

## Q11 Linking teacher beliefs, practices and student inquiry learning in a CSCL environment: A tale of two teachers 4 5

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**Abstract** The links uncovered by research connecting teacher beliefs to classroom practice and student inquiry-based learning are tenuous. This study aims at examining (a) *how* teacher beliefs influenced practices; and (b) *how* the influence on practices, in turn, impacted student inquiry learning in a CSCL environment. Through a fine-grained comparative analysis of two cases, this study explores how two teachers with different collections of beliefs enacted the same mathematics lesson on division and fractions in a CSCL environment premised on inquiry principles, and what the connections between different enactments and students' progressive inquiry process and outcomes were. The findings suggest that the two teachers' adherence to different beliefs led to different practices, which in turn contributed to different student learning processes and outcomes. We interpret these differences that shaped the students' opportunities for progressive inquiry in the CSCL environment. We conclude that the teacher holding "innovation-oriented" beliefs tended to enact the lesson in patterns of inquiry-principle-based practices and technology-enhanced orchestration; these patterns interacted with each other to contribute to student inquiry learning and effective use of technology affordances. 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

**Keywords** Teacher beliefs · Teacher practices · Student learning · CSCL · Progressive inquiry learning · Inquiry principle-based practices 25 26 27

### Introduction 28

Studies have shown that there is a strong correlation between teacher beliefs and teacher practices (e.g., Beyer and Davis 2008; Chen et al. 2009; Crawford 2007; Speer 2008; Wallace and Kang 2004). Other studies have found that different teacher practices have exerted varied impact on students' learning. Researchers have analyzed small group and 29 30 31 32

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whole class discussions in inquiry-based science learning (Sandoval and Daniszewski 2004; Weinberger and Fischer 2006) and discourse patterns of different teachers that have shaped students' opportunities for learning (Sandoval and Daniszewski 2004) in CSCL environments. However, few studies have addressed the relationship between teacher beliefs, teacher practices and student learning in CSCL environments. Fishman et al. (2003)'s study develops a model for understanding professional development that includes teacher knowledge, beliefs and attitude in an interactive relationship with the interpretation of change in student learning represented by different forms of assessment through classroom enactment experiences supported by learner-centred design software tools. Yet, the authors admit that this study is based on teachers' self-report data without direct examination of the relationship between teacher beliefs, teacher practices and student learning. *How* these elements are related remains inadequately explored. There is an emerging need for research into the intertwined relationships of teacher beliefs, teacher practices and student learning in a more fine-grained detail.

The current study aims to link teacher beliefs to teacher practices and student inquiry learning situated in a CSCL environment, and to scrutinize *how* they are related at a micro-level by analyzing a mathematics lesson for Primary 5 students in two classes by different teachers. The organization of this paper is as follows: the literature review is first presented, followed by the description of the research methods and the results of this study. The paper concludes with a further discussion of this study.

## Literature

### Teacher beliefs

Teachers' beliefs shape their decisions in planning and interpretations of the curriculum, prior to starting the lesson and during implementing their plans in the classroom (Crawford 2007). A better understanding of teacher beliefs is expected to contribute to the success of curriculum innovative practices. Teacher beliefs take the form of varied categories. Some researchers have attempted to identify exhaustive categories of beliefs (e.g., Jacobson et al. 2010), while others have chosen to focus on examining a single category of belief or a small set of categories (e.g., Fives and Buehl 2008; Wallace and Kang 2004). We can hardly find conformity of the categories of teacher beliefs except the top-level beliefs about teaching and about mathematics (Speer 2008). Nevertheless, existing studies on teacher beliefs have shown some evidence that changes in teacher beliefs and changes in teaching practices are intertwined (Jacobson et al. 2010; Tillema and Orland-Barak 2006). In many cases, these studies have been designed to examine the correlations between a general characterization of beliefs and a general characterization of teacher practices by adopting a mainly quantitative approach. They may not indicate how teachers' specific practices reflect specific beliefs (Speers 2008). Thus, the study of how specific beliefs about student learning in domain-specific areas shape specific teacher practices, such as in inquiry learning, is under-explored.

A recent study dealt with this issue. Speer (2008) carried out a study, focusing on fine-grained details of beliefs, practices, and connections between them in a mathematics class. The unit of analysis for beliefs is a collection of beliefs that connects teachers' beliefs to their moment-to-moment decisions and instructional practices captured in the videotaped lessons. The author claims that a collection of beliefs may contain one or more beliefs that fall into one or more categories typically used to describe beliefs such as teaching, learning,

students, and the nature of mathematics. The author posits that combining beliefs in this way helps keep the integrity of the individual teacher beliefs, and in the meantime creates a unit of analysis that reflects the interconnected nature of beliefs. Findings indicate that particular units of analysis—collections of beliefs about how learning happens and about evidence of student understanding are particularly influential in investigating connections between beliefs and specific practices. In the study, collection of beliefs about how learning happens is defined as “How the teacher thinks learning happens”; and collection of beliefs about evidence of student understanding is defined as “What is taken by the teacher as sufficient evidence that students understand an idea or problem?” and “What explanations does the teacher generate when students are unable to produce evidence of understanding (either when they do not respond or respond incorrectly)?”

As for teacher beliefs in technology use for enhancing student learning, few studies have researched how teacher beliefs about technology are formed (Ertmer 2005). Some teachers may hold preconceived ideas about technologies as a tool that can be used to facilitate student learning, others may take them as an add-on to classroom practices (Ertmer 2005). These early perceptions result in vastly different beliefs regarding when and how to use the technologies to for innovative practices. However, the collections of beliefs proposed by Speer do not address teacher beliefs about student learning leveraged by technologies. We consider it crucial to understand teacher beliefs about how learning happens and about evidence of student learning in a technology-supported environment, which may influence the teacher’s innovative practices.

#### Teacher practices

Inquiry-based pedagogical practices are mainly researched in the area of science and mathematics education (e.g., Jaworski 2006; Schoenfeld 2002; Staples 2007). A growing body of research has provided evidence of positive impact of inquiry practices on student learning in mathematics (Schoenfeld 2002). Nonetheless, teachers may not be able to implement inquiry pedagogical approaches in CSCL environments in actual classrooms for many reasons. One is that science and mathematics teachers are reluctant to accept innovative approaches because these are deemed complex and contradictory to their beliefs about assessment-oriented educational goals and routine practices (Lawless and Pellegrino 2007). To fully engage students in collaborative inquiry processes in CSCL environments, it is important to find a balance between teacher-controlled and student-controlled aspects of inquiry (Brown and Campione 1996; Hakkarainen et al. 2002). Teachers are expected to play a facilitating role to help students brainstorm initial ideas, generate questions for exploration, plan and carry out investigations, collect data, gather information, and apply the information to analyze and interpret the data supported by collaborative technologies (Blumenfeld et al. 2000).

There are three approaches to inquiry instruction, namely, structured inquiry, guided inquiry and open inquiry (Colburn 2000). In structured inquiry, the teacher sets up a hands-on problem for students to investigate, and provides procedures and resources, but does not inform them of expected outcomes. In guided inquiry, the teacher sets up a problem to investigate, and provides resources, but she also allows students to devise their own procedures to solve the problem. In open inquiry, the students set up their own problems, search for resources and plan procedures and work out solutions by themselves. Yet, concerns are raised regarding whether all levels of students have the capabilities to do inquiry learning to develop conceptual understanding without scaffolding. In addition, different from science inquiry learning where students are expected to be engaged in open

inquiry, in mathematical classrooms, most often, the students are engaged in working on mathematical concepts and algorithms (e.g., Yim 2010).

Hakkarainen (2003) proposes an inquiry pedagogical approach termed as “progressive inquiry” for young learners in learning science. The characteristics of progressive inquiry are to (a) guide learners to systematically generate their own research questions, (b) construct their own intuitive working theories, (c) critically evaluate various intuitive conceptions generated, (d) search for new scientific information, (e) engage in progressive generation of subordinate questions, and (f) build new working theories as the inquiry process continues. The work reported here explores the application of an adaptation of this approach to mathematics inquiry learning for young learners.

Different methods have been used to examine teacher practices. Some studies have used various discourse patterns to investigate teacher’s role in fostering student question generation, change in understanding of the problem, and collective knowledge advancement (e.g., Hmelo-Silver and Barrows 2008). Other studies have examined the role that teacher facilitation has played in helping students focus on relations between various activity structures and concepts student have learned (Puntambekar et al. 2007). These methods have enriched the literature in terms of understanding teacher practices. A recent study investigated how students assessed their own collective learning using four knowledge-building principles as criteria and scaffolds in a CSCL environment (van Aalst and Chan 2007). The findings show that the principles helped capture the key ideas of collaborative inquiry. Research methods for examining teacher practices, which are rarely adopted, are those using inquiry instructional principles as criteria to examine teacher practices, which may also help capture specific key elements in inquiry practices.

## Student learning

Inquiry learning has its origins in the practices of scientific inquiry and focuses on posing questions, gathering and analyzing data, and constructing evidence-based explanations and arguments by collaboratively engaging in investigations (Hakkarainen et al. 2002; Krajcik and Blumenfeld 2006). Hakkarainen et al. (2002) posit that from a cognitive point of view, inquiry can be characterized as a question-driven process of understanding, which, on one hand, provides heuristic guidance in the search for new scientific information, and on the other hand, helps generate one’s own explanations, hypotheses or conjectures. Students learn content as well as discipline-specific reasoning skills and practices by collaboratively engaging in investigations to advance knowledge (Hmelo-Silver et al. 2007). Networked technologies offer new opportunities to support inquiry learning in a CSCL environment. The teacher’s role in the inquiry environment shifts from one of telling students correct answers to one of facilitating student inquiry activity (Barab and Luehmann 2003). For example, in mathematics inquiry classrooms, students are expected to propose mathematics ideas and conjectures, analyze and explain them to their peers as opposed to traditional mathematical classrooms where the teacher usually adopts a teacher-dominated approach and students listen to and watch the teacher’s demonstration of mathematical procedures, and then practice them (Goos 2004).

