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Collaborative Inquiry with a Web-Based Science Learning Environment: When Teachers Enact It Differently

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ABSTRACT

Though discussion of the teacher factor in ICT-enabled science learning abounds in the literature, the investigation of Teacher Enactments (TEs) of ICT-facilitated lessons through exploring teaching practices is still under-explored and under-recognized. Current studies are still lacking in evidence-based findings of TEs based on the investigation of teaching practices. This study explores the TEs of science lessons supported by a web-based learning platform, namely, Collaborative Science Inquiry (CSI), by two experienced teachers in their respective classes. The CSI system is built on a model-based inquiry framework integrated with Computer-Supported Collaborative Learning (CSCL) elements. The CSI lessons selected were on the topic of “Diffusion and Osmosis” in Grade 7. Through examining the ways in which teachers instructed, questioned, and interacted with the students, we identified the commonalities and differences in TEs that subsequently influenced students’ conceptual understanding and their involvement in collaborative inquiry. The factors that contributed to these discrepancies were then discussed. Implications were proposed to inform the use of complex ICT tools in the science classroom.

Keywords
Collaborative inquiry, Science learning, Teacher enactment, Collaborative Science Inquiry learning environment

Introduction

With a burgeoning volume of work on the integration of Information and Communications Technology (ICT) tools into science education, much research has explored students’ learning processes and performances in the ICT-facilitated science classroom (Buckley et al., 2004; Jacobson & Archodidou, 2000). Recently, research focus has been placed on investigating the relationship between teacher attributes (e.g., technological pedagogical content knowledge, beliefs and attitudes) and their teaching practices with the intention to improve the quality of ICT-facilitated instruction (Song & Looi, 2012; Voogt et al., 2013). Despite the rapid technological advances, pedagogically effective and sustainable use of ICT tools in education is still far from reality (Dimitriadis, 2010). In the ICT-facilitated classroom, teachers need to coordinate ICT and non-ICT activities and artifacts, and handle different levels of social interactions (Dillenbourg, Järvelä, & Fischer, 2009). Hence, Teacher Enactment (TE) of the ICT-facilitated lessons in the classrooms has been regarded as a critical indicator for evaluating teacher performance on ICT integration in the classroom.

An in-depth understanding of teacher practices is indeed crucial for the successful implementation of ICT-based initiatives, yet most studies only employed self-reported teaching beliefs and practices as the sources of evidence to prove these issues (Mama & Hennessy, 2013). The dominance of and constraints inherent in survey studies motivate an in-depth investigation of TE of ICT-facilitated science lessons by directly observing the actual happenings in the classroom. This study attempts to represent, interpret and compare the TEs by two experienced teachers of a lesson design that incorporated the Collaborative Science Inquiry (CSI) learning environment. Through fine-grained analysis of classroom practices, the commonalities and differences in TEs and student performances were identified. The findings can inform the effective use of ICT tools in science instruction via bridging the gap between the intended lessons and their actual enactment.

An overview of the CSI learning environment

Incorporating multiple features that support collaborative science inquiry, CSI is designed to help secondary school students (Grade 7 - 11) develop sophisticated understanding of scientific concepts, scientific skills (i.e., modeling
skills) and reflective thinking skills (Sun & Looi, 2013). CSI consists of two functional modules: Teacher Module and Student Module. Teacher Module encompasses four sections including Subject Management, Project Management, Simulation Library, and Solutions Review, with which teachers can design instructions and questions, attach simulations, manage groups, and review learning artifacts. Figure 1 illustrates the interface of “Project Management” used to create and manage inquiry-based projects. The inquiry phases of Overview, Contextualize, Question & Hypothesize (Q&H), Pre-Model, Investigate, Model, Reflect and Apply are incorporated. Teachers can select an intended inquiry phase, instantiate it with specific content and instructions, and employ modeling or visualization tools depending on the lesson objectives.

Student Module is comprised of Profile, My Project, Group Management, and Mailbox. The main tool “My Project” consists of four panes: inquiry phases, shared workspace, group members, and chat tool. Student inquiry is guided by the inquiry phases laid out on the tool bar (Figure 2). The shared workspace stores the content and tools for completing tasks at each phase. The embedded Computer-Supported Collaborative Learning (CSCL) design elements (e.g., shared workspace, chat tool, peer review, and social presence) enable students to do various forms of collaboration during the inquiry activities.

