice without reviewing the explanations.

Teachers and Students Attitudes towards CSI lessons

The interview transcripts indicates that both teachers and students conveyed overall positive attitudes toward the CSI implementation in the science class. After conducting CSI lessons, the teachers recognize that the lessons have its unique educational value on fostering conceptual understanding and developing collaborative learning skills in pupils: 1) CSI can be an active and innovative pedagogy for science instruction; 2) the lessons can improve students' involvement in the activities, and lead them towards new conceptual understanding through various forms of manipulating data and information, collaborative work, peer review and discussion; 3) students are given more opportunities to exhibit their thoughts about topic (e.g. do peer discussion with a partner instead of in front of an entire class). Overall, the teachers are interested in continuing to use the system for other scientific topics to probe more about potential value of the system in science education. The students comment that they are more motivated when they were participating in the activities that were facilitated by real-time chatting, modelling and visualization. In the lessons, their learning can be guided by both instruction and questions within the system. Meanwhile, peer discussion, review and social presence also help them to keep at pace with their team member(s), which improve their time management skills and collaborative learning skills. Furthermore, they benefit from the activities in Pre-model and Investigate. The Pre-model has been identified as the most interesting and engaging stage for students, as it provides an avenue for them to explore and discuss in great depth what they observe and construct. The simulations in Investigate provide important information for them to learn new ideas such that when they were answering the guided questions, they can manipulate the simulations to review the results and then check whether the answer agrees with the simulation result.

Conclusions and Further Work

In summary, the CSI system has been demonstrated as a valuable application for enhancing students' conceptual understanding if the lessons are well designed and implemented. During the collaborative inquiry process with the system, students were provided with more opportunities to deal with the complex problems. Students' conceptual understanding are mutually improved and elaborated which are the outcomes associated with the use of multiple CSCL design elements. Besides the great improvement on the post-test achievement, students' conceptual changes were revealed in the inquiry process progressively. It can be depicted as: eliciting and applying prior knowledge in Contextualize and Q&H (exposing misconceptions) → transferring knowledge from the view of macroscopic level to particulate level in Pre-model (exposing misconceptions and establishing the microscopic view of representing the scientific phenomena) → obtaining new knowledge at particulate level through Investigate (acquiring normative ideas of the scientific phenomena) → revising and improving prior knowledge by reflection (Revising prior knowledge) → reinforcing new knowledge through their applications in the new problematized context (elaborating new understanding). The presented method of learning also enables teachers to trace students' progress in inquiry activities, their status of conceptual understanding, as well as to identify their learning difficulties in particular phases (e.g. group modelling, responses to Q₂ in Apply) as we discussed in the above section. In lessons, students have more opportunities to participate in various forms of collaboration as they become more engaged in CSI activities. Students were particularly more active with respect to collaborating with their team member(s) in Pre-model, Investigate and Reflect phases. In conclusion, the multiple CSCL design elements that are integrated at the inquiry phases in a flexible way supplement the different demands in the collaborative inquiry.

Our future research will focus on the instruction of biochemistry topic "photosynthesis". More emphasis will be paid on teachers' influence in the lessons through comparisons on the system implementation and instruction among different teachers. The studies intend to investigate the relations between students' performance and teachers' teaching methods, strategies, as well as their teaching belief on CSCL learning environment.

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