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# Principle-based design: Development of adaptive mathematics teaching practices and beliefs in a knowledge building environment

Huang-Yao Hong [a], [*], Ching Sing Chai [b]

[a] *National Chengchi University, Taiwan, ROC*
[b] *National Institute of Education, Singapore*

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A B S T R A C T

This study investigated teacher-education students' development of adaptive mathematics teaching practices and beliefs in an online knowledge building environment under principle-based design guidance. Participants were students who took a university course titled Middle-School Mathematics Teaching over a year. Data analyses focused on (a) students' collaborative lesson design activities as documented in an online database, (b) students' video-taped teaching practices, and (c) students' mathematical beliefs using a survey. Correspondingly, the results indicate that the principle-based design guidance (a) was conducive in promoting reflective and collaborative knowledge work in the online community, (b) was likely to motivate the participants to progressively practice more adaptive teaching, and (c) facilitated their development towards more constructivist-oriented mathematical beliefs.

## 1. Introduction

This study investigates whether engaging teacher-education students in principle-based innovation activities (Bereiter, 2014) would help them to develop adaptive teaching practices and informed mathematics beliefs. All teacher-education programs aim to cultivate competent future teachers. To this end, a popular approach is to ensure prospective teachers acquire core teaching knowledge and skills identified in literature or from exemplary model teachers (Hirsch, 1996; Slavin & Madden, 2001). Such approach is often associated with direct instruction that encourages practices based on word-for-word teaching scripts (Adams & Engelmann, 1996; Magliaro, Lockee, & Burton, 2005; McMullen & Madelaine, 2014; Slavin & Madden, 2001). In contrast, an alternative approach may be to guide teacher-education students to assume the role of theory-builder or researcher, and to develop more adaptive disposition for sustained improvement in their teaching practices (Bereiter, 2002). Concepts related to such approach include adventurous teaching (Cohen, 1989), creative teaching (Sawyer, 2004), adaptive teaching expertise (Darling-Hammond & Bransford, 2005), and teaching as knowledge-building (Bereiter & Scardamalia, 1993) or as knowledge-creation (Hargreaves, 1999). Yet, while cultivating adaptive teaching practices and attitude is gradually gaining recognition, the question of how to transform teachers into knowledge-workers, teaching into a creative enterprise, and teacher education into a progressive science, remains to be explored (Bereiter, 2002; Darling-

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[*] Corresponding author. National Chengchi University, No.64, Sec.2, Zhinan Rd., Wenshan District, Taipei 11605, Taiwan, ROC.
*E-mail address:* hyhong@nccu.edu.tw (H.-Y. Hong).

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Hammond & Bransford, 2005; Hargreaves, 1999; Sawyer, 2004). If teacher education programs are to prepare future teachers with adaptive competencies and beliefs, it is essential for teacher educators to continue exploring more effective methods of instruction while developing more sophisticated theories. The present study attempted to introduce an innovative principle-based approach (Bereiter, 2014) to teacher education based on the knowledge-building theory (Scardamalia & Bereiter, 2006). Consequently, the researchers examined whether it would better prepare teacher-education students to develop more adaptable teaching practices and more informed beliefs in mathematics. In the following, in order to organize and interpret data, this paper reviews literature related to three areas: mathematics teaching practices, mathematical beliefs, and knowledge-building theory.

## 2. Mathematics teaching practices

Practice is essential to the growth of expertise. According to Hatano and Inagaki (1986), there are two general types of expertise: routine and adaptive. They conceptualized routine expertise as a core set of competencies that is developed through high, but rather narrow, procedural proficiency. An essential dimension of routine expertise is ‘efficiency’. As argued by Hammerness et al. (2005), efficiency means “greater abilities to perform particular tasks without having to devote too many attentional resources to achieve them” (p. 361). Routine expertise in teaching implies that a teacher is able to appropriately apply a set of well-defined knowledge and skills to solve recurring teaching-related problems. Routine teaching expertise is pursued to help teacher-education students master some specified teaching knowledge and skills and apply them efficiently to solve common classroom problems. Typically, such knowledge and skills are identified through research or model teaching (Hirsch, 1996; Slavin & Madden, 2001) and are useful for implementing highly structured scripted teaching (Adams & Engelmann, 1996). Previous research suggests that mastery of routinized teaching knowledge and skills improves students' academic achievements in mathematics (Adams & Engelmann, 1996). Nevertheless, routinized teaching practice emphasizes simple tasks more than complex problem-solving and focuses the teacher mainly towards measurable learning outcomes. Such practice does not take the teacher's creativity and personality into consideration (Sawyer, 2004). Teachers trained in this approach reportedly hold deep rooted beliefs that hamper them from engaging in constructivist oriented use of ICT for teaching and learning (Lim & Chai, 2008). Overemphasis on efficiency through routinized work practice is unlikely to be congruent to current calls for reform towards 21st century learning (Voogt & Roblin, 2012).

In contrast to routine expertise, Hatano and Inagaki (1986) conceptualize the adaptive expertise as the ability and attitude to continuously make adjustments in and add to core competencies for future development (Bransford & Schwartz, 1999; Schwartz & Martin, 2004). Unlike routine expertise, which emphasizes ‘efficiency’, an important dimension of adaptive expertise is ‘innovation’; it means “moving beyond existing routines and often requires people to rethink key ideas, practices, and even values in order to change what they are doing” (Hammerness et al., 2005, p. 361). Accordingly, adaptive expertise in teaching implies that a teacher is able to solve recurring or novel teaching problems by continuously improvising and improving innovative solutions (Darling-Hammond & Bransford, 2005). Adaptive expertise also involves teachers' critical problematization of current established or even best teaching practices to open up new possibilities. Many 21st century learning currently advocated is in fact demanding that students have deep knowledge of what they are learning and concurrently learn how to learn and learn collaboratively (Voogt & Roblin, 2012). When adaptive teaching expertise is deemed a primary goal to be pursued in a teacher-education program, learning (to teach) is likely to emphasize the ability to adapt to new instructional situations and to generate fresh ideas to address emerging pedagogical challenges. Typically, such knowledge and skills are difficult to pre-define, and can only be gradually developed during the process of progressive problem-solving or knowledge-building for better teaching (Hong & Sullivan, 2009; Zhang, Hong, Scardamalia, Teo, & Morley, 2011). The focus of adaptive teaching practices is therefore not to emulate exemplary teaching, but to engage in sustained improvement of one's own practices (Bereiter, 2002; Cohen, 1989; Darling-Hammond & Bransford, 2005; Sawyer, 2004).

Undoubtedly, adaptive expertise in mathematics teaching is an important educational goal for teacher preparation and development (Russ, Sherin, & Sherin, 2011). Hatano and Inagaki (1986) asked the educationally relevant question of how “novices become adaptive experts” (p. 262). Yet the question of how to help engage teacher-education students in a learning-to-teach course that would help them develop more adaptive teaching remains an instructional challenge (Bransford & Schwartz, 1999). Previous research by Schwartz, Martin, and Nasir (2005) showed evidence that students engaged in a more adaptive type of mathematics learning performed better than students engaged in a more routine-based mathematics learning in far-transfer problem-solving tasks. In other words, these students were better prepared for their future learning (see also Martin, Rayne, Kemp, Hart, & Diller, 2005). To develop adaptive teaching, teacher educators have also started to re-think the typical process of learning-to-teach that highlights routine practices (Darling-Hammond & Bransford, 2005). It is posited that in the initial stage of learning to teach adaptively, prospective teachers may feel less certain and comfortable in their teaching, as their new practices will be less efficient compared with previous practices. But to develop adaptive attitude, prospective teachers will need to perceive such initial experiences as a productive learning process rather than as a failed learning outcome (Kapur, 2010). This approach emphasizes that learning-to-teach is more than just the mastery of pre-defined curricular and pedagogical knowledge; it is also to learn how to surpass oneself (Bereiter & Scardamalia, 1993) and to explore and advance one's practices. As such, scripted or routinized practices would be less relevant for teacher-education students in the long run as compared with adaptive teaching. Arguably, less routinized and more adaptation-oriented teaching practices would be likely to provide better opportunities for teacher-education students to develop adaptive disposition leading to better preparation for future learning-to-teach (Darling-Hammond & Bransford, 2005).

## 3. Mathematical beliefs

Ernest (1991) conceptualized two general epistemological views of mathematics: absolutists/foundationalists and or fallibilists, humanists, relativists and constructivists (see also Handal, 2003). The former sees mathematics knowledge as certain, cumulative and unaffected by social interests or personal value. In contrast, the latter believes that mathematics knowledge comes through historical, social and cultural awareness, and that there are limitations to its claims of certainty and absoluteness. The two views are in opposition to each other and studies suggest that people tend to hold one particular views of mathematics. For example, Thompson (1992) indicates that teacher-education students hold beliefs consistent with the more absolutist view of mathematics that sees it as a science of facts and rules. Research by Benbow (1993) reveals that students who enter into teacher-education programs usually possess deeply rooted beliefs aligned with the absolutist view of mathematics; and consequently tend to emphasize the importance of acquiring facts and procedures in the learning of mathematics. Other studies (e.g., Civil, 1990; Nisbert & Warren, 2000) have also shown that most in-service teachers view mathematics as either completely right or wrong, and there is usually one ‘best’ way to arrive at the answer.