Figure 1. Interface of “Project Management”

Figure 2. Interface of “My Project”
Theoretical framework

Pedagogical model of CSI learning environment

The design of CSI is motivated by the educational benefits brought about by model-based science inquiry and CSCL. Science inquiry is a process where students ask questions, search for information, design and conduct investigations, analyze data and make conclusions, create artifacts, and communicate findings (Krajcik et al., 1998; NRC, 1996). When integrated with models or modeling, it can facilitate learners to develop deep scientific understanding, strong scientific skills and a solid understanding of the nature of science (Schwarz & Gwekwerer, 2007). Model-based inquiry that follows the sequential processes of question-hypothesis-plan-investigation-model-conclusion proves to be effective for science learning (Bell et al., 2010; Schwarz & White, 2005; Windschitl, Thompson, & Braaten, 2008) and is adopted in the design of CSI. Informed by the POE (Predict-Observe-Explain) instructional principle practiced in some Singapore schools (White & Gunstone, 1992), a Pre-Model phase that precedes the Model phase in inquiry is incorporated. The main purpose of embedding model progression (from Pre-Model to Model) into the science inquiry is to guide students to elicit prior knowledge through constructing pre-models before investigation and to elaborate models after inquiry activities. Finally, the model-based inquiry of CSI incorporates eight phases that run in sequence, namely, Contextualize, Question & Hypothesize (Q&H), Pre-Model, Plan, Investigate, Model, Reflect, and Apply.

Besides the presence of a Pre-Model phase in inquiry, the uniqueness of CSI also lies in the integration of CSCL elements. Informed by established design principles and applications (e.g., WISE, CMapTools, Co-Lab, and ModelingSpace) that incorporate CSCL ingredients to further empower learning (Avouris et al., 2005; Cañas, Novak, & González, 2004; Linn, Clark, & Slotta, 2003; van Joolingen et al., 2005), synchronous modeling and editing, shared workspace, peer review, chat tool, and social presence are employed in the CSI inquiry. In Overview and Contextualize, online members can view the problem statement presented. Students work in small groups to respond to the inquiry questions and problems. Students are allowed to edit and revise their answers synchronously. The shared and synchronized workspace in Pre-Model and Model allows for inputs from multiple devices to support concurrent multi-user operations, such as co-constructing, reviewing or revising models in real time. The design is intended to encourage students to pursue the common goal of creating joint models through processes of collaboration and interaction. Coupled with a chat tool, each inquiry phase supports synchronized peer discussion. Thus, the unique feature of the CSI system is the marriage of relevant CSCL functionalities with each inquiry phase, such that each phase can be utilised in a flexible way towards collaborative inquiry learning.

ICT integration into teaching and learning

The way in which technology actually appointed in a classroom for teaching and learning is a critical measurement of its success. Ertmer (2012) distinguished two types of barriers that hinder ICT integration. First-order barriers include resources, training and support, and second-order barriers include teacher confidence, beliefs and their perception of the technology. With advances in ICT and support from policymakers and administrators, the first-order barriers are gradually lessened, and now the focus is to address the second-order of barriers. Existing research has discussed teacher perception of the technology and their pedagogical approaches to ICT integration intensively. Baylor and Ritchie (2002) advocated the use of ICT as cognitive and integral tools in the curriculum to support the development of existing cognitive structures and new knowledge in students. Moreover, constructivist approaches of instruction, such as conducting learner-centred activities, asking exploratory questions, and providing flexible scaffolds are advocated in ICT-facilitated lessons (Hermans et al., 2008). Through these strategies, students will become active learners who benefit more in both knowledge and skills development.

The design features of CSI are intended to guide the teachers to integrate ICT tools in a more constructivist way. The CSI inquiry encourages students to pose hypothesis, investigate scientific phenomena, construct scientific models, collect evidence and reflect upon the processes in and out of classroom. This may enhance learner autonomy in learning. It offers opportunities for students to discuss solutions, co-construct knowledge, assess artifacts, and interact with teachers. With frequent use of CSI, teachers’ traditional pedagogical approach to ICT integration will be shifted to the constructivist approach.