There are various ways to examine collaborative knowledge advancement in inquiry learning in the existing literature (Stahl et al. 2006). Some studies have focused on examining classroom interactional data to uncover how students participate in the discussion (e.g., Zemel et al. 2007). Other studies have examined collaboration as knowledge convergence, which focuses on individual contributions independent from each other (e.g., Weinberger et al. 2007). However, Stahl (2002) posits that to understand

collaborative learning, it is important to understand how groups work together to make sense of the problem in inquiry situations.

Harasim (2002), focusing on collaborative learning in an online discourse environment, proposes a theoretical framework to investigate collaborative inquiry through the path from divergent to convergent thinking at a group level: (a) idea generating, (b) idea linking, and (c) intellectual convergence. Idea generating refers to diverse ideas, brainstorming, and idea sharing. Idea linking refers to the evidence of conceptual change, the knowledge construction process and the beginning of the convergence of ideas when new or different ideas become clarified, identified, and clustered into various states such as agreement, disagreement, questioning and elaboration. Intellectual convergence is especially evident in knowledge advancement through collaborative investigation, whether it is a theory, a publication, an assignment, a work of art, or a similar output authored by the group. This framework helps capture collaborative and progressive inquiry in a CSCL environment.

## Professional development

According to Speer (2008), two common characteristics of successful professional development programs in enabling teachers to adopt reform-oriented practices are: (a) focusing on specific and meaningful aspects of practices, such as providing support for teachers' knowledge and sharing good practices through tasks and activities, or through "Lesson Study" (e.g. Lieberman and Mace 2008), and (b) recognizing that people make sense of new information in view of their existing knowledge, beliefs and practices. However, these programs have not focused on the change of beliefs in shaping specific practices at a fine-grained detail. Although the practices have already been widely recognized, questions remain as to how we can understand and foster teachers' understanding for innovation in classroom (Oshima et al. 2004).

Change in teacher beliefs requires teachers to shift from tasks and activities common among teacher development practices to principle-based understanding to enable knowledge advances and sustained classroom innovation (Scardamalia and Bereiter 2008). Scardamalia (2002) has developed a set of principles pivotal for examining and designing knowledge-building inquiry and practices. Although the system of knowledge-building principles seems complex for teachers, there is evidence that teachers holding principle-based understanding are more likely to adopt innovative practices (Chan and Song 2010; Schwarz 2009). For example, in a study that investigated teachers' belief changes in knowledge-building pedagogical practices in a professional development program premised on twelve knowledge-building principles (Scardamalia and Bereiter 2002), the findings show that teachers who already understood knowledge-building principles had their students experiencing more productive collaborative inquiry (Chan and Song 2010). Even though this study addressed the change in teacher beliefs about principle-based understanding contributing to changes in general teacher practices, what is not well studied is the question of how the change contributes to specific aspects of teacher practices and student learning in classroom innovations.

## Methods

Despite a number of studies that have shown that teacher beliefs influence teacher practices, and teacher practices influence student learning, rarely explored are studies on linking

teacher beliefs to teacher practices and student learning in a fine-grained detail (e.g., Desimone 2009; van Driel et al. 2007) in a CSCL environment. The research questions are:

- (1) Did the teacher beliefs influence the teacher practices in a CSCL environment? If yes, how did the teacher beliefs influence the teacher practices?
- (2) Did the teacher beliefs and practices influence student inquiry learning in a CSCL environment? If yes, what particular evidence of student learning shows the influence of the teaching beliefs and practices?

This paper uses a comparative study (Merriam 1998) to answer these questions. Using case studies of two teachers enacting the same lesson plans in a CSCL environment, data were analyzed for insights both within each case and across cases.

## Instructional context

Inquiry learning in primary science has been advocated in Primary Science Syllabus by MOE (Ministry of Education) (2008) in Singapore (<http://www.moe.gov.sg/education/syllabuses/sciences/files/science-primary-2008.pdf>). Although some schools have attempted to adopt the pedagogy, it is reported that schools are far from attaining the goals stated in the syllabus. For example, a study investigated the impact of teacher beliefs about the nature of knowledge and learning on teacher practices in Singapore schools (Jacobson et al. 2010). The findings show that some Singaporean teachers considered teacher-directed didactic teaching approaches as being more effective for low-achievers in examinations. The authors call for further investigations into different ways in which teacher beliefs about knowledge and learning influence pedagogical decision-making and practices in Singapore classrooms.

MOE (2008) proposes that teachers be encouraged to employ varied approaches to facilitate the inquiry process. Although student-directed inquiry will provide the optimal opportunities for cognitive development and scientific reasoning, teacher-guided inquiry may provide the optimal opportunities for students to focus learning on the development of particular science concepts. To balance the inquiry approaches, illuminated by Hakkarainen's (2003) pedagogical approach of "progressive inquiry", we developed our pedagogical approach to inquiry learning in a progressive and cyclic process consisting of six interacting elements, namely, (a) creating a collaborative inquiry culture; (b) setting up problems; (c) constructing working concepts collaboratively; (d) peer evaluation; (e) developing deepened knowledge; and (f) developing new working concepts. The process is not linear, and may not involve all the components in each learning cycle.

This study is situated in an ongoing 3-year inquiry learning project that integrates teacher beliefs, practices and student learning at a primary level supported by Group-Scribbles (GS)—a collaborative technology (Looi et al. 2011). Five principles as instructional principles were designed, aiming at elucidating the processes and dynamics of collaborative knowledge improvement using the inquiry pedagogical approach. These five principles are adapted from a set of principles for Rapid Collaborative Knowledge Improvement (RCKI) (Looi et al. 2010) and other related research (Scardamalia 2002; van Aalst and Chan 2007). The five principles are listed in Table 1.

## Collaborative technology—Group Scribbles

A typical GS classroom is equipped with an Interactive Whiteboard (IWB), and each student in the classroom has a Tablet PC with the GS client software installed. GS is a

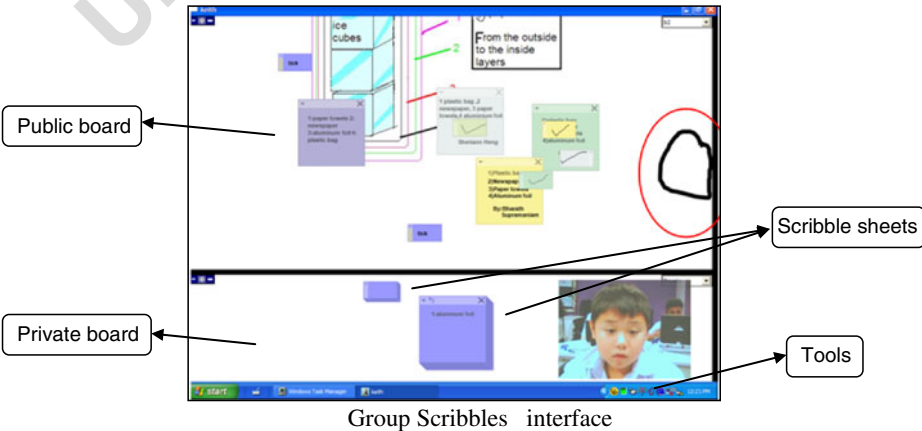


**Table 1** Inquiry learning instructional principles

Principles	Characteristics
Working on authentic problems	This principle proposes to set up real life problems rather than abstract concepts.
Encouraging diverse ideas	This principle focuses on encouraging students to express their ideas voluntarily. There are no right or wrong answers. Every idea is valued and unique.
Making progressive inquiry	This principle relates to whether collaborative learning proceeds progressively, in line with the pedagogical approach.
Providing collaborative opportunities	This principle emphasizes the importance of collective effort and responsibility in the learning process.
Doing embedded assessment	This principle concerns whether peer assessment and teacher feedback is provided concurrently in the collaborative process.

platform that can be used to create flexible and shared representations that highlight an important new capacity for interactive engagement. GS allows students to create, publish and edit lightweight multimodal expressions for collaborative and group activities without the need for additional programming. The GS user interface presents each student with a two-paned window (Fig. 1). The lower pane is an individual work area, or a private board, with a virtual pad of fresh scribble sheets of different sizes. The upper pane is a group work area, or a Group Board. The student can draw or type on the scribble and can drag and drop it into different screen arrangements on the Group Board in the upper pane. Other participants' screens are updated to reflect changes on the Group Board. Group members may interact with group scribbles in a variety of ways, such as browsing their content, repositioning them, or moving one scribble from the public board into the private board. New public boards can be created to support multiple activities or spaces for small groups to work. The tools shown at the bottom on the right hand side of the private board allow students to choose different styles such as typing and drawing.

GS technology offers unique affordances as following shown in Table 2.



**Q10** Fig. 1 Group Scribbles interface

t2.1	<b>Table 2</b> Affordances of GroupScribbles	
t2.2	Affordances	Characteristics
t2.3	Multimodal representations	Allow multimodal representations: GS can capture diagrams and drawings as well as text.
t2.4	Lightweightness	The scribble sheets are for expressing concise ideas instead of lengthy explanations.
t2.5	Persistence	All ideas generated in GS can be recorded in the shared space as a group working memory.
t2.6	Re-configurableness	The scribble sheets can be positioned and repositioned to convey meaning.
t2.7	Physical proximity	GS supports improvable ideas as Scribble Sheets are designed to be overlaid with new sheets or annotated with labels, all the while preserving the integrity of the original idea.
t2.8	Public space and private space	Private space allows individual reflection, and public space offers a shared space for collaborative interaction and knowledge construction.