Research also shows that teachers' beliefs about the nature of mathematics can influence how they actually teach their students (Thompson, 1992). If teachers see mathematics as a body of facts and procedures to be acquired and applied by students, they are more likely to teach in a more didactic manner, emphasizing the importance of conceptual and procedural knowledge acquisition in mathematics. But if teachers view mathematics as an exploratory and problem-solving process, they are more likely to teach adaptively and flexibly, and accordingly help students explore and construct their own understanding of the mathematics problems (Thompson, 1984). Evidence also suggests that teachers' pedagogical beliefs developed during their teacher education can influence their later classroom performance (Pajares, 1992; Richardson, Anders, Tidwell, & Lloyd, 1991; Wilson, 1990). Yet investigation of belief change and development during the teacher-education period is often neglected or not appropriately addressed within teacher-education programs (Hong, 2014). Most teacher-education curricula are more concerned with preparing future teachers by providing necessary professional content and pedagogical knowledge. Nevertheless, studies have found that teachers’ beliefs can play an even more essential role than their knowledge in influencing their instructional behaviors. For example, Fairbanks et al. (2010) found that even with the same professional content knowledge, teacher candidates practice their teaching in a very different manner, simply because of the differences in their beliefs about what is knowledge and knowing. So, if teacher-education programs want to cultivate future teachers who teach adaptively, they need to address the belief issue.

The challenge, however, is that beliefs are generally difficult to change. In an experiment, Benbow (1995) tried to change preservice elementary teachers’ ($n = 25$) mathematical beliefs and teaching practices by introducing an intervention program. No significant change in these teachers was found at the end of the program. Hammerness et al. (2005) and Richardson and Placier (2001) have made similar observation. Despite this, many scholars continue to argue that fostering positive belief change among pre-service teachers is essential (Brownlee, Purdie, & Boulton-Lewis, 2001; Gill, Ashton, & Algina, 2004; Howard, McGee, Schwartz, & Puecell, 2000). The challenge is to design effective instruction to help teacher-education students to develop more informed, constructive teaching beliefs. More empirical studies are needed to address this challenge.

## 4. Knowledge building

Research shows that beliefs are closely related to learning experiences (Pajares, 1992; Richardson et al., 1991; Schommer, 1994; Wilson, 1990). If students' learning experiences are related to more didactic instructional approaches, it is more likely that they will develop more absolutist-oriented beliefs. As commonly observed in conventional mathematics classrooms, such belief tends to be fostered through encouraging students to rely on textbooks or teachers as authoritative knowledge sources (Cooney, Shealy, & Arvold, 1998; Green, 1971; Schoenfeld, 1989; Szydlik, Szydlik, & Benson, 2003). In contrast, when learners are prompted to learn through more discovery-guided instructional approaches, they are more likely to develop constructivist-oriented beliefs. Similarly, teacher-education students' beliefs can also closely relate to their learning-to-teach and teaching practice experiences. To help teacher-education students cultivate more productive mathematical beliefs, the present study employed ‘knowledge-building’ theory in a mathematics teaching course.

Knowledge building engenders “deep constructivism” (Scardamalia, 2002, p. 4). It is defined as a social process focused on sustained community knowledge advancement (Scardamalia & Bereiter, 2006). Unlike most educational approaches that highlight learning through acquiring and accumulating well-established knowledge, knowledge-building employs ideas as building blocks for advancing deeper knowledge around a specific theme or topic. The importance of valuing ideas as basic units of thought or objects of inquiry was manifested by means of Popper's (1972) 3-World epistemic conceptualization. Popper refers to World-1 as an objective world constituted by natural and physical objects; World-2 as a subjective psychological world constructed within the human mind but not explicated and thus not accessible by others; and World-3 as a conceptual world constituted mainly by ideas (e.g., theories, models) that have been made public. He argues that ideas are the creative results of human beings (such as engineers, scientists, researchers, artists, and the like) and that all forms of human knowledge are related to the creation of ideas in a human community (Scardamalia, 2002). Bereiter (2002) further argues that ideas are conceptual objects which once made public, can possess a social life of their own and can be continually tinkered with, modified, and improved.

To bring about productive community knowledge advancement through improving ideas, Scardamalia (2002) proposed a set of knowledge-building principles. For example, the principle of ‘idea diversity’ states that “[i]dea diversity is essential to the development of knowledge advancement, just as biodiversity is essential to the success of an ecosystem. To understand an idea is to understand the ideas that surround it, including those that stand in contrast to it. Idea diversity creates a rich environment for ideas to evolve into new and more refined forms" (p. 79) (see Scardamalia & Bereiter, 2010; for detailed descriptions for all principles). Typical classroom work is usually defined by pre-specified procedures (see e.g. Dick & Carey, 1990; Mager, 1975), clear rules and scripts (cf. Sawyer, 2004), or highly structured, routinized learning activities (e.g., Merrill, 1983; Gagne, Briggs, & Wagner, 1992) that represent fixed rather than improvable classroom procedures (cf. Hong & Sullivan, 2009). In contrast, knowledge-building highlights the use of abstract principles as guidelines to illustrate some pedagogical challenges that would pave the way towards sustained knowledge advancement for the community's work (Bereiter & Scardamalia, 2006; Bereiter, 2014).

Unfortunately, the contemporary educational systems still tend to focus on learning through knowledge acquisition and accumulation (i.e., understanding World-1 by changing students' mind in World-2), but not working creatively with ideas (e.g., transforming students into knowledge workers in World-3) (Bereiter, 1994; Paavola, Lipponen, & Hakkarainen, 2004). Similarly, teacher-education students are unaccustomed to the ways of assuming the role of theory-builder or knowledge-worker. Instead, they are more often encouraged to emulate exemplary teaching practices after some model teachers. If teacher-education students do not know how to work innovatively as knowledge-workers, it is questionable that they will be able to guide school pupils to develop the kind of innovative competencies essential in a knowledge-based society (Hong, 2011; Zhang et al., 2011). Thus, in addition to learning about content-based knowledge and exemplary teaching practices, it is perhaps equally important to help teacher-education students develop relevant disposition and beliefs for adaptive teaching practice. Previous research on in-service teachers who have been practicing knowledge-building pedagogy for years suggests that such practice may stimulate epistemological growth among these teachers (Chai & Tan, 2009; Zhang et al., 2011). Building on this line of research, it is posited that engaging teacher-education students in principle-based innovation and knowledge-building activities should change their views about the mathematics and their teaching capacity.

## 5. The present study

In the field of computer-supported collaborative learning, there have been studies dedicated to teacher learning (e.g., Barab, MaKinster, & Scheckler, 2003; Greiffenhagen, 2012; Song & Looi, 2012). Particularly, some studies have investigated the relationships between computer-supported collaborative knowledge building and teacher preparation or development (e.g., Cesareni, Martini, & Mancini, 2011; Chan & van Aalst, 2006; Chan, 2011; Laferriere, Lamon, & Chan, 2006; van Aalst & Chan, 2001, pp. 20–28) Nevertheless, few studies have actually explored specific instructional models or approaches in the knowledge building area for fostering mathematic belief change. To address the challenge, this study proposes and tests a principle-based design approach (Bereiter, 2014; Hong & Sullivan, 2009; Zhang et al., 2011). Overall, the principle-based instructional design model is very different from conventional instructional design models that are inclined to foster routinized practices; for example, task-driven instructional design models (Dick & Carey, 1990), Criterion Referenced Instruction (Mager, 1975), and Component Display Theory (Merrill, 1983). Such design approaches tend to emphasize the importance of employing well-defined procedures, rules, and/or componential tasks (Reigeluth, 1996) in order to help students acquire pre-defined knowledge and skills. In contrast, the proposed principle-based approach is characterized by the use of abstract principles to guide students' knowledge work. In this study, three knowledge building principles were highlighted, namely "idea improvement", "epistemic agency", and "community knowledge" (see detail below in the Method section). This study examine the proposed principle-based instructional design approach by answering the following questions: (1) How do the participants in this study engage in their online knowledge work (i.e., lesson design activities) in a principle-based design knowledge building environment? (2) How do the participants develop their mathematics teaching practices and beliefs in a principle-based design knowledge building environment?