Teacher enactment in collaborative inquiry learning environment

To explore how the teachers use CSI in the classroom, we identified some indicators based on a literature review. Previous research showed that good TE could not be achieved without appropriate facilitation. Crawford (2000)
found that teacher responses to the key instructional events and their roles acted in the inquiry phases were the key factors for inquiry-based instruction. He suggested that teachers should play a wider range of roles in facilitating inquiry activities. Abdu et al., (2012) advocated that teachers should serve as moderators to provide three types of assistances (i.e., presenting challenges, supporting group collaboration, and scaffolding meaning making) to establish successful teacher-student interactions. Onrubia and Engel (2012) pointed out that patterns of teacher assistance with the use of macro-scripts affected students’ plans, organization and coordination of work, and levels of achievement in collaboration. Chiu (2004) found that teachers’ initiating interventions, evaluating student’s work, and using higher levels of cognitive assistances could generate positive educational effects. From these studies, it is known that the ways teachers assist, respond to, and intervene in students’ work are important indicators for evaluating TE, and thus they are used in our study.

These studies also show that patterns of teacher-student discursive interactions reflect the nature of classroom activity (Jones & Charles, 2007). Three categories of teacher verbal behavior are identified, namely, instruction, question, and scaffoldings for mediated-learning (Gillies, 2006). Instructions are lectures that provide content facts and explanations, giving expression onto teacher ideas and opinions (Flanders, 1970). Questions are enquiries of content or procedures with the intent that students can answer. Mediated-learning is a way of interaction between the teacher and students. As a mediator, the teacher may provide different scaffolds through the form of micro- or macro-scripts to regulate the processes through the sequencing and distribution of roles and activities (Weinberger & Fischer, 2006). Teachers may also provide hints, suggestions, and reminders in the form of prompts to help students complete tasks (Ge & Land, 2004; Morris et al., 2010). Moreover, teachers can scaffold potential learning through challenging students’ thinking and encouraging them to consider alternative perspectives. When teachers frequently encourage autonomous behavior by students, students show more initiative and willingness to explore activities (Prieto et al., 2011). These factors influence the completion and quality of student work in ICT-facilitated lessons.

Research questions

The goal of this study is to generate teaching strategies that can improve the enactment of CSI lessons via characterizing and comparing TEs by different teachers and exploring the impact on students’ science learning. To achieve this goal, the following research questions will be addressed:

- What were the major differences between the desired TEs as proposed in the lesson design and the actual TEs as observed?
- What were the major differences in TEs by two different teachers when they implemented CSI lessons?
- How did different TEs affect students’ performance in collaborative inquiry?

Methods

Participants

In this study, two science teachers - Katherine (Class K, n = 21) and Charley (Class C, n = 20) (pseudonyms) and their respective classes from a junior secondary school in Singapore were selected as the participants. Katherine and Charley were comparable in their ages, length of teaching experiences, and educational backgrounds. Both possessed good ICT skills and used ICT as their instructional tools in the classroom. Through attending regular CSI project meetings, the two teachers had gained some understanding of the system design and its underlying pedagogy. Both teachers had strong enthusiasm in transforming their pedagogical orientation from the traditional way to the constructivist way. In the collaborating school, each student owned and used a MacBook for his or her daily lessons. In CSI lessons, students mostly worked in pairs using their personal laptops.

CSI lesson design

The topic of “Diffusion and Osmosis” was identified as one of the most difficult topics in Grade 7 science curriculum (Odom & Kelly, 2001), and was thus selected for implementation and analysis. The researchers and teachers co-designed CSI lessons consisting of two consecutive lessons (50 minutes per lesson) which followed the order of (Overview) → Contextualize → Q&H → Pre-Model → Investigate → Reflect → Apply (Table 1).
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Proposed Teaching Strategies for TEs</th>
<th>Form of Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview</td>
<td>• Introduce learning objectives&lt;br&gt;• Emphasize tasks in different inquiry phases&lt;br&gt;• Remind students to click task checklist when they have completed their work</td>
<td>Individual</td>
</tr>
<tr>
<td>Contextualize</td>
<td>• Present and extract the key information&lt;br&gt;• Pose guiding questions</td>
<td>Individual</td>
</tr>
<tr>
<td>Q&amp;H</td>
<td>• Encourage peer discussion&lt;br&gt;• Assist in and coordinate students’ synchronous writing&lt;br&gt;• Review students’ collaborative work and provide assistance</td>
<td>Collaborative</td>
</tr>
<tr>
<td>Pre-Model</td>
<td>• Ask students to review “Instruction”&lt;br&gt;• Observe and assist in students’ individual modeling activities&lt;br&gt;• Encourage and assist in peer review and peer discussion of individual models&lt;br&gt;• Encourage and assist in peer discussion and peer work in building models together&lt;br&gt;• Observe, review and assist in collaborative modeling activities&lt;br&gt;• Present students’ typical models and highlight misconceptions</td>
<td>Individual and collaborative</td>
</tr>
<tr>
<td>Investigate</td>
<td>• Ask students to manipulate and observe simulations individually&lt;br&gt;• Encourage and assist in peer discussion and collaborative answering of guiding questions&lt;br&gt;• Encourage and assist in students’ collaborative work</td>
<td>Individual and collaborative</td>
</tr>
<tr>
<td>Reflect</td>
<td>• Emphasize critical reflection on work produced in Pre-Model and Q&amp;H&lt;br&gt;• Encourage students to reflect upon their process of conceptual changes, if any</td>
<td>Individual and collaborative</td>
</tr>
<tr>
<td>Apply</td>
<td>• Emphasize and assist in individual work</td>
<td>Individual</td>
</tr>
</tbody>
</table>