(Adapted from Chen et al. 2009)

Two cases 275

Using a cross-case comparison design (Merriam 1998), two teacher cases are analyzed in depth to illustrate the role that the beliefs of the two teachers play in shaping their teacher practices and the relationship between the teacher beliefs, practices and student learning in fine-grain detail. In this section, we describe the methods used to obtain and analyze data on the teacher’s beliefs, practices, student learning, and connections among specific constructs. The mathematics lessons in two Primary five classes were conducted at the beginning of the second year of the project. Both classes had 42 students. A female teacher (hereafter Ping) with 35 years of teaching experience conducted a lesson in one classroom. This teacher joined the 3 year GS project on a voluntary basis although she used technology for emailing and word processing purposes. A young female teacher (hereafter Yao) with 5 years of teaching experience conducted the other lesson. Compared to Ping, Yao was savvier with technology use. To carry out detailed analyses and make a distinctive comparison between the two teachers, we chose to examine one parallel lesson on “division and fractions” using the same lesson plan.

The lesson plan 290

The two teachers co-designed the lesson plan on division and fractions together with the researchers for Primary five students guided by the instructional principles and the pedagogical approach to inquiry learning. The lesson plan is shown in Appendix I. The teachers used the same teaching plan, but they could make flexible changes during their plan implementation.

Professional development model 296

As reviewed in the previous section, although there have been a number of studies on different approaches to professional development (e.g., Glazer and Hannafin 2006; Tillema



and Orland-Barak 2006), few have focused on changing teachers' beliefs to influence teacher practices and student learning. A growing concern about changing teacher beliefs in science education is through cultivating teacher instructional principle-based understanding (e.g., Chan and Song 2010; Schwarz 2009). We follow this trend to develop a professional model termed APPRE (Enculturation-Principles-Planning & Practices-Reflection & Evaluation):

- (a) *Enculturation* introduces teachers to the inquiry pedagogy in a GS-supported collaborative learning environment,
- (b) *Principles* enable teachers to understand the inquiry instructional principles to enact innovative practices in the spirit of those principles,
- (c) *Planning and Practices* create the curriculum plan premised on the instructional principles and the pedagogical approach for classroom enactment, and
- (d) *Reflection and Evaluation* enables iterating and improving of innovative practices.

Each cycle took about 10 training hours in five training lessons in one semester. Because professional development is beyond the scope of this paper, we are not going to elaborate it in detail. Up to the time of the present study, both of the teachers had participated in two cycles of teacher professional development on how to design and enact the inquiry learning practice with GS. Both teachers had used GS and IWB to support collaborative inquiry learning in their science and mathematics classes for more than two semesters. The teachers used the technologies for 10 lessons over 10 weeks in the first two semesters. In the third semester, another five GS lessons were offered to the Primary five students. We chose the same mathematics lesson offered by the two teachers from the beginning of the third semester for the analysis because we assumed that at this stage, there should be some change in teacher beliefs, practices, and student collaborative inquiry learning after more than one-year's implementation of the innovative practices.

## Data collection

To generate results that are closely tied to practices and that can enrich the research community's understanding of how the two teachers' (Ping and Yao) beliefs, practices, and student learning are different, we adopted the following methods to collect data:

- (a) Data in relation to teacher beliefs includes recorded videos of the professional training programs, observations and field notes, and interviews about their beliefs, including their attitudes,
- (b) Data regarding teacher practices includes captured classroom videos, the teaching plan, observations and field notes, and
- (c) Data in terms of student learning includes artifacts created in GS during the group and class interactions, class observations and field notes.

## Data analysis

Data analysis was conducted in an iterative and cyclic manner using coding and "conceptually clustered matrix" strategies (Miles and Huberman 1994, p. 128). Coding was to "fracture" (Strauss 1987, p. 29) the data and classify it into broader themes or categories (Merriam 1998). Teacher beliefs, teacher practices and student learning were coded using existing coding schemes or doing open coding when existing coding schemes did not apply to develop categories. The conceptually clustered matrix was used to generate cross-case comparison for the two cases. Specifically, building on the results of coding or

open coding, it was developed to display key categories to represent teacher beliefs, teacher practice and student learning. Constant comparative analysis (Miles and Huberman 1994) across the two cases (Ping and Yao) could help to understand how different teacher beliefs impacted teacher practices, and in turn, on student learning. Whenever necessary, field notes were used in all the three streams of the data analysis process for the purposes of clarification and confirmation. The data sources for the data analysis are (Table 3):

Analyzing teacher beliefs

To code teacher beliefs, we used the coding scheme of (a) beliefs about how learning happens, and (b) beliefs about evidence of student understanding.

Analyzing teacher practices

Capturing teachers' moment-to-moment instructional practices and classroom interactions is central to the study. The data analysis consisted of two steps. First, the transcribed video data about teacher practices was coded based on the themes of discourse, which will be elaborated in the next paragraph. Second, data about the teacher practices was coded again on Studio Code—a kind of video data analysis software, to contextualize the teacher practices and to provide visual representations of the patterns of the teacher practices.

The captured video analysis enabled teacher practices and interactions with students to be represented in a very fine-grained detail through transcript records of classroom discourse using a theme of the discourse as the unit of analysis. Each categorized theme was considered one instance of the teacher practice. We first coded the transcriptions of teacher practices based on the themes of five instructional principles as criteria: working on authentic problems, encouraging diverse ideas, making progressive inquiry, providing collaborative opportunities, and doing embedded assessment. This enables the examination of how each teacher attempted to create a collaborative culture, raise questions, construct working concepts, carry out evaluation, improve knowledge, and develop new working concepts. For example, when the teacher Ping said, "I would like you to explain what you mean by fractions", we consider that she was encouraging diverse ideas from students, and this was put into the category of "encouraging diverse ideas". However, when analyzing the data, it was found that some data were beyond these categories. Thus we coded and obtained another five more categories grounded from the data. They are: working on abstract concepts, seeking correct answers, providing information to students, shifting focus of problem inquiry, and making a judgment by the teacher. For details, please refer to Appendix II. In addition, the teaching plan and observation field notes were also used for data triangulation.

Table 3 Data sources for data analysis

Data	Teacher beliefs	Teacher practices	Student learning
Semi-structured teacher interviews	x		
Professional development videos	x		
Videos and transcripts of classroom videos		x	x
Teaching plan		x	
Field notes		x	x
Student group work (Artifacts)			x

*Analyzing student learning*

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To capture student moment-to-moment learning in the classroom practices, we also conducted the analysis in two steps. First, we analyzed student group work as artifacts created on GS group board in four dimensions, focusing on student learning outcomes. The first three dimensions of collaborative inquiry learning are categorized based on Harasim's (2002) coding schemes. They are: (a) idea generating and (b) idea linking that showed the process of student learning; and (c) intellectual convergence. In addition, data in terms of students' expression of emotions (e.g., praising other's work) is considered more relevant to affective aspects of social support or social presence (So 2009). Hence, social support is included as the fourth dimension in analyzing student learning. Second, we used Studio Code software to code a student group video data along the four dimensions to contextualize student learning process and outcomes.

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The inter-coder reliability regarding teacher beliefs, teacher practices, and student learning were assessed by two independent researchers. The Pearson correlation between the number of collection of teacher beliefs by the two coders was 90.6, the number of categories of teacher practices was 91.7, and the number of categories of student learning was 93.5 (student generated artifacts on GS).

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393**Results: Ping and Yao's beliefs, practices and student learning**

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The results show that Ping and Yao held different beliefs about how learning happens and about evidence of student understanding (Refer to [Appendix III](#)); their enactment of principle-based instructional design in classroom practices and practice patterns were contrasting; and student learning processes and outcomes also varied.

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398**Ping's beliefs**

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Ping's beliefs about how learning happens were that students learned best from progressive inquiry learning, which helped students to develop analytical skills and higher order thinking. Ping, quoting a researcher (Mr Lee—pseudonym)'s remark in the professional development program, said, "You want inquiry based, you want pupils to develop what Mr. Lee told us 'higher order thinking'". She continued,

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Inquiry-based, you know, is like: they have to read, gather all the information, then analyze together. Then they have to synthesize you know, put them together and see whether it [the concept or theory] works or not. So the process helps develop the children's thinking, you know.

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She tended to ask students open-ended questions with no absolute right or wrong answers. Ping considered that GS provided the opportunities for students to read and comment on other's work and to learn from each other. Ping showed great empathy to students, especially those with low self-efficacy in learning mathematics. Her philosophy of teaching was "patience" because "Patience makes a child learn". Ping mentioned that every child had his/her own strong points, so she tended to encourage each of them to contribute ideas.

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Regarding her beliefs about evidence of student understanding, Ping mentioned whenever students worked out an answer to a question or problem, she would ask the

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students to support their answers with evidence. If the student did not understand a concept, s/he should make every effort to figure it out. It was crucial for students to develop an inquiry mind. Although asking students to explain the reasons for the answers was important for her to understand whether students truly comprehended an idea or not, Ping reckoned that it was even more important for her to provide opportunities for students to consolidate the ideas by applying them into practice. In many cases, students thought they understood the concept or the idea by referring to other's ideas. However, in practice, they might not understand it. Ping added,

Only when they are able to apply [the idea/concept], then they can comprehend it. After that, they can really know whether they know it or not.

Ping, in the course of attending two cycles of the professional development program, shared that the five instructional principles were very useful for guiding her pedagogical approach. In her classroom practices, Ping mentioned that by bearing in mind all the principles, she intended to apply them in her teaching. Ping did her reflections after she completed her lesson. She would also ask the researcher who attended her class to comment on whether she had covered all the principles, and what improvement she might need to make. Ping considered that GS was very useful for students to do collaborative learning. By learning from each other within a group and between groups, students experienced more varied classroom activity patterns.