## 6. Method

### 6.1. Study design, participants, and instructional context

This case study gathered on-site data embedded in a course context. The duration of the study was a year (from 2008 to 2009)—i.e. two semesters, with each semester lasting about 16 weeks. Participants were nine teaching-education students (four females and five males) and their age ranged from 19 to 23 years ($M = 21$; $SD = 1.59$). The participants were planning to become middle-school mathematics teachers in Taiwan after graduation, so they took this university-level course entitled Middle School Mathematics Teaching. The course is a prerequisite for their student-teaching internship. Students need to complete sufficient theory-based courses—for instance, instructional theories and adolescent psychology before taking this course. The main instructional goal of this course was to foster adaptive practices and disposition in mathematics teaching among the participants, and to help them pass a future teaching-practice examination, which actually requires the examinee to demonstrate his or her teaching in front of a group of expert reviewers. Major research and instructional activities throughout the academic year were as follows: First, A pre-post belief survey was conducted at the beginning and end of the study to measure participants' mathematical belief changes. This was done using open-ended questions concerning the nature of mathematics and that of ideal mathematics teaching and learning (see below for details). Second, a tutorial workshop about how to use an online forum called Knowledge Forum (KF) was conducted in the first two weeks of the school year. Students were introduced to some basic functions of KF, for instance, creating a note in a KF “view” (i.e., an online problem-solving space) or building on a note. The right side of Fig. 1 shows a screenshot of a KF view excerpted from this study. Each square box in this view represents a note generated by a class member. To elaborate, enrich, exchange or improve ideas, members provide comments or suggestions by building on a note. Third, in terms of instructional design, the present study employed a principle-based approach to supporting students' online lesson design activities. The left side of Fig. 1 shows a lesson design cycle implemented in this course and the detailed activities were described as follows.

(1) Lesson ideas: Participants were guided to generate initial lesson ideas; then, they worked on the details such as setting instructional goals, preparing learning materials and worksheets, etc. Before this activity, students were also encouraged to reflect on the teaching problems they have encountered in their previous teaching practice (if any), in order for them to go beyond their current best practice.
(2) Beyond current best practice: Based on lesson ideas, the participants performed their teaching practices in class, with the rest of the classmates serving as the audience and critical reviewers. Each teaching practice took about 25 min. All nine students in this course took turns to practice teaching. There were in total three lesson design cycles implemented in the whole school year.
(3) Peer feedback: The teaching performance was then critically reviewed by all other classmates who would comment on the practiced teaching by identifying issues, acknowledging strengths, and giving constructive feedback for improvement, etc.
(4) Co-design discussion: All participants were further guided to collaboratively discuss some design questions such as: “If you were to design this same lesson, how would you do differently to improve the teaching practices?”; “What is your main design idea?”; “Why is it useful?”; “How is it going to improve this particular teaching?” etc.
(5) Reflection: The student who finished her/his turn of teaching practice could further reflect on her/his video-taped teaching, online peer-feedback, and co-design discussion comments, etc., in order to rise above previous lesson design ideas. Then, she/he will start to prepare for the next design cycle. In addition, the participants were also required to write reflection notes at the end of each practice and a reflection paper at the end of the course.

Supported by knowledge building theory, all the lesson design activities were guided by the following three knowledge building principles: (1) idea improvement, (2) epistemic agency, and (3) community knowledge. To elaborate, the principle of “idea improvement” highlights the importance of treating all lesson ideas as improvable and accordingly participants continuously work “to improve the quality, coherence, and utility of ideas. For such work to prosper, the culture must be one of psychological safety, so that people feel safe in taking risks—revealing ignorance, voicing half-baked notions, giving and receiving criticism” (Scardamalia, 2002, p. 79); the principle of ‘epistemic agency’ states that participants need to “set forth their ideas and negotiate a fit between personal ideas and ideas of others, using contrasts to spark and sustain knowledge advancement rather than depending on others to chart that course for them. They deal with problems of goals, motivation, evaluation, and long-range planning that are normally left to teachers or managers” (p. 79); and the principle of ‘community knowledge’ states that participants' “contributions to shared, top-level goals of the organization are prized and rewarded as much as individual achievements. Team members produce ideas of value to others and share responsibility for the overall advancement of knowledge in the community” (p. 80). The above principles were purposefully selected because ideas (as building blocks of knowledge), epistemic agents (as knowledge workers), and community (as the context for knowledge creation and interaction) represents three essential knowledge-building components—i.e., object, subject, and contexts of knowledge creation (Lin, Hong, & Chai, 2014). These principles were implicitly integrated into the lesson design activities rather than explicitly taught in class. Firstly, to integrate the “idea improvement” principle, participants were encouraged to reflect on the authentic teaching problems they previously encountered (if any), to generate potential lesson ideas for solving these problems, and to improve one another's lesson ideas during the feedback and co-design discussion activities. Secondly, to foster the “epistemic agency” principle, students were encouraged to think in a design mode (Bereiter & Scardamalia, 2006). They take charge of the entire lesson design process from producing initial lesson ideas, practicing their teaching, negotiating with peers during feedback and co-design activities, to becoming a critically reflective practitioner. Lastly, to nurture the “community knowledge” principle, students were encouraged to work collaboratively as a community by engaging in collective idea exchange, feedback, and co-design discussion activities as a community (Hong & Scardamalia, 2014). All the lesson design activities were only guided by the principles. Students did not practice any teaching scripts to acquire certain prescribed core teaching knowledge.

### *6.2. Knowledge forum—an online knowledge-building environment*

While the course was blended, only the tutorial workshop activity and teaching practices were held physically in class (2 h per week throughout a school year); the rest of all other activities (e.g., generation of lesson ideas, peer-feedback, co-design discussion, and self-reflection) were held online in the Knowledge Forum (KF) (the time spent online was about 2 h per week). KF is an online platform that allows users to simultaneously create online postings that explicate ideas. KF runs in both a threaded-text and a graphics mode. In the graphics mode, linkages of postings are depicted to represent the interconnectivity and dialogical nature of knowledge. The students work as a community in KF by explicating their problem of interest,

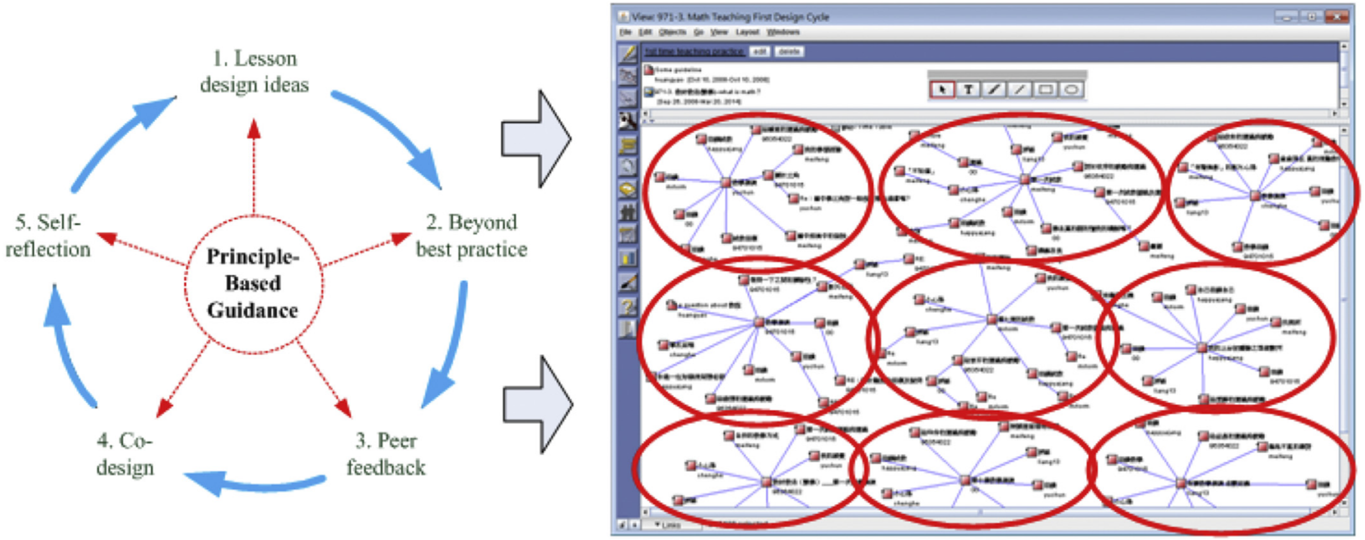


**Fig. 1.** Students' collaborative lesson design activities in Knowledge Forum as guided by knowledge building principles. As there were nine participants in this class, there were nine complete teaching practices in each principle-guided design cycle. The left side of the figure illustrates students' general lesson design process (Note: the design process is not necessarily linear, as ideation, feedback, co-design discussion, and reflection activities can occur anytime in the forum). The right side of the figure shows the collaborative results of the first lesson design cycle, in which each small square represents a note contributed and each connected line implies some built-on discussion comments. Each oval represents the notes created for a complete teaching practice initiated by a given participant.

producing lesson ideas, sharing information, building-on each other's lesson ideas, synthesizing thoughts, and deepening collective understanding of the teaching and design problems at issue. Specifically for this study, a key problem of interest in the course was concerned with improving lesson designs and teaching practices and attaining deeper understanding of the nature of mathematics, mathematics teaching, and mathematics learning.