In the first lesson, students reviewed the textual information in Overview. In Contextualize, a story was introduced to arouse students’ interests and motivation. In Q&H, students discussed and articulated their responses to two inquiry questions posed. In Pre-Model, students watched two videos of lab experiments (the diffusion of red ink in water and the changes of raw egg in corn syrup and in water) to gain some ideas on the macro-phenomena of diffusion and osmosis. Students then were required to build models to represent the processes of diffusion and osmosis at the particulate level in the individual modeling space, and to collaborate with their partner to elaborate their shared models in the group modeling space (Figure 3). In the second lesson, the teacher summarized students’ work in Pre-Model and Q&H, and selected some work for plenary class sharing. Then students continued their inquiry, interacting with three simulations and answering the questions based on their observations of the virtual experiments in Investigate. After this, each student did a self-reflection on their conceptual change and learning process. Finally, students consolidated their new understanding via answering questions in Apply.

![Figure 3. Interface of pre-model](image-url)
Data sources and analysis

To answer the research questions, a case study approach was adopted. In analysis, the first focus was on teacher verbal interaction and assistance to specific students or groups. The data collected include videos and audios of classroom activities (e.g., inquiry activities, group activities, and individual activities) and field observation notes (where teacher questions, scaffoldings, and responses to students were recorded) taken by two researchers. Based on these data, the types and frequency of teacher verbal behavior relative to instructions, questions, prompts and challenging students’ ideas in key instructional events (e.g., Q&H, Pre-Model, Investigate, etc.) were identified and analyzed. The recipients (i.e., the verbal behavior as to who it was targeted at, namely, to the individual or group, or class) were also coded (Prieto et al., 2011). To identify the differences and commonalities in the TEs, a diagram was constructed to represent teacher verbal behaviors, such as how they performed in instruction, how they scaffolded students’ group work, and what kind of scaffoldings they offered at the different phases of inquiry. To identify the roles teachers played in the CSI lessons, the patterns of teacher facilitation (e.g., frequency, content, and recipients) were also examined at each phase (Onrubia & Engel, 2012).

To explore the impact of TE on student learning, data on student test scores, learning artifacts in CSI and their performance in collaborative work were collected and investigated. A pre-test and post-test (10 minutes for each test) using identical test items were adopted to probe students’ conceptual change. In the test, 10 paired questions were designed based on the validated two-tier “Diffusion and Osmosis Diagnostic Test” (DODT) (Odom & Barrow, 1995) (The tests can be retrieved from: https://sites.google.com/site/futureschoolcsinquiry/pedagogical-resources/diffusion_osmosis_test). Each correct answer was assigned 1 mark, so the total score was 20 marks. A paired-samples t-test was conducted to examine students’ conceptual change in each class. Student learning artifacts created in Q&H, Investigate and Apply, individual and collaborative pre-models and reflections were mined and assessed as to identify their completion rates and quality levels. Finally, students’ involvement in collaborative inquiry tasks and peer discussion were examined. Figure 4 shows the structure of the data sources and analysis.

The transcription and analysis of the qualitative data was conducted by the two researchers. The inter-rater agreement reached 89.15% for teacher verbal behavior, 92% for patterns of teacher facilitation, and 95% for students’ learning artifacts, and 93.46% for student performance.