#### Yao's beliefs

One of Yao's beliefs about how learning happens was that as students did not have good prior knowledge about new mathematics concepts, they were unable to work out rules related to the concepts. It was important for her to use content-based instruction. To her, when introducing a new concept to students, she would teach the content knowledge or rules first. Otherwise, students might not be able to comprehend the concept or rules. She explained,

When I ask students, 'based on what you've learned, tell me why this algorithm is correct, and that is wrong'. They have no idea. I really can't expect them to give me an answer. So I have to tell them how the algorithm is manipulated by certain rules before they can tell the reasons by themselves.

Yao conceived that students were unable to work out problems without her guidance, and what was even worse was that if students were allowed to work on their own without her guidance, they would formulate misconceptions. It seems that Yao was aware of her teacher-centred approach but she had a "good reason" for her approach,

I remembered Mr. Tang [a researcher's pseudonym] once mentioned to me that my lessons are very teacher-centred. So I'm learning how to set up questions for students rather than telling them the answers. But you know that there are so many misconceptions out there (on the GS board). I have to explain and clarify.

Regarding Yao's beliefs about evidence of student understanding, Yao tended to ask students "right" or "wrong" questions to check whether students understood a concept or not. To Yao, if the students could work out correct answers on GS, meaning that they had learned the concept. She considered that much of her efforts should be placed on identifying and then addressing students' mistakes or misconceptions because she conceived that students would be misled and confused by these.

## Ping and Yao's practices on division and fractions

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## Chronological representation of Ping and Yao's practices

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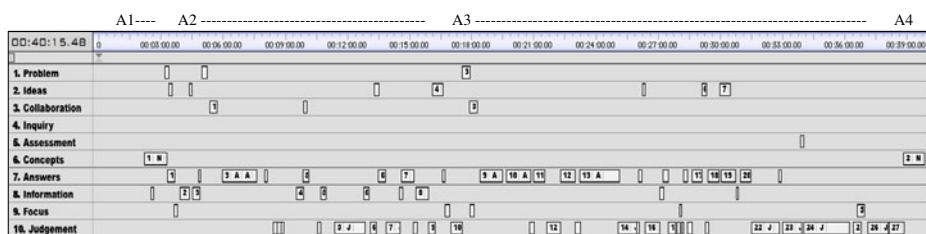
To understand how the two teachers facilitated classroom interactions leading to the progressive inquiry process holding different beliefs, we used a chronological representation of the classroom discourse in teacher practices supported by the Studio Code software to make collaborative learning visible (Stahl 2002). Figure 2(a and b) describes Ping (a) and Yao (b)'s practices based on classroom discourse and coded in 10 categories, illuminating how they developed over time, starting from creating a collaborative culture, setting up a problem, constructing working concepts, carrying out evaluation and improving knowledge, to developing new working concepts. Each line in the figures depicts a single category described on the left side of the figure, with the instances of teacher practices in that category represented along the horizontal line on the top of the figure. Each practice instance is represented using a bar code. The longer the bar code is, the longer the instance is.

Table 4 shows the number of instances of Ping (a) and Yao (b)'s practices occurring in each category.

From Fig. 2(a and b) and Table 8, it is observed that Ping's practices focused on "assessment (doing embedded assessment) (27.1%), ideas (encouraging diverse ideas) (25.7%), and problems (setting up problems) (12.9%)". The least focused instances are "concepts (working on abstract concepts) (1.4%) and focus (shifting focus of problem inquiry) (1.4%)". Although there were only seven instances (10%) for collaboration (providing collaborative opportunities), by examining Fig. 2a, it is noted that two of the instances have the longest duration among all other instances. We observe that Yao's practices were focused on "answers (seeking correct answers) (26.6%), judgment (making judgment by the teacher) (34.2%), and information (providing information to students) (5.7%)". The least focused instances were "inquiry (making progressive inquiry) (0%) and assessment (doing embedded assessment) 1.3%".



**a** Chronological representation of Ping's practices



**b** Chronological representation of Yao's practices

**Fig. 2** a Chronological representation of Ping's practices b Chronological representation of Yao's practices

Table 4 Number (percentage) of instances of Ping and Yao’s practices

Categories of practices	No. (percentage) of Ping’s instances		No. (percentage) of Yao’s instances	
Problem (Working on authentic problems)	9	(12.9%)	3	(3.8%)
Ideas (Encouraging diverse ideas)	18	(25.7%)	7	(8.9%)
Collaboration (Providing collaborative opportunities)	7	(10%)	3	(3.8%)
Inquiry (Making progressive inquiry)	3	(4.3%)	0	(0%)
Assessment (Doing embedded assessment)	19	(27.1%)	1	(1.3%)
Concepts (Working on abstract concepts)	1	(1.4%)	2	(2.5%)
Answers (Seeking correct answers)	5	(7.1%)	21	(26.6%)
Information (Providing information to students)	4	(5.7%)	10	(12.7%)
Focus (Shifting focus of problem inquiry)	1	(1.4%)	5	(6.3%)
Judgment (Making judgment by the teacher)	3	(4.3%)	27	(34.2%)

With the assistance of Studio Code software, we were also able to sequence the five activities in Ping and Yao’s lesson enactment (Appendix IV). Ping only used 2 min to prepare the class regarding shifting students to the computer room, setting up the computers and making students ready for class; while Yao spent 12 min in doing such preparations. In addition, in the five activities designed in the teaching plan, Ping spent 9 min to create the collaborative inquiry culture by working on authentic problems, while Yao only spent 3 min to talk about the abstract concepts of division and fractions. In addition, Ping completed all the class activities, while Yao did not have time to do the last activity—setting up a new problem for students to reflect and inquiry after class.

Ping and Yao’s practice patterns in the “division and fractions” lesson

In Fig. 2(a and b), we identified different patterns of the two teachers orchestrating the activities of the lesson shown in Table 5. This is consistent with the results of the qualitative data analysis.

In Ping’s practice, two inquiry principle-based patterns were identified in her practice: (a) The interplay between “problems (working on authentic problems)” and “ideas (encouraging diverse ideas)” in all of the activities except the last one; and (b)

Table 5 Ping and Yao’s practice patterns

Activity	Ping’s practice pattern		Yao’s practice pattern	
A1	Brainstorming concepts of division and fractions	Problems and ideas	Problems and ideas	Problems, answers and information
A2	First problem inquiry into division and fractions		Collaboration, and assessment	Answers and judgment
A3&A4	Second problem inquiry into division and fractions, and developing deep knowledge (no clear cut between A3 & A4)		Collaboration and assessment followed by ideas and assessment	Answers, information and judgment
A5	Posing a new problem for inquiry	Setting up a new problem	Skipped	Answers and judgment



the interplay between “collaboration (providing collaborative opportunities) and assessment (doing embedded assessment)” followed by “ideas (encouraging diverse ideas) and assessment (doing embedded assessment)” in A2, A3 and A4; and finally “setting up a new problem” in A5. However, in Yao’s practice, we could hardly find inquiry principle-based patterns as those of Ping. Instead, Yao’s practice pattern was dominated by the interplay between “problems, answers and information (providing information to students)” in A1, the interplay between “answers (seeking correct answers) and judgment (making judgment by the teacher)” in A2, A3 and A4. In Yao’s class, A5 was skipped due to time constraints.

#### *Ping’s inquiry principle-based practice patterns*

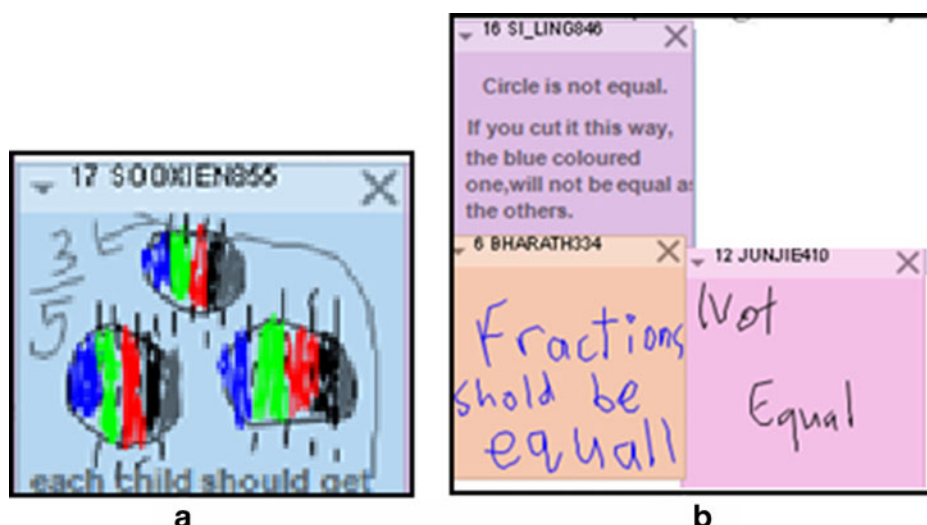
The interplay between problems and ideas in brainstorming and later activities: In analyzing the qualitative data, we found that in Ping’s class activities, the instructional principles of problems and ideas were intertwined. Ping guided the students from brainstorming questions to more complicated ones progressively as follows:

- A1        A number of questions related to the concept of division and fractions for brainstorming and drawing out students’ prior knowledge (e.g., Who can tell me “I would like you to explain what you mean by fractions”).
- A2        Now please do a collaborative activity: To divide 2 pizzas among 3 children on your group board of GS.
- A3 & 4    Let’s do a more challenging activity: To divide different numbers of cakes for different numbers of children in different groups on your group board.
- A5         $4 \div 2/3 =$  How to explain? What do we mean by this? How to draw and show me? ... This is homework.