### 6.3. Data source and analysis

The main datasets came from (a) participants' online activities, (b) video-taped teaching practices, and (c) a pre-post belief survey. Moreover, students were required to write reflection notes after each teaching practice and a final reflection paper at the end of the course. Using mixed-analysis approach, online collaborative activities were quantitatively analyzed, while online feedback/co-design/reflection comments, teaching videos, and belief survey were content-analyzed. Using Chi's (1997) coding techniques, qualitative data were quantified for performing inferential statistics. The following provides more details.

First, online activity data recorded in a KF database were analyzed focusing on two areas: (a) online activities (e.g., note creation and reading) and social dynamics (e.g., network density), and (b) the online feedback/co-design/reflection comments in the three lesson design cycles. Student online activities were analyzed with non-parametric Wilcoxon signed rank tests given the small sample size. This analysis measured the students' progress in terms of the amount of online activities from the first to the second semester. In addition, social network analysis was used to examine network density defined as the sum of the values of all ties divided by the number of possible ties (Wasserman & Faust, 1994).; Higher density scores suggest that a community has stronger social dynamics. In addition, feedback/co-design/reflection comments or suggestions that provide a clear course of action for teaching improvement were identified (e.g., suggesting to give students more response time when asking a question). Content analysis on participants' collaborative knowledge work based on the feedback/co-design/reflection comments was then performed. Zhang et al.'s (2007) concept of ‘inquiry thread’ was employed to trace participants' collective design improvement for teaching practice. Using the open coding process (Strauss & Corbin, 1990) to examine all 368 feedback/co-design/reflection comments recorded in the database, 12 different inquiry threads under two broad types of teaching practices (efficiency-oriented vs. innovation-oriented) were identified (see Table 1). Two coders independently categorized all comments into different inquiry threads and a Kappa coefficient was calculated to be 0.72. Additionally, the following three indicators were used, including the number of feedback/co-design/reflection comments contributed in one particular teaching practice, the number of collaborators who worked together in a teaching practice, and the number of reads (i.e., the number of times online comments were read or referred or reflected by the participants in the database). Wilcoxon signed rank tests were employed to illustrate whether there were any differences between efficiency-oriented and innovation-oriented teaching practices in terms of students' lesson design efforts.

Regarding teaching practices, data mainly came from video-taping of students' teaching practices. In addition, participants' reflection notes written after each teaching practice were used as complementary data. Using activity as unit of analysis, the videotaped teaching practices were parsed from the video and classified into various teaching activities. Next, accuracy of classification of each activity during teaching practices was confirmed by the participants. Then, the activities

**Table 1**
Two design dimensions (efficiency-oriented vs. innovation-oriented) for teaching improvement.

| Design focus | Example of feedback/co-design/reflection comments |
|---|---|
| Efficiency-oriented | |
| Control over lesson plan | I realized that I should not spend too much time talking with students during my teaching practice so that I can more efficiently finish my planned teaching practice in time. (S6) |
| Control over teaching strategies | To use time more efficiently, you may want to explain the concept while you are writing it on the whiteboard, rather than explaining it after writing. (S6) |
| Control over class activity | You may want to have a drill and practice exercise each time when you introduce a property of similar triangles, instead of having all the exercises after introducing all properties and characteristics of similar triangles. (S4) |
| Control over presentation skills | I need to practice more as I often repeated myself, using too many redundant words, and not fluent in my lecture. (S1) |
| Control over what to teach | I suggest that you use hexagonal patterns to teach trigonometric function. (S8) |
| Control over the use of teaching aids | To make your teaching more efficient, you may want to glue soft magnets on the back of your teaching aid, instead of using separate magnets. (S9) |
| Innovation-oriented | |
| Adaptability in teaching design | In my teaching practice in the second design cycle, I did not completely follow my teaching plan/script, but I tried to adapt my teaching methods based on how students responded to my instruction at the moment. (S8) |
| Flexibility in teaching strategies | Your teaching practice has given me some ideas to transform my teaching into more interactive and creative instruction. (S1) |
| Interactive discussion in class | To make your class more engaging, I would suggest you engage students in more interactive discussion using topics that are more related to students' mathematics experiences. (S4) |
| Open and engaging learning environments | It is important for you as a teacher to foster a more open and engaged leaning climate so that students can become more active and interactive learners. (S3) |
| Improvised learning activities | I think it would be helpful to improvise a few activities (e.g., quizzes) to motivate young students and help them learn. (S7) |
| Creative use of learning materials | Some novelists and writers integrate mathematics or physics concepts into their writing and vice versa; we can borrow materials from other disciplines to make the learning of mathematics more interesting and approachable. (S5) |

were content-analyzed based on a coding scheme highlighting three types of instructional activities (Collins, 1996): passive, active, and interactive learning. The passive mode highlighted instructional activities (mainly teacher-led) such as demonstration, direct instruction, lecture, asking factual questions, and the like. The active mode highlighted students' self-directed learning activities, such as hands-on exercises, independent work, quizzes, and the like. The interactive mode highlights team-based interactions (e.g., group discussion, group work, debate, or collaborative problem-solving). For the purpose of analysis, this study examined the percentage of time spent on each mode of activity for each of the different teaching practices. Two coders independently coded each class activity into a mode. The inter-coder kappa was calculated to be 0.91.

Finally, the pre-post belief survey was developed based on Handal's (2003) conceptualization of mathematics beliefs in three aspects: views of the nature of mathematics, views of mathematics teaching, and views of mathematics learning (see also Ernest, 1991). A previous study by Tsai (1998) investigating students' epistemological beliefs in natural sciences used a belief survey with eight open-ended questions. This study adopted Tsai's survey, with minor text revision (e.g., changing the word ‘science’ into ‘mathematics’). The eight questions are as follows: (1) What is mathematics? (2) What does doing mathematics mean to you? (3) What is an ideal way to teach mathematics? (4) What are some key factors for successful mathematics teaching? (5) What makes an ideal mathematics teacher? (6) What is an ideal way to learn mathematics? (7) What are some key factors for successful mathematics learning? (8) What makes an ideal mathematics learning environment? Of the items, questions 1 and 2 concern the nature of mathematics; questions 3 to 5 concern the nature of mathematics teaching; and questions 6 to 8 concern the nature of mathematics learning. Using each response as unit of analysis and a predetermined coding scheme developed based on the above conceptualization of mathematics beliefs (Handal, 2003) (see Table 2), content analysis was employed to extract themes from the responses and then to record the occurrence of each theme for statistics purpose; then Wilcoxon signed rank tests were conducted to measure if there were any pre-post belief changes. Two coders independently performed the coding process. The inter-coder kappa was calculated to be 0.95. In addition, students were asked to write a year-end, final reflection paper and this dataset was used to complement the above analysis on belief survey.

## 7. Results and discussion

### 7.1. Online collaborative design activities

In this course, students were guided, under knowledge-building principles, to work collaboratively as a community to help one another improve their lesson design and practice and accordingly to advance their understanding about the nature of mathematics, mathematics teaching, and mathematics learning. To this end, they contributed lesson ideas online and collaboratively worked with and reflected upon these ideas. The following analysis summarizes participants' online performance in two areas: (a) online activities and social dynamics, and (b) improvement patterns of their design ideas. First, Table 3 shows overall KF activities. Overall, the participants contributed 160 notes ($M = 17.8$ and $SD = 4.29$) in the first semester and 242 notes ($M = 26.9$ and $SD = 2.52$) in the second semester. There was a significant increase from the first to the second semester for the three main KF activities, including number of notes created, number of notes read, and number of notes built-on. In addition, social network analysis was conducted to explore connection patterns and network density for ‘note-reading’ and ‘note-building’. Fig. 2 shows the connection patterns in the community in each of the two semesters. In the Figure, each node represents a participant, each line between two nodes represents a relationship (i.e., note-reading or note-building), and the numbers on each line represent the number of connections between one participant/node and another. As is shown, all nine participants worked closely with one another in both semesters. The results (see Table 4) show that there was an overall increase in network density over time from the first to the second semester. In particular, the increase for note-reading was statistically significant.