Findings and discussions

Teacher verbal behavior (VB)

Table 2 shows Charley’s and Katherine’s verbal behaviors during their TE. As we observed, Charley acted as a guide and mentor who offered instructions for specific tasks before the activity. Being not frequently involved in students’ peer discussion, Charley spent most time in prescribing scripts and walking around the class to check and monitor students’ progress. Consequently, 6 instructions and 18 scripts were delivered. Katherine was involved in peer discussion in most groups, explaining the tasks to the students. More prompts (38) were generated in her lessons. To
guide students’ conceptual understanding, Katherine often challenged students’ existing ideas through questioning (3). Thus, in CSI lessons, Katherine acted as a motivator, diagnostician and collaborator in students’ collaborative inquiry.

<table>
<thead>
<tr>
<th>Categories of VB</th>
<th>Instructions</th>
<th>Questions</th>
<th>Mediated-learning</th>
<th>Scripts</th>
<th>Prompts</th>
<th>Challenging ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charley (Class C)</td>
<td>6</td>
<td>3</td>
<td></td>
<td>18</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Katherine (Class K)</td>
<td>3</td>
<td>3</td>
<td></td>
<td>15</td>
<td>38</td>
<td>13</td>
</tr>
</tbody>
</table>

**Charley’s verbal behavior**

As Figure 5 shows, all the verbal behavior observed in Charley’s lessons was targeted at the class level. This indicates that he laid great emphasis on classroom management through offering task-related scripts and procedural prompts (9 instructions and 34 mediated learning scaffoldings with 18 scripts and 16 prompts). He tended to manage the class in the stages of pre-test, system login, overview and inquiry (i.e., Q&H, Pre-Model, and Investigate). The regulation of group and individual work was neglected as there was little talk directed to individuals or groups. Before the inquiry, Charley went through all the tabs by introducing the purpose, procedures, and sequence of the tasks at each phase. Strategies on the use of chat tool, peer review and assessment, and collaborative modeling were also elaborated. During inquiry, he spent most of the time providing methods and procedures for task completion in a step by step manner, such as:

Charley: Now I have two persons, later you will see your name there and your partner’s name there. For example, you can key in one sentence. Then your friend thinks that “I can improve your sentence”. So “my friend said that …” (types on the system) and so you can continue, are you clear?
Charley: So to prevent overwrite of your answers, there is one way. You and your partner try to strategize it. You key in the answer to the first question, and then your friend keys in the answer to the second question. When you have finished, you tell each other you have finished, and then you go and check, and edit (the answer to the other question). Then you won’t overwrite each other’s answers.

Although most students managed to follow the instructions and complete the activities assisted by the scripts and prompts provided, few scaffolds were offered to groups and individuals. In several groups, some low ability students were unclear of what they were expected to do in the tasks. Even though they raised their hands for help, Charley did not attend to these requests and continued to move rounds among groups as he focused more on the progress of the whole class. In addition, his strict management of time made these students nervous. Peer discussion was also interrupted. This led to the emergence of passive attitudes, relatively low work completion rate, and infrequent peer interaction in some groups.

**Katherine’s verbal behavior**

Unlike Charley, Katherine was always busy walking through the groups, assisting groups or individuals at each inquiry phase. As Figure 5 shows, a similar frequency of scripts and prompts was observed at each phase. This demonstrates that Katherine had competence in managing the students’ progress. She was more frequently involved in students’ collaborative activities and discussion in inquiry, especially in the Pre-Model phase. 8 prompts for groups and 10 prompts for individuals were found at this phase. She provided immediate feedback to students’ requests and acted as an adoptive facilitator to help students complete the tasks at both individual and group levels. Compared with Charley, Katherine’s instructions and mediated-learning scaffoldings were more related to the content knowledge of diffusion and osmosis. She was good at motivating groups’ deep thinking of concepts through challenging established ideas or knowledge. Though the purposes and objectives of each phase lacked elaboration, Katherine highlighted the sequence of tasks at each phase, and steered students’ activities and collaboration towards the right direction. Generally, Katherine’s instruction was more student-centred. She created a comfortable discourse environment where she pointed out students’ misconceptions, described how she expected the students to converse, listened to students’ ideas, clarified contributions, and provided suggestions (van Zee et al., 2001).