These questions started from general questions in brainstorming activity A1 to more focused problems searching in later activities with increasing complexity in the inquiring process supported by GS and IWB technologies. Meanwhile, in the course of inquiring the problems, Ping was open to diverse ideas from students and always provided positive feedback. This encouraged the students to generate more ideas, which helped the progressive inquiry.

The interplay between collaboration and assessment followed by ideas and assessment: Following the brainstorming activity in Ping’s practice in A2, in addition to the interplay between problems and ideas, the results of data analysis of Ping’s practice indicate that the two categories of inquiry principle-based practice—collaboration and assessment were enacted interchangeably in student inquiry into the problem of dividing two pizzas among three children to construct the initial concepts of division and fractions. In the students’ inquiry process, she provided the opportunities for the students to work collaboratively in groups on GS to generate their ideas. She monitored students’ collaborative work on GS, and scaffolded their inquiry when necessary. In the meantime, she encouraged the students to link, share, and comment on each other’s work. To Ping, assessing other’s work did not mean to simply give it a tick or a cross, but to comment and show how it should be done in order to know whether the students really understood the problem. The students in the class formulated a positive attitude towards evaluating their peers’ work towards collective idea improvement. For example, when a group of students working on the problem of dividing three cakes among five people, one group member drew the graphs (Refer Fig. 3a) to show the division process, and other group members commented on the graphs (Refer Fig. 3b).

In order to make the students consolidate the working concept and develop deep knowledge about the concept of division and fractions, in the subsequent activity A3, Ping



**Fig. 3** a and b Dividing 3 cakes among 5 children and peers' comments

posed a more complicated problem for the groups of students to solve: to divide different numbers of cakes among different numbers of children.

However, it is noted that in activities A3 and A4, the classroom discourse patterns changed from the interplay between collaboration and assessment to ideas and assessment. Instead of doing inter-group and intra-group assessment on GS, the assessment was conducted at the class level by projecting each group's work onto the IWB so that all the students could grasp the opportunity to comment on other group's work. They learned how their peers evaluated the group work of their own, and how they could explain their ideas to their peers.

### *Yao's practice*

The interplay between problems, answers and information in brainstorming activity: To brainstorm the concept of division and fractions, Yao used an "authentic" example of dividing nine cupcakes among three children as a problem for students to understand these concepts. The following is an extract of the classroom discourse:

Teacher: This is an easy problem. Divide 9 cupcakes among 3 children. How many cupcakes does each child get?

Students: 3.

Teacher: How did you get it? Why didn't you think "3 divided by 9"?

Student1: Small number cannot be divided by big number.

...

Teacher: Please think about it because just now some students told me that 3 cannot be divided by 9, small cannot be divided by big. When a small number is divided by a big number, you usually get something called a fraction, which can be expressed as part of a whole. Here 9 cupcakes are divided by 3. Do you know why?

Students: Because they want each child to have 3 cakes.

Teacher: When you are doing the dividing, what are you doing to the cupcakes? You are actually dividing the cakes into groups.

**Q12**

From this episode, we can see that Yao wanted to use the example of 9 cupcakes divided by 3 as an authentic example to make students understand the concept of division. Before presenting this concept to students, she focused on working at the abstract concept of division by reversing the order of the numerator and denominator, and asked the students why they did not think of using three to divide nine. One student said that a small number could not be divided by a big number, which was ignored by Yao. Instead, she provided the information about the concept of fraction by stating that when a small number was divided by a big number, a fraction would be obtained. This concept was problematic in that a fraction can also be obtained even if a big number is divided by a small number. The difference was that the former one was a proper fraction and the later one was an improper fraction. After this misinterpretation of the concept of fraction, she reversed the order of using nine cupcakes divided by three to provide the information about the concept of division that meant to divide things into groups. In the course of brainstorming, students' prior knowledge and introducing the concepts, it was basically Yao who dominated the classroom discourse. She posed questions, answered the questions herself, or provided information to the students. The students did not quite follow what she wanted to teach and could not associate the concept of fraction with division because she introduced the two abstract concepts separately and inaccurately. The inquiry principles could hardly be identified in her practices.

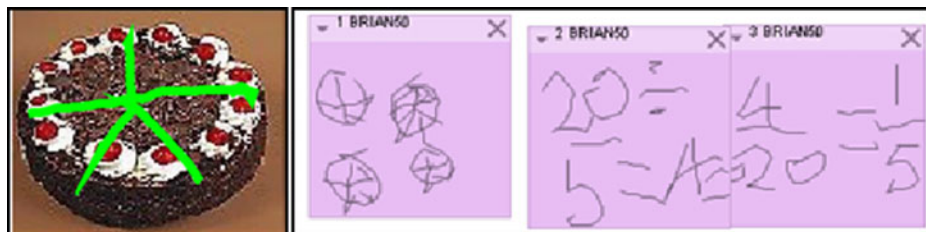
The interplay between answers and judgment in later activities: In Yao's practice, the interplay between answers and judgment was found in all the activities except the brainstorming activity. In many cases, after Yao assigned the problems of dividing cakes or pizzas to students, she would say things like,

OK, Group 1 got a fraction as an answer, and cut the cakes into parts. But I want to see a *number statement*...

This group also cut the pizza properly (on GS)...There are two fractions. One is 2 over 3. The other one is 3 over 2, or 1 and  $\frac{1}{2}$ . Which one is your answer? ...

Providing the time for collaboration did not mean that students could automatically work together in their inquiry. From the beginning to the end of the student group work, it seemed that Yao focused on identifying what answers each group provided without facilitating the students to comment on inter- or intra-group member's work. In the evaluation session, most often, it was Yao who had the final say. Diverse ideas were not encouraged. Occasionally, the students got the opportunity to talk but generally they could not receive Yao's recognition or encouraging remarks. The following is one episode of her comment on one group member's work on dividing four cakes among five children (refer to Fig. 4).

Teacher: This group cut the pizzas into five equal pieces. And this one even gave me the working. 20 divided by 5 equals 4. Now the answer 4 is very misleading. Why is it misleading?



**Fig. 4** Group member's work on dividing 4 cakes among 5 children

Students: Not a fraction. 636  
Teacher: Not a fraction. Why must the answer be a fraction? 639  
Student5: If the answer is 20, each child gets 4 pieces. 640  
Teacher: If the answer is 20, each child gets 4 cakes. If one gets 4 cakes, how much 643  
the rest get? 644  
645

In fact, referring to the group member's work, it was obvious that the student 646  
understood the process of how to divide four cakes into 20 pieces. The statement 647  
"20÷5=4" indicated that each child could get four pieces from 20 pieces of four 648  
cakes divided by five children. The way that the students did the division might be 649  
influenced by Yao's way of introducing the concept of division in the brainstorming 650  
stage, in which nine cupcakes were divided by three. Because Yao did not relate 651  
division to fractions in the brainstorming activity, the student did not understand how 652  
to work out the fraction. Now that each child could get four pieces in total from five 653  
cakes, then the number statement should be 4 (pieces) ÷ 5 (cakes)=4/5. The student's 654  
misconception lay in using 20 pieces cakes rather than five cakes as the denominator. 655  
However, Yao made the judgment that "20÷5=4" meant that each child got 4 cakes. 656  
This judgment was even more misleading. 657

Ping and Yao's practices in terms of technology use for class orchestration 658

In Ping and Yao's practices, we found that they used the GS and IWB technologies to 659  
orchestrate class activities in different ways (see Table 6). 660

*Ping's orchestration using GS and IWB technologies* 661

Ping made use of the GS and IWB technologies to orchestrate class activities. While the 662  
students were doing their collaborative work on GS, Ping made a gallery view of the group 663

t6.1 **Table 6** Ping and Yao's GS and IWB technology use for class orchestration

t6.2	Activity level	Ping	Yao
t6.3		Orchestration purposes	Orchestration purposes
t6.4	Group level	To orchestrate group participation by getting a bird's eye view of group contribution on the group board on GS	To monitor group work by counting the number of postings and checking correct answers from group contributions on GS
t6.5		To orchestrate collaborative inquiry by observing each group's multi-modal representations in GS	x
t6.6		To orchestrate intra- and inter- group embedded assessment and social interactions by observing intra- and inter-group comments based on the proximity of the postings on GS	x
t6.7	Whole class level	To orchestrate whole class embedded assessment and scaffold key concepts in the inquiry by projecting group work from the group board on GS onto the IWB	To do teacher-centered judgment of the group work by projecting the group work from the group board on GS onto the whiteboard

work on each of the group board to monitor group participation. When she found a blank group board, she prompted, “G2 has not done anything yet, please contribute”; when she noticed that representations of the group work were not multi-modal, she facilitated, “G2, can you show me the diagram about division and fractions?” “G4, can you give me the number statement?”; and when she observed that there were few postings that were in proximity on the group board, she prompted, “Please comment each other’s work”. These pedagogical orchestrations helped the students to be more sensitive to contributing to their group work using multi-modal representations and evaluating other’s work to co-construct knowledge in their collaborative inquiry.

The representations in GS and IWB mediated group and whole class interactions for the inquiry practice. The students in different groups addressed the problem of dividing two pizzas among three children in different ways. For example, in the course of the inquiry, one group posted the fraction  $\frac{2}{6}$  obtained from the division on their group board (see Fig. 5a), which was challenged by a peer from another group (see Fig. 5b).

Ping, recognizing that the group made the common mistake of adding both the numerators and denominators while doing the addition, projected the group work onto the whiteboard, and helped to scaffold the students to remove the misconceptions for the whole class. The following is the episode:

Teacher: How to divide the pizzas into 6 parts. One can get one piece on each pizza.