Second, content analysis on students' notes revealed that there are 12 emerging inquiry threads that were developed from a total of 368 feedback/co-design/reflect comments contributed in the KF throughout the school year. To explore the collaborative design processes among participants, analysis was performed to look into how collaborative design activity was sustained over time. The results are shown in Fig. 3, in which the top (vs. lower) half is represented by students' three discussion cycles with a focus on efficiency-oriented (vs. innovation-oriented) teaching practices. Moreover, the figure contains 12 straight lines, each representing a discussion thread, and the black dots in each straight line denote the distinct feedback/co-design/reflection comments. The three numbers inside each parenthesis indicate number of comments being contributed, number of collaborators involved, and number of reads occurred in each teaching practice (see the figure vertically) or each idea/inquiry thread (see the figure horizontally). For example, (11, 8, 79) in P1 (i.e., the 1st teaching practice) under the efficiency-oriented teaching practices means that there were 11 comments being contributed/worked-on by eight different collaborators in this particular practice, with these comments also being read/reflected for 79 times in the database. Overall, there were more collaborative design efforts towards improving efficiency-oriented teaching practices than innovation-oriented teaching practices, as indicated by the number of comments ($M = 9.22$, $SD = 3.45$, for efficiency-oriented practices; $M = 4.41$, $SD = 3.05$, for innovation-oriented practices; $z = -3.56$, $p < 0.001$), the number of collaborators ($M = 6.26$, $SD = 1.70$, for efficiency-oriented practices; $M = 3.74$, $SD = 2.46$, for innovation-oriented practices; $z = -3.16$, $p < 0.01$), and the number of reads ($M = 67.41$, $SD = 27.28$, for efficiency-oriented practices; $M = 32.70$, $SD = 23.25$, for innovation-oriented practices; $z = -3.48$, $p < 0.001$). But when each individual lesson design cycle was examined over time, there was progressive change towards less routinized teaching practices and more adaptive teaching practices from the 1st to the 3rd design cycle.

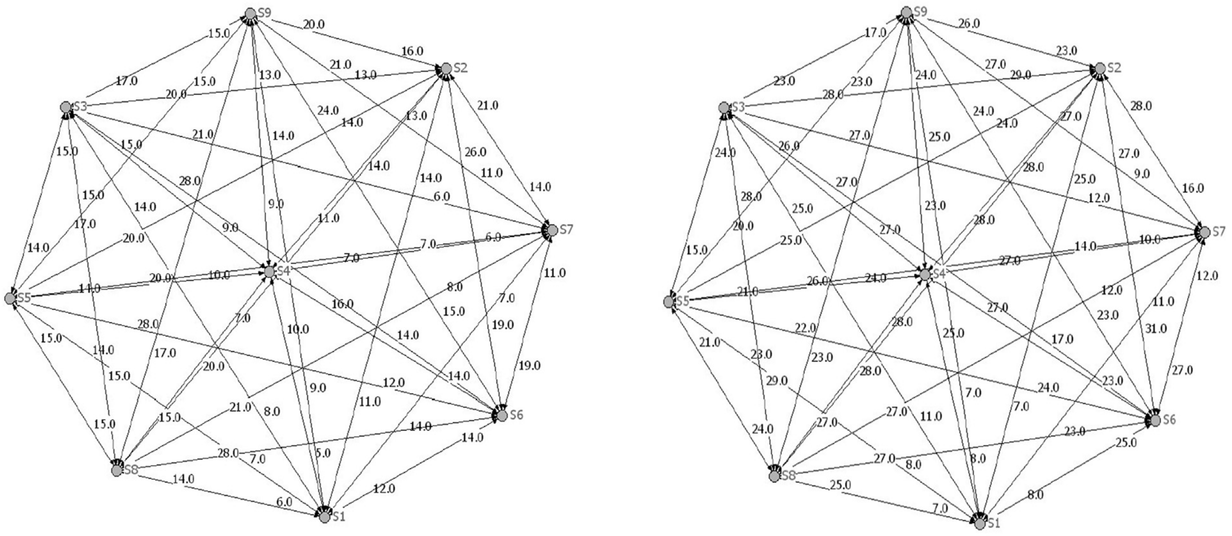
**Table 2**
Coding scheme of mathematical beliefs.

| Category | Theme | Example |
|---|---|---|
| **Absolutist-oriented beliefs:** Regarding mathematics as a set of tools, consisting of formulas, theorems and theories. Students need to master the use of tools in order to achieve teaching objectives (Ernest, 1989). | **Mathematics**: is a science (or group of related sciences) dealing with number, quantity and measure (Risteski, Carlos, & Garcia, 2008). | - Mathematics is geometry, algebra, statistics, probability, number, quantity, etc.—a combination of different mathematical knowledge and [tools]. (S1).<br>- Math is a science about calculating numbers. (S4) |
| | **Mathematics teaching**: is to train students' thinking ability. | - I think Mathematics is a subject that trains and exercises our brain. (S2).<br>- The best way to teach a math course is to lecture, using the simplest and most straightforward way to explain concepts in order to help students understand them, as complex mathematics builds upon simple mathematical facts and concepts. (S1). |
| | **Mathematics learning**: is to acquire basic mathematics concepts and procedures by means of continual practices. | - Practice makes perfect. (S3)<br>- The more you think, try, and practice math quizzes/problems the better you can solve similar quizzes or problems and understand the concepts and facts that are required to solve these problems. (S5). |
| **Constructivist-oriented beliefs**: Mathematics is a course of dynamic exploration and creative invention. The course includes making mistakes and sustained revision and correction. Mathematics does not necessarily represent absolute truth or eternal knowledge, but can be validated or falsified by continual exploration and improvement (Ernest, 1989). | **Mathematics**: is a science of exploring patterns, orders, and relations (Franklin, 1994). | - Doing mathematics is to seek for patterns or principles by means of given conditions, using symbols and numbers to predict, estimate, or conjecture possible outcomes. (S9)<br>- Math is a way to find patterns and orders in life, through the use of symbols and numbers and that of logical thinking … math provides a means to knowing the world, exploring rules in complex affairs, and reducing errors. (S4) |
| | **Mathematics teaching**: is to help students develop their own way of mathematics learning, and to guide them to explore and solve problems, through discussion and collaboration. | - It is (a) to make students like math and be interested in it; (b) to want to explore a math problem in depth and discuss with others about it; (c) to be willing to collaborate with others and try various means collectively to solve problems. (S9).<br>- I think teaching is not to lecture myself, but is to provide opportunities for students to explore math in a natural way, to frequently interact with students and to motivate students to think about problems, to allow students to try and learn from their own mistakes, by giving them enough time to think and discuss among themselves; one-way talking will be unlikely to motivate students to learn. (S8). |
| | **Mathematics learning**: is to develop one's own way of understanding through mathematical problem-solving. | - It is to establish one's own learning style by learning how to learn math and by working and discussing with others; by accumulating such experiences, one will not be limited to one's habitual ways of thinking and will be able to think from multiple perspectives, and be able to come up with even better solutions to the same math problem. (S6).<br>- Learning is to explore and identify a more systemic way for one's own math learning and to gradually develop more effective learning processes. (S2). |

**Table 3**
Summary of major online activities in Knowledge Forum (N = 9).

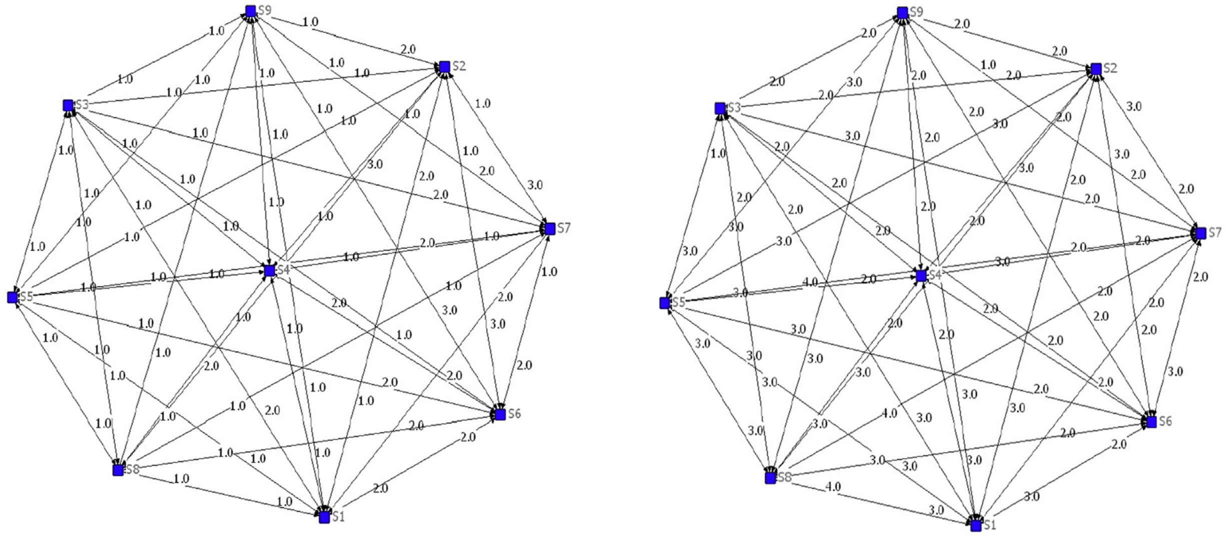
| Activity | First semester | | Second semester | | z value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| No. of notes created | 17.8 | 4.29 | 26.9 | 2.52 | $-2.55^{**}$ |
| No. of notes read | 140.2 | 32.94 | 205.9 | 56.07 | $-2.67^{***}$ |
| No. of notes built-on | 11.3 | 2.49 | 19.9 | 1.90 | $-2.68^{***}$ |