More specifically, during her interactions with individuals or groups, Katherine focused on reviewing and commenting on students’ work. Katherine was able to comment on students’ current understanding and discussion. In particular, she guided students’ modeling tasks through reasoning the components of diffusion and osmosis,
explaining the possible changes of particles (i.e., states, sizes, and numbers) before and after diffusion, challenging students’ previous ideas, and leading them to gradually comprehend the new knowledge, such as:

Katherine: You have learnt molecules right? In chemistry, what are water molecules? Will they be exactly the same as other water molecules? If they are all water, when you draw the H₂O right, (the water molecules) should be the same, is it? Is it possible that I have another water molecule that is bigger with a lot of other atoms or things, or do they actually have the same number of atoms, and the same size of the molecule?

Encouraging students to analyse their own thinking and misconceptions helped them to predict, identify, and generate solutions. In comparison with Charley, Katherine provided her students with limited structural and procedural information before the tasks. Consequently, the students generally lacked understanding of the task purpose. Some students were confused, unfocused and unproductive in their work. This resulted in a considerable amount of requests for clarification on the task procedures and purposes from the students. So, the time management issue arose for Katherine as more class time was spent in answering students’ questions or requests.

Teacher facilitation

In CSI lessons, teachers tended to provide students with appropriate help for the completion of the tasks, the coordination of collaborative work, and the understanding of intended concepts. Figure 6 depicts the frequency of teacher assistance at each inquiry phase. From pre-test to Investigate, substantial assistance was offered by both teachers (34 times in Charley’s class; 70 times in Katherine’s class). Katherine provided more of these as she actively diagnosed and facilitated students’ problems. Charley provided general assistance to the class when he reviewed students’ work. As Figure 6 shows, Charley provided more assistance at the beginning phrases (from pre-test to Q&H). Starting from Pre-Model, Katherine provided more assistance than Charley, especially in individual and group activities. An explanation for the dramatic reduction of assistance from Charley might be students’ focusing on observing simulation and doing self-reflections and thus requiring limited structural information. With regard to the recipients, Charley’s assistance was primarily targeted at the class (24 times for class, 11 times for individuals) before and during tasks (17 times before, 15 times during, and 2 times after tasks). Katherine preferred to offer assistance to groups or individuals (25 times for class; 45 times for individuals) while they were doing their tasks (11 times before, and 59 times during tasks).
Students performance

Test achievements

Results of paired-samples t-test showed that students’ test scores of the pre- and post-test differed in both classes (Class C: $t = -4.152$, $df = 16$, $p = 0.001 < .05$; $t = -5.920$, $df = 18$, $p = 0.000 < .05$; Class K: $t = -5.920$, $df = 18$, $p = 0.000 < .05$) (Table 3). Both classes had improved their test scores after the CSI lessons. Class C had comparatively better prior knowledge ($M = 10.53$; $SD = 2.503$) than Class K did ($M = 8.53$; $SD = 2.695$). Yet the disparity of mean scores between Class C and Class K was reduced from 2 to 0.97 after the CSI lessons.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Pretest M</th>
<th>Pretest SD</th>
<th>Posttest M</th>
<th>Posttest SD</th>
<th>n</th>
<th>Difference</th>
<th>95% CI for Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc/Class C</td>
<td>10.53</td>
<td>2.503</td>
<td>14.18</td>
<td>3.187</td>
<td>17</td>
<td>-5.509</td>
<td>-1.785</td>
<td>-4.152</td>
<td>16</td>
<td>.001</td>
</tr>
<tr>
<td>Tk/Class K</td>
<td>8.53</td>
<td>2.695</td>
<td>13.21</td>
<td>2.573</td>
<td>19</td>
<td>-6.347</td>
<td>-3.022</td>
<td>-5.920</td>
<td>18</td>
<td>.000</td>
</tr>
</tbody>
</table>

The results indicate that the CSI lessons in general could improve students’ conceptual understanding. The class (Class K) who had less prior knowledge benefited more. It is inferred that:

- The CSI lessons could enhance students’ conceptual understanding through collaborative inquiry approach;
- The guided-inquiry and collaborative work in CSI lessons facilitated low ability students in learning abstract concepts;
- TEs may affect students’ conceptual understanding.

The teacher who paid more attention to diagnosing students’ misconceptions and providing assistance for conceptual understanding might be more effective in enhancing students’ conceptual understanding.

Learning artifacts

Both classes went through the designed tasks, but their task completion degree and work quality differed. This could be ascribed to the discrepancies of TEs. As aforementioned, Charley provided more instructions at the beginning phases of inquiry. Consequently, students’ performance differed in the Q&H phase. More students in Class C completed their work (73.5%) and responded appropriately to Q1 (53.4%) and Q2 (44.4%). In Class K, 60% students responded in the Q&H phase, with 50% and 35.3% appropriate answers to Q1 and Q2. This indicated that the elaboration upon skills for peer review and discussion by Charley facilitated students’ responses to questions at Q&H. For Class K, students’ confusion about the purposes and skills for the Q&H tasks resulted in students’ failure to complete the task.