How to improve it? Who can improve it?

Student4: Divide the pizza into 3 parts.

Teacher: 1 pizza is divided into 3 parts. How much does each child get?

Students: 2 over 6.

Teacher: 2 over 6? Let’s see. 2 pizzas for 3 children. 1 pizza for 3 parts, 2 pizzas for 3 equal parts. Let’s draw the pizza on the whiteboard. How much can each child get?

Student5: Plus together, one can get  $\frac{2}{3}$ .

Teacher: Yes. Clever...

Teacher: So how do you get the fraction from a number statement?

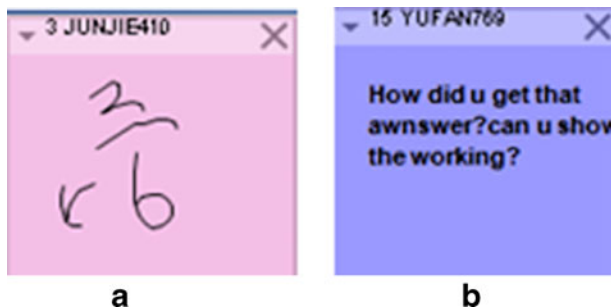
Students:  $\frac{1}{3} + \frac{1}{3} = \frac{2}{3}$

Teacher: What pattern do you get from the addition?

Students: Add the numerators only, and the denominator keeps the same.

By drawing the pictures on the whiteboard, the students could visualize the process of dividing the pizzas, which helped them reflect and correct the mistake on the group board. In the process, it is noted that by raising questions, praising and encouraging ideas from the students, and providing opportunities for the students to work collaboratively on GS, the students were enabled to solve the problems they encountered in their inquiry on their own.

**Fig. 5** a and b Group work of the fraction  $\frac{2}{6}$  and comments of a peer from another group



## *Yao's orchestration using GS and IWB technologies*

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It is noted that Yao mainly used GS as a means to monitor the group contribution by counting the number of postings from each group. When the students were working on GS, she counted,

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G 3 has got 6 posts. Please go on. G 4 has one post. G 5 has one post. G 6, nobody posts. G 7...

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To Yao, it seemed that as long as the students posted, the students were doing collaborative learning despite the similarity of the postings (see Fig. 6).

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## **Ping's and Yao's student learning**

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### Overview of the results of student learning

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With the assistance of Studio Code software, the student group's chronologically ordered actions of postings on the Group Board of GS in Ping and Yao's classes respectively were depicted in Fig. 7(a and b). They describe Ping and Yao's student group posting actions regarding idea generating, idea linking, intellectual convergence and social support, and how they changed over time. Each line of the figures depicts a single category described on the left side of the figure, with the actions of student postings in that category represented along the horizontal line on the top of the figure. Each action is represented using a bar code.

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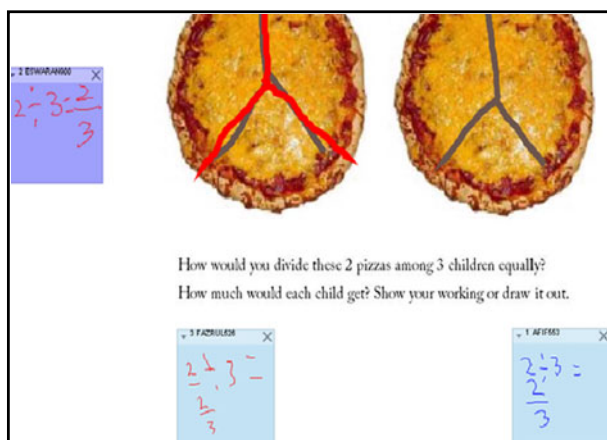
Table 7 shows the number of actions of student postings in Ping (a) and Yao (b)'s class occurring in each category.

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From Fig. 7(a and b) and Table 7, we observed that in Ping's student group, the student learning practice is characterized as the interplay between idea generating (30.8%), idea linking (53.8%) and social support (12.3%), which led to "idea convergence (3.1%) in the two collaborative activities of dividing two pizzas among three children, and dividing different number of cakes among different number of children. However, we observed that in Yao's student group, members only generated a few ideas (92.9%) in the two collaborative activities, with only one idea linking (7.1%) and without any intellectual convergence and social support. The results are very useful for us to get an overview of the student collaborative inquiry process

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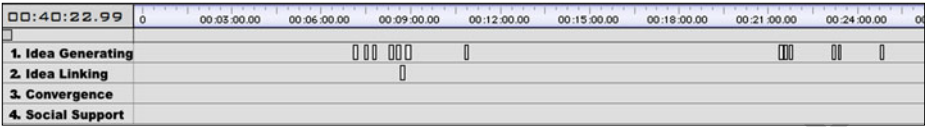
**Fig. 6** Student group postings in Yao's class







a Chronological representation of Ping's student group work



b Chronological representation of Yao's student group work

**Fig. 7** a Chronological representation of Ping's student group work b Chronological representation of Yao's student group work

and outcomes. In the next section, we present how the group's ideas were developed by examining the evolvement of the group artifacts presented on GS.

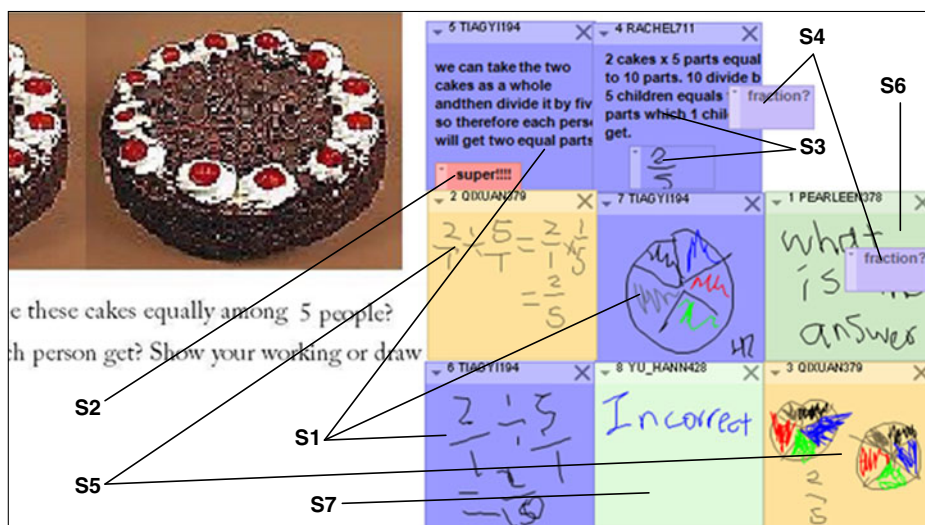
The interplay between idea generating, idea linking and social support: Ping's student learning

In Ping's class, while working on the problems of dividing the pizzas and cakes, we observe that students actively participated in the problem solving: questioning, clarifying, commenting, elaborating and encouraging each other using multiple expressions—drawings, number statements and texts and co-constructed knowledge, making use of the affordances provided by GS. In the meantime, the students cared for each other's feelings and appreciated their contributions. They tended to use encouraging words like nice, super, and extremely good to comment on other group members' work in the first collaborative activity. Because Ping always kindly reminded students to provide reasons for their comments (e.g., why do you say it's super?), so in the second collaborative inquiry (A3), students tended to have more idea linking by providing reasons or opinions on other's work instead of simply posting encouraging words for emotional support. One example of Ping's student learning featured by the interplay between idea generating, idea linking and social support leading to intellectual convergence was revealed in the group work on investigating into how to divide two cakes among five children shown in Fig. 8.

In Fig. 8, Student 1 suggested combining the two cakes as a whole and dividing it by five children, so each child could get two equal pieces of the cakes. Student 2 appreciated this idea. However, Student 3 questioned that the description by Student 1 was not clear, he re-

**Table 7** Number (percentage) of actions on GS in one group of Ping and Yao's student learning

Categories of student learning	No. (percentage) of actions in one group of student learning of Ping	No. (percentage) of actions in one group of student learning of Yao
Idea generating	20 (30.8%)	13 (92.9%)
Idea Linking	35 (53.8%)	1 (7.1%)
Intellectual convergence	2 (3.1%)	0
Social support	8 (12.3%)	0



Note: S = Student

**Fig. 8** Intellectual convergence in the group work on dividing 2 cakes among 5 children

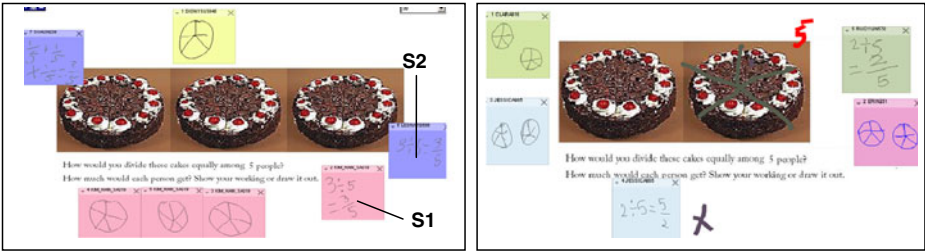
Q8

interpreted that  $2 \text{ cakes} \times 5 \text{ pieces} = 10 \text{ pieces}$ ;  $10 \div 5 \text{ children} = 2 \text{ pieces}$ , which was the amount that each child got. Student 4 followed this interpretation and asked Student 3 to provide the fraction, which helped Student 3 to move a step forward to work out the fraction  $2/5$ . The idea development did not halt here. Student 5, recognizing that there was no number statement in working out the fraction, provided the number statement for the fraction. Whereas, Student 1 did not agree with the result, to elaborate the concept, Student 1 drew a picture of a combined cake and used colors to indicate that each child obtained one piece of the combined cake. This was challenged by Student 4 and Student 6 by asking Student 1 to provide the answer or the fraction. Thus, Student 1 wrote the number statement to indicate what he meant was that each child got  $2/10$  of the cakes, which was a misconception because of his wrong calculation ( $2/1 \div 5/1 = 2/10$ ). Student 7 pointed out this mistake. Followed by Student 7's comment, Student 5 drew two divided cakes using colors to indicate how many pieces each child got, and provided the fraction for the division. In the collaborative investigation, starting from generating diverse ideas to linking different ideas up via comments, social support, questioning and elaborating, the group members worked out the concepts of division and fractions by themselves and accomplished the task of dividing two pizzas among five children.