$^{**}p < 0.01$ $^{***}p < 0.001$.



a. Note reading (First Semester)

b. Note reading (Second Semester)



c. Note linking (First Semester)

d. Note linking (Second Semester)

**Fig. 2.** Interaction patterns in the community from the first to the second semester (N = 9).

**Table 4**
Changes in terms of network density in this community (N = 9).

| Network density | First Semester | | Second Semester | | t value |
|---|---|---|---|---|---|
| | M | SD | M | SD | |
| Note-reading | 14.40% | 5.35% | 21.60% | 6.81% | −4.91** |
| Note-linking | 3.49% | 2.55% | 4.58% | 2.16% | −1.86 |

*Note*. Network density was calculated using the actual values shown in Fig. 2. If these values were converted to simple binary values ('0' = connected, and '1' = connected), the network density would be 100% for both note-reading and note-linking, in both semesters.
**$p < 0.01$.

Specifically, in the 1st cycle, collaborative design effort towards improving teaching practices was more routinized than adaptive, as indicated by the number of comments (M = 11.67, SD = 3.12, for efficiency-oriented practices; M = 2.78, SD = 2.39, for innovation-oriented practices; $z = -2.68$, $p < 0.01$), the number of collaborators (M = 7.00, SD = 0.87, for efficiency-oriented practices; M = 2.67, SD = 2.40, for innovation-oriented practices; $z = -2.54$, $p < 0.05$), and the number of reads (M = 82.67, SD = 27.17, for efficiency-oriented practices; M = 19.67, SD = 17.05, for innovation-oriented practices; $z = -2.67$, $p < 0.001$). In the 2nd design cycle, there were relatively less collaborative design efforts towards routinized practices and more collaborative design efforts towards adaptive practices, but the distribution of comments remained to be more focused on routine than adaptive teaching practice: as indicated by the number of comments (M = 9.44, SD = 2.51, for efficiency-oriented practices; M = 5.22, SD = 2.95, for innovation-oriented practices; $z = -2.14$, $p < 0.05$), the number of collaborators (M = 6.67, SD = 1.66, for efficiency-oriented practices; M = 4.33, SD = 2.50, for innovation-oriented practices; $z = -1.90$, $p = 0.058$), and the number of reads (M = 73.89, SD = 20.26, for efficiency-oriented practices; M = 40.78, SD = 23.04, for innovation-oriented practices; $z = -2.07$, $p < 0.05$). In the 3rd design cycle, however, the difference between the routine and adaptive teaching practices became statistically insignificant; as evidenced by the number of comments (M = 6.56, SD = 2.79, for efficiency-oriented practices; M = 5.22, SD = 3.38, for innovation-oriented practices; $z = -1.01$, $p = 0.313$), the number of collaborators (M = 5.11, SD = 1.90, for efficiency-oriented practices; M = 4.22, SD = 2.39, for innovation-oriented practices; $z = -0.71$, $p = 0.48$), and the number of reads (M = 45.67, SD = 20.73, for efficiency-oriented practices; M = 37.67, SD = 25.35, for innovation-oriented practices; $z = -0.83$, $p = 0.41$). The results suggest that progressively the participants were developing a more adaptive disposition towards their teaching practices.

The content of participants' feedbacks/co-design/reflection comments were further examined to explore how collaborative design efforts for improving efficiency-oriented or innovation-oriented teaching practices was qualitatively sustained over time. In terms of collaborative design efforts towards the efficiency-oriented teaching practices, for instance, the first inquiry thread in the figure (with 27 comments) was concerned with “control over lesson plan”. In the 1st design cycle, it was found that the participants' comments were highly concerned about how to control their lesson plans with greater accuracy. Such comments include “I realized that I should not spend too much time talking with students during my teaching practice so that I can more efficiently finish my planned teaching practice in time” (S6 in P3 or the 3rd practice); and “Based on my teaching plan, my teaching pace was too fast, so I need to slow down to better help students acquire the knowledge I want to teach” (S8 in P6). In the 2nd design cycle, the participants still paid much attention to whether they were teaching according to their lesson planned, even though there were relatively fewer feedbacks contributed. For example, some participants commented, “I need to be more consistent in my classroom management as I was always behind my teaching schedule” (S4 in P13), and “I need to carefully follow my lesson plan step by step to avoid unexpected interruption so that I can practice my teaching more as I planned” (S3 in P18). In the 3rd design cycle, comments concerning “control over lesson plan” was greatly reduced. The comments also became less harsh; for example, “You may want to make sure there is still room to include additional learning activities in your lesson plan” (S1 in P21); and “You still need to work on time management, although you have done a good job to cover all the materials you planned to teach” (S9 in P24). These excerpts indicated that participants' collaborative design efforts towards teaching practice became progressively less routine oriented.

In contrast, participants' collaborative design efforts towards innovation-oriented teaching practices also changed over time. For example, in the inquiry thread titled “adaptability in teaching design” (which received 29 comments), it was found that the participants did not generate any comments or ideas that were suggestive of more adaptable teaching practices in the 1st design cycle. However, in the 2nd design cycle, they began to produce and share comments related to adaptive teaching. For instance, some participants commented: “If you could flexibly provide more time for students to take over their learning path, that could better enrich their learning experiences and you would also learn how to teach in a less rigid manner” (S9 in P10); and “In my teaching practice in the second design cycle, I did not completely follow my teaching plan/script, but I tried to adapt my teaching methods based on how students responded to my instruction at the moment” (S8 in P13). Entering into the 3rd design cycle, it can be seen that participants' disposition towards innovation-oriented practices was becoming obvious. For example, some participants commented, “You have been dedicated to improving your teaching skills, but since every teacher has different personality traits, I suggest that you think about how to adapt your teaching strategies by making good use of your personality strengths” (S1 in P22); and “You need to think about how to empathize with students in order to improvise; the question is not how to teach, but to help students learn by using appropriate method at the right moment” (S6 in P25). These excerpts indicated a shift towards progressively more innovation-oriented teaching practices.

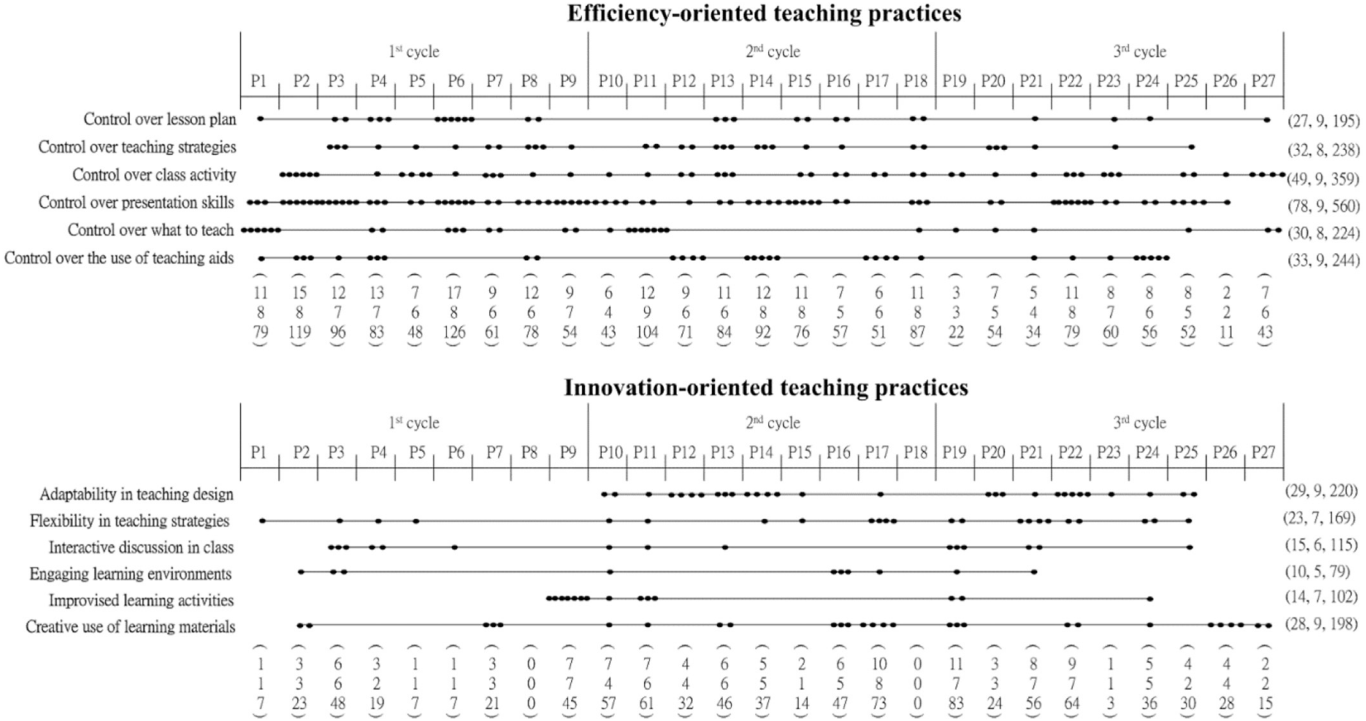


**Fig. 3.** Online collaborative design efforts to improve efficiency-oriented and innovation-oriented teaching practices.