In Pre-Model, Class C and Class K constructed comparable numbers of individual models (Class C: $n = 16$, Class K: $n = 14$). With regard to model quality, Class K performed better. For Class K, 10 models (out of 14) represented the components of diffusion and osmosis and their relationship links (though sometimes the relationships were partially incorrect), yet for Class C 8 models (out of 16) contained incorrect components and relationship links. This indicates that greater involvement in peer discussion and more scaffolds provided for modeling by the teacher facilitated students’ understanding of relevant concepts (i.e., the components of diffusion, the process of diffusion, and the mechanism of osmosis). For collaborative models, students’ work completion degree was not as high as the individual ones. This could be resulted from the limited class time.

Similar findings were found in Investigate. Both classes provided answers after they observed and manipulated simulations, and their knowledge about diffusion and osmosis was improved. Although Class K received lower scores in the pre-test, they responded equally well to the questions in Investigate as Class C did. For some questions, their answers were even better. In Reflect, Class C provided more critical reflections (45%) than Class K did (36.4%). Class C went through the dual processes of self- and peer-reflection directed by Charley, yet Class K solely focused on self-reflection due to the lack of emphasis and guidance. In Apply, Class C and Class K both provided highly correct answers to the three questions (83% on average). This further indicates students’ improvement in conceptual understanding as they could apply the knowledge to new contexts.
Performance in collaborative tasks

Class C

In Class C, the TE of tasks was consistent with our lesson plan. Students had clear understanding of the tasks. In the collaborative work, students sat normally and chatted with their group members using the chat tool. The classroom was quiet and in order (Figure 7a). “Noise” was only heard during the Pre-Model phase as students in the same group sat together to do face-to-face discussion. At this phase, students shared ideas with their group members to review, evaluate and elaborate their models (Figure 7b). Most groups were highly engaged in open and extended discussions. As they received substantive scripts and prompts from the teacher, they rarely asked for assistance. Below is an excerpt of a selected student dialogue from Class C:

[S1]: OK, you draw diffusion and I draw osmosis.
[S2]: Huh? This is not I do osmosis.
[S1]: Yes, which side do you prefer?
[S2]: I will take right side.
[S1]: Ok. I draw at left side. Let’s do it.

Figure 7a. Students were quiet during Q&H phase

Figure 7b. Students were talking during Pre-Model phase

Class K

In Class K, students sat with their partners throughout all collaborative activities as proposed in the lesson plan. Most students chatted with their partners in a face-to-face manner. Hence, more “noise” was heard (Figure 8a). There were multiple instances in which Katherine provided assistance to individuals and groups. Students engaged in active interaction, sharing and discussing ideas. Their collaboration was more productive in terms of knowledge understanding. They had strong willingness to invite Katherine to join their discussion to evaluate their artifacts, share understanding of concepts, and explain task purposes and procedures (Figure 8b). However, with limited knowledge and skills on collaborative learning, students requested more scripts regarding labor division and task procedures from the teacher. Here is an excerpt of a student dialogue from Class K:

[S1]: I had no idea what is the diffusion.
[S2]: That’s what I’m typing now. Diffusion is molecules spreading throughout the air from higher concentration to lower concentration.
[S1]: Higher concentration to a lower concentration. Ethan was able to smell the fishes, the cooked fishes due to diffusion of molecules ...

In Pre-Model, one student requested Katherine to review and evaluate his model quality. He responded to the teacher’s questions and followed her instruction on the modeling.

[S]: Can you help me look through this drawing?
[Katherine]: But they are all different sizes. Shall all ink particles be of same sizes? They are of the same or different particles?
[S]: They are all the same.
[Katherine]: Did you copy and paste (the particle drawing)? First copy, paste (the particle representation) and get them all of the same size.
[Katherine]: Why then have one (particle), is that clear (some student name)?
[S]: To get the same size. That’s the main aim.
[Katherine]: So you draw a lot of rings. A lot of the same size, but all concentrated in that area. That should be pretty sufficient already to represent.