#### Idea generating—Yao's student learning

In Yao's class, when the students were asked to work on the problems of dividing the pizzas and cakes on GS, we observed that they were quite at a loss as for how to solve the problems because they could not connect the concept of division with the concept of fractions. In addition, a collaborative inquiry culture was not established in the class. The students focused more on providing one or two answers on the group board for Yao to "judge". Idea linking was rarely found in their group work and there was no social support from each other (Fig. 9).

In Fig. 9a, the group members basically posted their own ideas without linking to other's ideas. In addition, Student 1 and student 2 posted the same number statement about the result of the division. In Fig. 9b, the group members' postings did not seem to relate to each



Note: S = Student

Fig. 9 a and b Student group work on dividing 3 cakes among 5 children and dividing 2 cakes among 5 children

other’s ideas. They used similar drawings, and none of them indicated how many pieces each child could get. Two members posted the number statements. One statement “ $2 \div 5 = 5/2$ ” was incorrect and was identified by another group member, who crossed this statement without giving any reasons to back up the evaluation.

Discussion: Comparison of beliefs, practices and student learning

In this section, we compare the two teachers’ beliefs, practices and student learning by discussing the two research questions: (1) Did the teacher beliefs influence the teacher practices in CSCL environment? If yes, how did the teacher beliefs influence the teacher practices? and (2) Did the teacher beliefs and practices influence student inquiry learning in CSCL environment? If yes, what particular evidence of student learning shows the influence of the teaching beliefs and practices?

Beliefs

As the research findings illustrate, although, both Ping and Yao participated in two cycles of professional development on inquiry learning design and practice in GS-supported CSCL environment. Ping and Yao had very different beliefs about how learning happens and about evidence of student understanding in a CSCL environment. What seemed to be significantly different in their beliefs lay in two aspects. First, to Ping, students learned better in inquiry-based learning environment supported by collaborative technologies, while Yao believed that the students learned better using a content-based and teacher-centred approach. Second, Ping believed in students’ explanation-based understanding, while Yao believed in students’ being able to provide correct answers with technology support. We term Ping’s beliefs as innovation-oriented beliefs, and Yao’s beliefs as teacher-centred beliefs. Drawing on these different beliefs, Ping and Yao enacted the lesson with different practices.

Linking teacher beliefs with teacher practices

Inquiry principle-based practice patterns and integrated inquiry activities

Because beliefs play a major role in teacher decision-making about planning and enactment of instructional activities (Crawford 2007), holding innovation-oriented beliefs, Ping’s practices were identified to be in line with inquiry principles and the lesson activities were

integrated into a progressive inquiry unit using the progressive inquiry approach. This contributed to particular principle-based patterns of practices. The pattern of working on authentic problems and encouraging diverse ideas was recurrent throughout the inquiry activities. According to Hakkarainen (2003), an essential aspect of progressive inquiry is to set up problems that guide the inquiry process, and questions generated by the students' need to have a special value in their inquiry process. Although Ping guided the students to set up the big problems for the inquiry activities, what she valued most was to provide opportunities for the students to generate their own questions, explanations, hypotheses or conjectures for the phenomena being investigated, which is crucial for inquiry (Hakkarainen 2003; Hakkarainen et al. 2002; Krajcik and Blumenfeld 2006). This helped create a collaborative inquiry culture, activate the students' prior knowledge in division and fractions, and facilitate student inquiry processes.

Although the concept of division of fractions is often considered one of the least understood topic in elementary schools; and children are most likely to make mistakes and develop misconceptions in dividing fractions (Tirosch 2000), Ping carefully orchestrated the class activities progressively, guiding the students from developing initial understanding of the concepts of division and fractions, to developing deep understanding of more complicated concepts. This was achieved by the principle-based practice pattern of the interplay between providing collaborative opportunities and doing embedded assessment, followed by the interplay between encouraging diverse ideas and doing embedded assessment.

While Yao attempted to enact her class based on the lesson plan, the enactment of the activities was rather disconnected and task-based. Her practice pattern at the brainstorming stage was characterized as work on authentic problems, seeking correct answers and providing information to the students. In her later activities, Yao focused more on seeking correct answers and making judgment of the students' work because she believed that the students learned if they were able to provide correct answers. The inquiry activities were enacted as procedures (Chan 2011) that she followed to complete her lesson rather than as a progressive inquiry process. Working on these activities did not help students develop deep understanding of the concepts. Yao's practice patterns are suggestive that she did not fully understand the inquiry instructional principles and the progressive inquiry approach, and thus led to a teacher-dominated pedagogy.

The results of the teacher beliefs and practices indicate that only teachers who have a understanding of student inquiry-based learning and technology use tended to have better understandings of instructional principles and produce principled-based practice patterns. Research into knowledge building principle-based understanding has been rising (e.g., Chan 2011; van Aalst and Chan 2007). Chan (2011) posits that these principles may make the complicated constructs more accessible to teachers for interpreting their practices. Our research goes a step further to use inquiry-principles to examine teacher practices and identify principle-based patterns that help orchestrate progressive activities into an integrated whole. These patterns may be applicable to other inquiry learning practices and guide teacher professional development.

### *Inquiry principle-based technology-enhanced orchestration patterns*

According to Dillenbourg et al. (2011), orchestration refers to the real time management of multiple activities and multiple constraints, and orchestration can help expand instructional design. In the inquiry learning practice supported by GS and IWB technologies, the teachers may orchestrate in different ways based on their technological, pedagogical and content knowledge by different teachers with different beliefs. In our study, when Ping enacted the inquiry class, she made use of the affordances of GS and IWB technologies to

enhance her orchestrations of student progressive inquiry mainly at group and whole class levels to facilitate principle-based group participation, collaborative inquiry, and inter- and intra-group and whole class embedded assessment. Hence, the technologies enhanced Ping's real time class management, and made her inquiry learning practice effective.

In enacting the class by focusing on individual performance of the tasks, Yao was not able to make good use of the technologies to orchestrate the class activities cohesively although she was savvy in technology use than Ping. She mainly used the technologies for checking correct answers from different groups or providing information for the students on the technologies. This seems to be due to the fact that because Yao did not have an innovative mindset, and her practices were more liable to be teacher-directed so the technologies were used as a new means towards traditional ends (Salomon 1998). In Yao's case, technology is only a tool that cannot automatically support learning without a mind for pedagogical innovations (Jacobson et al. 2010).

The observations of the technology-enhanced orchestration by Ping and Yao suggest that teachers holding innovation-oriented beliefs were able to integrate collaborative technologies into the unfolding of the principle-based practices. Ping developed principle-based technology orchestration patterns that sought to align curriculum, pedagogy and technology affordances (Dillenbourg et al. 2009). We believe that these patterns of technology-enhanced orchestration at different social levels may serve as professional development tools for helping teachers to enact lessons dynamically in the classroom.

#### Linking teacher beliefs and teacher practices with the student inquiry learning

Ping's "innovation-oriented" beliefs, and inquiry principle-based patterns of practices in organizing progressive inquiry activities and in orchestrating the lesson unit seem to have exerted much impact on the student learning and the way the students used the technologies to support their inquiry process. The results of Ping's student learning reveal the pattern of idea generating, idea linking and intellectual convergence. The students actively participated in collaborative investigation into the problems related to division and fractions, and engaged systematically in question and explanation oriented interactions that led to idea advancement by making use of multi-modal representations, and public spaces and physical proximity affordances of GS technology.

It was noticeable that Yao's students represented very "homogeneous practices" (Hakkarainen et al. 2002, p. 143) of individual idea generating using mono-modal representations on GS technology that was bound to surface-level solutions. Students' own intuitive ideas or theories were not systematically facilitated (Hakkarainen et al. 2002). Regardless of whether the postings were good or not, students rarely questioned and commented on their work supported by the collaborative technology, and neither did they show any appreciation for other's work as a social support. Yao did not hold reformed-based beliefs, resulting in her teacher-centred practice patterns that shaped student learning opportunities (e.g., Hmelo-Silver and Bromme 2007; Sandoval and Daniszewski 2004).

The findings of the student inquiry learning are relevant to inquiry principle-based practices. This suggests that teachers, holding an innovative mindset and enacting principle-based practice, are likely to lead to effective principled-based student inquiry learning.

#### Conclusions

The fine-grained analysis of examining the relationships between teacher beliefs, teacher practices and student learning is an attempt to provide some specificity about the beliefs



that may be pivotal for teacher practices and student learning. First, it is noted in our study that the collections of teacher beliefs about how learning happens and evidence of student understanding appear to be crucial for shaping teacher practices which is in line with the findings in Speer’s research (2008). However, our research is unique in that we examined not only the link between collections of beliefs and teacher practices, but also the link between teacher beliefs and practices with student learning in a CSCL environment that has rarely been touched on in a fine grain detail in this field.

Secondly, our study suggests that using inquiry instructional principles to examine the moment-to-moment teacher practices may be a viable approach to capturing specific elements and patterns in innovative practices linked to teacher beliefs and student learning in a CSCL environment.