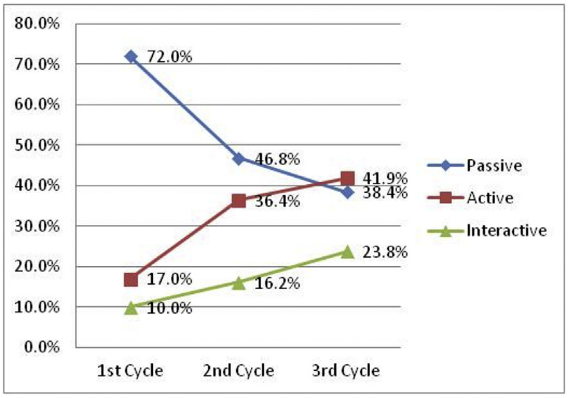


**Fig. 4.** Percentage of time spent in different instructional activities in three design cycles.

An intended goal of this course was to engage students in collaborative lesson design work for teaching improvement. Therefore, it was posited that students would progressively become more comfortable working collaboratively in KF. Overall, the increased online activities and enhanced social dynamics suggested that this is the case. Additional content analysis on the online feedback/co-design/reflection comments also suggested that the participants were able to progressively develop a more adaptive disposition towards mathematics teaching practices.

### *7.2. Change in teaching practices and beliefs*

All 27 teaching practices (3 per students over two semesters) were video-taped and uploaded for peer feedback, co-design discussion, and self-reflection. Video analysis was conducted to examine changes in teaching practices. Fig. 4 shows results in terms of percentage of time spent in the three different modes of instructional activities (passive vs. active vs. interactive learning) from the first to the last teaching practices. It was found that there was a progressive decrease in terms of the percentage of time used for passive learning activities, with the activity time spent in the practices being 72.0% (SD = 17.4%), 46.8% (SD = 19.5%), and 38.4% (SD = 17.1%). In contrast, there was a progressive increase in trend in terms of the percentage of time allocated to active learning activities, with the activity time spent in the practices being 17.0% (SD = 12.9%), 36.4% (SD = 18.6%), and 41.9% (SD = 13.8%). Moreover, it was found that there was a progressive increase in the percentage of time allocated to interactive learning activities, with the activity time spent in the practices being 10.0% (SD = 14.0%), 16.2% (SD = 13.3%), and 23.8% (SD = 12.2%).

Second, regarding general epistemological views in mathematics, as Table 5 shows, the Wilcoxon signed rank tests showed that there was significant decrease in ratings from pre-survey to post-survey in terms of absolutist-oriented views ($z = -2.25$, $p < 0.05$); in contrast, it was found that there was significant increase in ratings from pre-survey to post-survey in terms of constructivist-oriented views ($z = -2.67$, $p < 0.01$).

Further analyses were conducted to look into the three specific aspects of the epistemological views (beliefs in the nature of mathematics, beliefs in mathematics teaching, and beliefs in mathematics learning). First, regarding absolutist-oriented views, a significant pre-post change was found only in participants' beliefs in mathematics teaching ($z = -2.23$, $p < 0.05$). There was no significant pre-post change in participants' beliefs regarding the nature of mathematics and belief in mathematics learning. This may reflect that students still believed that acquisition of mathematical facts is needed as a base for

**Table 5**
Participants' mathematical beliefs.

| Mathematical views | Pre-survey | | Post-survey | | z value |
|---|---|---|---|---|---|
| | M | SD | M | SD | |
| Absolutist-oriented beliefs | 9.89 | 4.40 | 4.56 | 2.79 | 2.25* |
| - Mathematics: is a science (or group of related sciences) dealing with number, quantity and measure | 3.67 | 1.87 | 2.11 | 2.37 | 1.13 |
| - Mathematics teaching: is to train students' thinking ability | 4.11 | 2.42 | 1.89 | 1.36 | 2.23* |
| - Mathematics learning: is to acquire basic mathematics concepts and procedures and to practice again and again. | 2.11 | 2.2 | 0.56 | 0.73 | 1.7 |
| Constructivist-oriented beliefs | 0.89 | 1.05 | 10.22 | 6.63 | −2.67** |
| - Mathematics: is a science of exploring patterns, orders, and relations | 0.00 | 0.00 | 2.56 | 2.07 | −2.39* |
| - Mathematics teaching: is to help students develop their own way of mathematics learning, and to guide them to explore and solve problems, through discussion and collaboration | 0.67 | 0.87 | 3.67 | 4.42 | −1.98* |
| - Mathematics learning: is to develop one's own way of understanding through mathematical problem-solving | 0.22 | 0.44 | 4.00 | 2.06 | −2.53* |

*<0.05 ** < 0 .01.

higher levels of mathematics learning. Further study is needed to confirm whether this is the case. On the other hand, it was found that all three aspects of the constructivist-oriented views showed significant pre-post changes ($z = -2.39$, $p < 0.05$, in terms of beliefs in the nature of mathematics; $z = -1.98$, $p < 0.05$, in terms of beliefs in mathematics teaching; and $z = -2.53$, $p < 0.05$, in terms of beliefs in mathematics learning).

## 8. Summary and discussion

This case study documented how teacher-education students progressively changed their mathematics teaching practices and beliefs during three lesson design cycles in a knowledge-building environment under principle-based design guidance (Hong & Sullivan, 2009; Zhang et al., 2011). The major findings corresponding to the two main research questions are summarized as follows: (1) In terms of online collaborative lesson design, there were significant increases over time in the online activities, including note-posting, note-reading, and note-linking. The network density also increased as the course progressed, indicating consistent engagement in and enhanced community awareness of online design activities. Moreover, the analysis of feedback/co-design/reflection comments showed that the collaborative lesson design efforts were moving towards advancing more adaptive teaching practices. (2) The video analyses showed the participants gradually shifted from teaching that promotes passive learning to teaching that promotes active and interactive learning. Analysis of pre-post mathematic belief surveys showed that there was a significant decrease in the number of comments advocating more absolutist-oriented views. In contrast, comments supporting more constructivist-oriented views increased significantly.

Overall, the three knowledge building principles employed as lesson design guidance in this study were found to be very helpful. First, "idea improvement" encouraged the participants to create and tinker (or experiment) with new lesson ideas for the continual improvement of their teaching practices. As the findings suggested, the participants became gradually aware of both "efficiency" and "innovation" dimensions, rather than just emphasizing the "efficiency" dimension for their lesson design. An idea-centered environment nudges students to tinker or experiment with emergent ideas as tinkering or working creatively with ideas. Previous research regarding how experienced teachers improve their instruction also suggests that tinkering plays an important role in more active, interactive, and innovative teaching practices (Stevens, 1988; Zhang et al., 2011). In a review, Hargreaves (1999) also maintains the importance of tinkering among teachers as a key to successful knowledge creation in a school organization.

Second, the principle of "epistemic agency" encouraged the participants to frame all lesson design activities in a design mode of thinking. According to Bereiter and Scardamalia (2006), design mode of thinking highlights the ability to go beyond the justification of truth and to work innovatively with ideas. Creative knowledge work usually requires such a mode of thinking (Cross, 2007). As Bereiter and Scardamalia (2006) further pointed out, in order to guide learners to work in a design mode, it is important to encourage students as knowledge workers to reflectively ask themselves questions such as: (1) What is this idea good for? (2) What does it do/fail to do? (3) How can it be improved? In the present study, the participants were guided to ask similar design questions such as: "If you were to teach this same lesson, how would you do differently to improve the teaching practices?"; "What is your idea?"; "Why is it useful?"; and "How is it going to improve teaching?" In contrast, the belief mode of thinking, which represents a dominant way of intellectual life in schools, highlights the ability to evaluate and validate claims using the criteria of true and justified beliefs. When students are engaged in knowledge work that is based on belief mode of thinking, they tend to ask questions such as: Is it true? Is it reasonable? What are the assumptions? Such mode of thinking may lead teacher-education students to assume that becoming a good teacher means to validate and master pre-identified "best teaching practices". Consequently, they focus on mastering highly-scripted teaching to help students to perform appropriate mathematics calculations and develop related mathematical knowledge to pass examinations. . The participants' first teaching practice was indeed more efficiency-oriented. Although routinized mathematics teaching practice can be helpful for students to acquire relevant conceptual and procedural mathematics knowledge with efficiency, it may not be very helpful to guide students to see mathematics as a creative instrument (Ernest, 1989). As the conventional mathematics education in Taiwan is still largely concerned with helping learners prepare for tests and the participants did not have much teaching experience, it was not surprising to find in the pre-survey that participants' mathematical beliefs initially tended to be absolutist-oriented.