Figure 8a. Students were working together in collaborative tasks

Figure 8b. Katherine was involved in students’ discussion

Conclusions

Much research has identified that teacher attitudes and beliefs toward technology and their technological knowledge and skill predict their technology use (Ertmer, 2012; Liu, 2011; Tondeur et al., 2012). Yet there is little use of classroom enactment data to explore this issue more deeply. In this study, the enactments of ICT-supported lessons by two teachers and the performance of their respective classes were analyzed and compared to further unpack the role of the teacher factor in relation to the effectiveness of complex ICT-facilitated lessons.

CSI lessons are intended to create a learner-centred inquiry-based learning environment for students’ individual and collaborative investigation of science phenomena and concepts. In general, the lessons benefited students’ conceptual learning as indicated by the improvement in their test scores. Yet a gap was still identified between the designed and enacted lessons, and this deviation could possibly be explained by teachers’ pedagogical beliefs concerning the instruction. As observed, Charley who possessed more traditional pedagogical beliefs adopted a teacher-guided inquiry approach where more structural and procedural information was provided. Though the general activity pattern enacted was in concert with the designed lesson plan, the way he conducted, assisted, and scaffolded the inquiry and collaborative tasks deviated from what was expected for a good inquiry lesson. This implies that constructivist beliefs may be accompanied by a consistently strict, teacher-directed teaching style if traditional core beliefs of didactic teaching (e.g., regarding discipline and assessment) are still held by the teacher (Teo, 2009). The enactment of student inquiry and collaborative tasks by Katherine was more desirable, yet she failed to deliver a manageable lesson, which led to the different paces of inquiry work conducted by students. This echoes other studies arguing that an effective teacher does not just teach subject content, but also elaborates procedures for completing a task, reaching a goal, solving a problem and making sense of the experience (Rojas-Drummonda & Merce, 2003). The observed design-enactment gap calls for elaborated professional development programs to help teachers master the pedagogical principles of inquiry and CSCL activities and the use of ICTs as cognitive tools (Jonassen, 1995), and to shift their beliefs accordingly.
With the same CSI lesson design, teachers with different pedagogical beliefs and competencies in instructing collaborative inquiry enacted differently. With a traditional pedagogical orientation, the teacher intended to control the class and tended to ignore requests from individual students, yet the teacher with constructivist pedagogical beliefs focused more on scaffolding and elaborating students’ thinking. However, as CSI provides a complex collaborative inquiry approach featuring multiple instructional phrases, teachers are expected to have good understanding of the proposed pedagogical principles, the designed technological affordances, and the specified learning objectives of each inquiry phase to orchestrate the classroom to empower real-time adaptive yet effective enactment of activities leading to desirable processes and outcomes (Chen, Looi, & Chen, 2009). This was neglected in both teachers’ classrooms, with one scaffolding individual and group work insufficiently and the other inadequately attending to students’ skills in collaboration, modeling and reflection. The issues that need addressing include balancing teacher control and the level of student autonomy in inquiry activities (i.e., open inquiry vs guided inquiry); shifting the practices from a focus on logistics to a focus on inquiry (Williams et al., 2004); ensuring that teachers as adaptive facilitators in different inquiry phases; and assisting in students’ inquiry and collaborative activities appropriately.

Implications

Based on above analysis and discussion, implications for ICT-facilitated instruction have been drawn. For teachers whose TEs are more identical to Charley’s (teacher-guided) (Cuban, 1983), we suggest the teachers look for opportunities to intervene more in students’ collaboration and discussion and act as an adaptive facilitator in peer discussion. While moving among groups, teachers should focus more on monitoring students’ understanding than the correctness of answers and/or the completion of tasks. Teachers can interact more with their students to enhance their engagement and to probe their understanding. For teachers whose TEs are more identical to Katherine’s (student-centered), we suggest providing more scripts to them on the purposes and procedures before and during the tasks. The scaffolds should not only be aimed at improving conceptual understanding, but also at the development of regulatory strategies. Teachers need to encourage students into practices of peer review, collaboration and modeling. Additionally, more exploratory questions need to be asked if most students have difficulty in seeking solutions to problems (Cohen, 1994). For both classes, we suggest that the teachers guide students to conduct more productive and exploratory peer discussions, empowering them to lead and sustain their own dialogue on concepts, prior knowledge and methods. By enabling the students to dialogue together, students will gradually become skilled participants in intellectual communities of discourse and practice (Rummel, Spada, & Hauser, 2009).

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