Thirdly, the research findings show that teachers, holding “innovation-oriented” beliefs about inquiry-based learning and about explanation-based evidence of student understanding in CSCL environment tend to enact the lesson in patterns of inquiry principle-based practices and technology-enhanced orchestration. These patterns interacted with each other to contribute to particular instances of student inquiry learning, and effective use of technology affordances. We reckon that understanding deeply the intertwined relationship between teacher beliefs, teacher practice and student learning requires the examination of a set of complex factors at multiple dimensions such as cultural beliefs, socio-techno-spatial relations, pedagogical practices and interaction with the “outside world” within multiple contexts. This is what we aim at achieving in our future research into the alignment of teacher beliefs, teacher practice and student learning in a CSCL environment.

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Appendix I

Table 8 Lesson plan on division and fractions

No.	Activity	Means of interaction	Teacher-directed moves	Student-initiated moves
A1	Create collaborative inquiry culture: Brainstorming concepts related to division and fractions.	F-T-F + Whiteboard	Encourage students to think of concepts related to division and fractions.	Express opinions about what they know about division and fractions.
A2	First problem inquiry: “How to divide 2 pizzas among 3 pupils?” to have students working in groups to construct the initial concepts of division and fractions and to do peer evaluation.	GS + F-T-F	Facilitate students to perform the tasks and ask students to explain the results.	<ul style="list-style-type: none"><li>• Work out ways to divide the pizzas on private board and post on Group Board;</li><li>• Explain the fractional units orally by referring to the presentation created on GS;</li><li>• Do peer evaluation</li></ul>
A3	Second problem inquiry: “How to divide different	GS + F-T-F	Facilitate the students to perform the tasks and	<ul style="list-style-type: none"><li>• Work out ways to divide the cakes on private</li></ul>



t8.8

Table 8 (continued)

No.	Activity	Means of interaction	Teacher-directed moves	Student-initiated moves
				cakes among different pupils?" to consolidate the working concept and to do peer evaluation.
			ask them to explain the results.	board and post them on Group Board; <ul style="list-style-type: none"><li>• Explain the fractional units orally by referring to the presentation created on GS;</li><li>• Do peer evaluation</li></ul>
t8.10	A4	Develop deep knowledge by understanding abstract concept about division and fractions.	F-T-F + Whiteboard	Facilitate the students to understand the relationship between division and fractions.
				Do whole class discussion, e.g. <ul style="list-style-type: none"><li>• "2÷5" is the <i>process</i> of division</li><li>• "2/5" is the <i>fraction</i> derived from the process of division</li></ul>
t8.13	A5	Posing a new problem for developing a new working concept about fraction by division and sum up what students have learned.	F-T-F + Whiteboard	Facilitate the students to know how to address division as in an improper fraction.
				<ul style="list-style-type: none"><li>• Do homework. Draw and explain</li><li>• Understand how to derive a proper fraction from a number statement</li><li>• Reflect on how to derive a mixed number from an improper fraction</li></ul>

Appendix II

t9.1

Table 9 Ping and Yao's practices on the lesson division and fractions

Name	Ping (examples)	Yao (examples)
t9.2	Criteria	
t9.3		
t9.4	Working on authentic problems	<ul style="list-style-type: none"><li>• Set up problems/questions familiar and authentic to students with clear instructions (e.g., I have 42 children. I need to put equal number of children into each group? So what I'm I doing?)</li></ul>
t9.5	Encouraging diverse ideas	<ul style="list-style-type: none"><li>• Set up the problems of how to cut pizzas and cakes into equal parts without clear instructions (e.g., You can see a picture of some pizzas. I want you to divide. You are supposed now to draw.)</li></ul>
t9.6		<ul style="list-style-type: none"><li>• Ask students to provide ideas (e.g., What's the difference between 20/20 and 20/5?)</li></ul>
t9.7		<ul style="list-style-type: none"><li>• Accept student's critiques (e.g., Student: The question is not very clear. You have to divide them equally. Teacher: What you said is right...)</li></ul>
t9.8	Providing collaborative opportunities	<ul style="list-style-type: none"><li>• Encourage different ways to divide cakes/pizzas</li></ul>
t9.9		<ul style="list-style-type: none"><li>• Ask students to work in groups on GS (33 min in total): Cutting pizzas, and cutting cakes</li><li>• Ask students to work in groups on GS (19 min in total): Cutting pizzas, and cutting cakes, but collaborative work was not achieved</li></ul>
		<ul style="list-style-type: none"><li>• Encourage groups to contribute their ideas</li></ul>

Table 9 (continued)			
	Name	Ping (examples)	Yao (examples)
t9.12	Criteria		
t9.10		<ul style="list-style-type: none"> <li>Encourage different ways of working at the problems</li> </ul>	
t9.11	Making progressive inquiry	<ul style="list-style-type: none"> <li>Set up problems from low to high levels (e.g., Now you knew how to divide 2 pizzas among 3 children. Let's do a more challenging activity: Different number of cakes for different number of children for groups to do.)</li> </ul>	
t9.12		<ul style="list-style-type: none"> <li>Facilitate students to make progressive inquiries and improve their group work</li> </ul>	
t9.13	Doing embedded assessment	<ul style="list-style-type: none"> <li>Encourage groups to comment on other's ideas (e.g., Why do you cut it this way? Equal parts. Comment on it..)</li> </ul>	<ul style="list-style-type: none"> <li>Ask students to judge other group's work in the whole class (e.g., How about we look at the answers of 1A?)</li> </ul>
t9.14		<ul style="list-style-type: none"> <li>Encourage groups to elaborate their comments or improve their work (e.g., Go back to your Group Board and improve your group work.)</li> </ul>	
t9.15		<ul style="list-style-type: none"> <li>Ask the students to judge other group's work in the whole class (e.g., [Pointing to Group 5's work], How to improve it. Who can improve it?)</li> </ul>	
t9.16	Working on abstract concepts	<ul style="list-style-type: none"> <li>Sum up patterns of divisions and fractions and their relationships</li> </ul>	<ul style="list-style-type: none"> <li>Introduce the concepts of fractions by division using abstract numbers (e.g., <math>9/3</math> or <math>3/9</math>)</li> </ul>
t9.17	Seeking correct answers	<ul style="list-style-type: none"> <li>Ask students to tell correct answers after the teacher's facilitation (e.g., Can you give me the fractions please?)</li> </ul>	<ul style="list-style-type: none"> <li>Ask students to provide correct answers (e.g., "There are two fractions. One is 2 over 3; the other one is 3 over 2, or 1 and <math>\frac{1}{2}</math>. Which one is our answer?")</li> </ul>
t9.18	Providing information to students	<ul style="list-style-type: none"> <li>Provide students information about equal parts of a whole vs parts of a whole (e.g., I'm not just talking about fraction...For example, I only have a piece of cake. This is a fraction of a whole. Now we are going to look at equal parts)</li> </ul>	<ul style="list-style-type: none"> <li>Ask students to follow her instruction to divide the pizza (e.g., cut on the existing cakes directly)</li> </ul>
t9.19			<ul style="list-style-type: none"> <li>When a small number divided by a big number, you usually get something called a fraction, which can be expressed as part of a whole."</li> </ul>
t9.20	Shifting focus of problem inquiry	<ul style="list-style-type: none"> <li>Shift inquiry focus to addition of fractions (e.g., it should be <math>1/3 + 1/3 = 2/3</math>)</li> </ul>	<ul style="list-style-type: none"> <li>Shift inquiry focus from division and fraction to numerator and denominator (e.g., I want to see which number is the numerator and which number is the denominator?)</li> </ul>
t9.21			<ul style="list-style-type: none"> <li>Tend to work usually from a wrong concept to teach a correct concept (e.g., 2 divided by 3 is 3 over 2.)</li> </ul>
t9.22	Making judgement by teacher	<ul style="list-style-type: none"> <li>Tell whether the group work is correct or not (e.g., Let's go to Group3. It's extremely good. I'm very impressed.)</li> </ul>	<ul style="list-style-type: none"> <li>Give comments on groups' work by the teacher in the whole class (e.g., There is something wrong with the drawing (because the parts of the pizza are in different shapes))</li> </ul>
t9.23			<ul style="list-style-type: none"> <li>Tell which group work was "right" or "wrong" (e.g., Now the answer 4 is very misleading.)</li> </ul>

## Appendix III

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**Table 10** Ping and Yao's beliefs

Name	Ping	Yao
Criteria		
Beliefs about how learning happens	<ul style="list-style-type: none"> <li>• Learn better in inquiry-based learning environment</li> <li>• Learn from collaboration supported by GS</li> <li>• Count on social support</li> </ul>	<ul style="list-style-type: none"> <li>• Learn better using content-based and teacher-centred approach</li> <li>• Do not have prior knowledge</li> <li>• Be unable to identify problems without guidance</li> <li>• Develop misconceptions easily</li> </ul>
Beliefs about evidence of student understanding	<ul style="list-style-type: none"> <li>• Take ownership of group work</li> <li>• Have no hard rules and fixed answers</li> <li>• Show patience and believe in students' talents</li> <li>• Use evidence to support answers supported by GS</li> <li>• Be able to tell the reasons for mutual corrections on GS</li> <li>• Understand concepts by being able to apply them</li> </ul>	<ul style="list-style-type: none"> <li>• Provide correct answers on GS</li> </ul>

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## Appendix IV

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**Table 11** Activities within Ping and Yao's practices on division and fractions

Timing	Pre-class preparation	Class activities designed in the teaching plan					Total
Teacher		A1	A2	A3	A4	A5	5 activities
Ping	2 min	9 min	14 min	22 min	3 min	2 min	50 min
Yao	12 min	3 min	13 min	18 min	2 min	0 min	50 min

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