Third, the principle of "community knowledge" pushed the participants to collaborate opportunistically while interacting with emergent lesson ideas for teaching improvement. Such opportunistic collaboration is very different from structured or planed collaboration such as jigsaw collaboration (Aronson & Patnoe, 1997) or reciprocal teaching (Palinscar & Brown, 1984). A strength of well-structured collaboration is that collaborators can efficiently help one another master pre-defined teaching knowledge and skills. But structured collaboration may foster routine expertise that highlights repetitive pursuit of predetermined teaching skills. As a result, the preservice teachers may create for themselves a comfort zone—i.e., a mental state within which one can demonstrate a clearly defined set of knowledge or skills with a strong sense of security (White, 2009)—and be complacent with their current level of teaching practices. In contrast, working in a knowledge building community requires the participants to go beyond best practice and to think and reflect critically in pursuit of progressively more promising teaching practices that were discussed in the community (Bereiter & Scardamalia, 1993; Paavola et al., 2004). Going beyond best practice represents an important resource of adaptive or creative teaching expertise (Bereiter & Scardamalia, 1993). Collaborating opportunistically to continually improve lesson ideas and teaching practices seems to help the participants to teach adaptively. As the students experienced collaborative design as a way to build theoretical knowledge, they are also likely to wonder about how lesson can be designed to foster collaborative knowledge construction in their lesson ideas. The concurrency of experiencing collaborative idea-centered education as a way to build knowledge about teaching and designing collaborative idea-centered lessons as a way to teach could be important (see Chai & Tan, 2009; Hong & Sullivan, 2009).

In sum, a main factor why the students could participate in a highly engaging and collaborative manner in their online design work seems to have to do with the fact that the principle-based design fostered emergence of new lesson design ideas for continuous improvement of teaching practice. This is very different from a content-driven instructional approach that highlights learning-to-teach based on a well-structured curriculum. Under such mode of teacher preparation, teacher-education students are often encouraged to master some pre-defined core teaching knowledge and skills, and they are usually not given enough time and opportunities to express and experiment with novel ideas for teaching. Papert (1991) uses the term 'disempowering ideas' to describe the kind of educational phenomenon in which learning activities pertaining to idea generation and improvement are not valued and encouraged in a learning environment. The consequence of the 'disempowering ideas' phenomenon is the possible development of a mentality of 'idea aversion' among students—i.e., a strong bias against ideas while favoring the learning of fixed skills and facts (Papert, 1991)—which is in sharp contrast with the goal of this course to foster an idea-centered, principle-guided knowledge building environment.

## 9. Conclusions and implications

> To successfully prepare effective teachers, teacher education should lay a foundation for lifelong learning. However, the concept of lifelong learning must become something more than a cliché. Given the relatively short period available for preparing teachers and the fact that not everything can be taught, decisions must be made about what content and strategies are most likely to prepare new entrants to be able to learn from their own practice, as well as the insights of other teachers and researchers. (Darling-Hammond & Bransford, 2005, p. 359, p. 359)

It is thought that helping pre-service teachers develop the necessary skills and attitude for lifelong learning is of great consequence to the teaching profession (Bereiter, 2002; Hong, Chen, Chai, & Chan, 2011). To address this challenge, the present study focused on an instructional shift—from learning-to-teach by following a lesson script (Adams & Engelmann, 1996; Magliaro et al., 2005; McMullen & Madelaine, 2014; Sawyer, 2004; Slavin & Madden, 2001), to learning-to-teach by working innovatively with lesson design ideas under the guidance of three knowledge building principles (Bereiter, 2002). While scripted teaching practices can help teacher-education students acquire greater abilities in routinized teaching performance with high efficiency, such mode of teaching might lead practitioners to develop a habit that is inclined to seek a strong sense of mental security (White, 2009). In contrast to this approach, using knowledge building principles to guide teacher-education students to work innovatively with ideas for teaching practice is more likely to lead them to think beyond routines, to tinker with new lesson ideas, to continuously adapt their teaching to learners' needs, and to develop progressively more flexible and personalized teaching practices (Hammerness et al., 2005). Further, the present study also tried to enable another instructional shift from 'individualistic' processes to 'collaborative' knowledge advances for learning-to-teach (Shulman & Shulman, 2004; Hammerness et al., 2005). Arguably, most ways of individual learning for personal knowledge growth in teaching preparation need to be balanced with opportunities for more collaborative learning and knowledge sharing (Darling-Hammond & McLaughlin, 1995; Grossman, Wineburg, & Woolworth, 2001; Hammerness et al., 2005; Palinscar, Magnusson, Marano, Ford, & Brown, 1998). Particularly for teacher education, students need to be provided with more opportunities to work collaboratively, reflectively, and innovatively as a professional community for teaching knowledge advancement.

As 'deep constructivism' (Scardamalia, 2002, p. 4), knowledge-building attempts to guide classroom activities away from proceduralized tasks to innovative knowledge work (Zhang et al., 2011). Previous studies ranging from elementary-school classroom settings to university context provided convincing examples of what students can achieve in knowledge-building classrooms in the advancement of knowledge (e.g., see a special issue of the *Canadian Journal of Learning and Technology on knowledge-building*, Volume 36/1). In the present study, the findings further suggest that engaging teacher-education students in sustained knowledge-building in a teacher-education course could help the teacher-education students (a) learn to teach with progressively more adaptive disposition, and (b) develop more adaptable practices and constructivist-oriented views that sees teaching as adventurous and improvable. Adaptiveness, whether in teaching practice or some other form of professional practices, is highly priced in contemporary knowledge society (Bereiter, 2002, 2014; Voogt & Roblin, 2012).

The results of this study have some implications for teacher preparation. First, a long-standing challenge in teacher-education has been to help teacher-education students develop more competent teaching practices and attitudes. The findings suggest that principle-based instruction can help address this issue by providing teacher-education students with opportunities to learn-to-teach by working more adaptively. These principle-guided activities helped teacher-education students reflect on the typical ways of routinized teaching practices used in class while progressively tinker with new lesson design ideas. Second, in order for students to experiment with more adaptive teaching practices, more flexible teacher-education curriculum should be provided. In such a curriculum, teaching knowledge should be less prescriptive. The curriculum needs to encourage students to develop a strong sense of what (lesson ideas or teaching practices) are promising or problematic and how to improve them. How to design such a flexible and perhaps customizable curriculum represents an important area of future research. Finally, the principle-based design proposed in this study highlights the importance of learning *by group*, rather than learning *in group*, as well as *opportunistic* rather than *pre-structured* knowledge collaboration. This view of collaboration goes beyond individualistic learning and personal knowledge growth in a group to encompass the notion of viewing a whole class as a community where its learning goal co-evolves with the learning interests of community members, moving towards a collective aim of advancing community knowledge. Understanding how to create the appropriate conditions to foster such collaborative efforts in a course remains an important area for future research.

Admittedly, there are limitations in this study. First, there is a need for greater consideration regarding generalizability from a single class of only nine students. Although studies grounded in analyses of a single course may still be generalizable, as insights developed from such analyses can inform the interpretation of instruction in similar settings (e.g., Cobb, 2001; Steffe & Thompson, 2000), further research is needed in more diverse classroom environments. Second, while it is hypothesized that the changes in mathematics teaching practices and beliefs were made possible through principle-based design, as this is a case study, it is difficult to precisely specify the extent to which changes were made possible due to the proposed instruction. For future study, it would be better to compare how different designs influence students' learning in order to provide more substantiated evidence. Finally, it is also unclear whether the instruction would contribute to long-lasting belief change among the participants. It would be necessary to investigate further if the effects (i.e., changes in both teaching practices and beliefs) can be sustained over time.

In sum, this study examined the educational value of a principle-based instructional design which emphasizes using principles to guide an emerging teaching improvement process for collective knowledge work in a community. The results suggest that this design approach was helpful for cultivating more adaptive teaching capacity among teacher-education students. Future research agendas that focus on the classroom conditions, curriculum designs, and educational policies that affect complex teacher preparation processes are needed to advance further understanding of how to better prepare effective teachers.

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