Computer-Supported Collaborative Concept Mapping for Learning to Teach Mathematics

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Abstract. Although concept maps have been effectively used for knowledge representation and constructive learning, few studies have investigated how people collaboratively build knowledge with concept maps. The current study explored how pre-service teachers share and integrate their mathematical knowledge for teaching through *computer-supported collaborative concept mapping* (CSCM) activities. The pre-service teachers compared and integrated their digital concept maps, which represented lesson plans of defining exponential functions through discussions in a classroom. From multiple data sources, this study quantitatively and qualitatively analyzed knowledge building processes as well as benefits and limitations of CSCM. The CSCM contributed not only to the lesson-planning performance but also to collaborative knowledge building. Small groups were actively engaged in quick consensus building and integration-oriented consensus building rather than conflict-oriented consensus building. The limitations of CSCM were discussed for the improvement of the activity in pre-service teacher education.

Keywords: Concept map, computer-supported collaborative learning, lesson plan, mathematics, teacher education

Introduction

Lesson-planning activities are essential for school-based curriculum development (Juang, Liu, & Chan, 2008),lesson study (Fernandez, 2002; Sims & Walsh, 2009), and effective teaching practices. However, a number of pre-service teachers lack the competency of lesson planning and feel uncomfortable in developing new tasks and modifying existing curriculum materials (Ball & Feiman-Nemser, 1988; Grossman & Thompson, 2008; Nicol & Crespo, 2006). As such, it is important to investigate the instructional design that might aide these individuals. For the pre-service teachers with a lack of teaching experience, collaborative lesson planning is beneficial in developing their pedagogical content knowledge and teaching competencies (e.g., Chen, 2012; Sims & Walsh, 2009). Pre-service teachers can negotiate the meaning of pedagogical components like learning objectives, tasks, instructional strategies, and learning materials while collaboratively constructing a lesson plan.

The effectiveness of collaborative lesson planning can be enhanced by using instructional design, such as strategic designs of concept maps. Concept maps have been used as a cognitive tool to support knowledge representation, conceptual change, in-depth understanding, and problem solving (Jonassen, 2000; Nesbit & Adesope, 2006; Novak, 1990). In the literature of collaborative learning (van Boxtel, van der Linden, & Kanselaar, 2000; Chiu, Huang, & Chang, 2000; Roth, 1994), concept maps encourage learners to identify and elaborate their different viewpoints while carrying out a collaborative task. Engelmann and Hesse (2011) found that learners more actively discussed and shared their different perspectives when they received digital concept maps that represented knowledge structures of collaborators.

Despite the potential benefits of concept maps for instructional design, few studies have explored how concept maps could be used for effective collaborative lesson planning in pre-service teacher education. In the current study, a *computer-supported collaborative concept mapping* (CSCM) activity was designed to enhance a lesson-planning performance in mathematics teacher education. Moreover, this study explores how pre-service teachers collaboratively build mathematical knowledge for teaching through the CSCM activity and how they perceive the benefits and limitations of the activity. The findings of this study contribute to improving the design of CSCM activities in pre-service teacher education as well as an in-depth understanding of knowledge building processes in CSCM.

Collaborative Concept Mapping

Concept maps as instructional designs visually represent the structure of knowledge including conceptual nodes, links, and linking words that show a relationship between various concepts. Many educators have used concept maps for constructive learning activities in which students visually represent their knowledge with a concept map (Jonassen, 2000; Nesbit & Adesope, 2006). From the student-constructed concept maps, teachers can identify what students know, what they do not know, what they misunderstand, and can therefore enhance formative assessment and adaptive instruction. Moreover, teachers can provide students with well-constructed concept maps as learning materials that foster a conceptual understanding of a novel topic or problem. According to a meta-analysis of previous studies (Nesbit & Adesope, 2006), activities of constructing and studying concept maps were more beneficial for learning outcomes when compared to traditional school activities such as attending lectures and reading texts.

A growing number of studies have investigated collaborative concept mapping as a way to help learners negotiate the meanings of nodes and links (van Boxtel et al., 2000; Chiu et al., 2000; Roth, 1994). By comparing concept maps, learners can explicitly identify differences in nodes, links, and linking words and discuss them to integrate or challenge different viewpoints. Concept maps provide a joint space in which learners can share their knowledge with using such words as "this" and "that" or pointing to the nodes and links in a concept map (Roth & Roychoudhury, 1993). In addition, learners can visually represent what they have discussed about concepts and a relationship between concepts by modifying a concept map. Van Boxtel and her colleagues (2002) argued that the collaborative concept-mapping task is much helpful for articulating thoughts, elaborating the meaning of concepts, and co-constructing conceptual knowledge.

The development of computer-based visualization tools enables learners to create, modify, and share their concept maps efficiently. Computers help to create and revise complex concept maps including a number of nodes and links (Liu, 2011; Royer & Royer, 2004), and the advanced network technology enables learners to construct a concept map with collaborators at a distance. In addition, concept-mapping software can help learners to integrate their concept maps by visually representing what nodes and links are shared or unshared between concept maps (Kao, Lin, & Sun, 2008). It is also possible that learners clearly explain their own concept maps or provide comments to peer concept maps by adding an annotation (i.e., electronic "Post-It" notes) in a digital concept map (Novak & Cañas, 2008). Thus, CSCM can help learners to easily create a concept map, clearly communicate their ideas, and effectively integrate different viewpoints.

However, research has shown the effectiveness of CSCM will be limited when learners are not actively engaged in collaborative knowledge building process (Komis, Avouris, & Fidas, 2002; Liu, 2011) or spend substantial time on such activities as sharing tools and deciding roles, which are not directly related to meaningful learning (Chiu, 2004; Kirschner, Paas, & Kirschner, 2009). The design of the CSCM activity may influence peer interaction patterns, which in turn determine the quality of concept maps and collaborative learning outcomes (Chiu, 2004; Stoyanova & Kommers, 2002). For instance, Van Boxtel and her colleagues (2000) found that elaborative episodes (i.e., elaborated answers, collaborative elaboration of conflicts, and co-constructed reasoning) in the CSCM process were highly correlated to individual learning outcomes. For effective CSCM, instructors should carefully design learning activities to promote collaborative knowledge building and minimize unnecessary or redundant activities that increase extraneous cognitive load (Kirschner et al., 2009).

Design of Computer-Supported Collaborative Concept Mapping

The literature of concept mapping has shown that three design elements are crucial for effective CSCM: collaboration modes, concept-mapping tasks, and learning environments. First, an instructor should decide how learners interact with each other for CSCM. Stoyanova and Kommers (2002) distinguished *distributed* interaction from *shared* interaction in CSCM. In distributed concept mapping, learners individually create and revise concept maps based on interaction with group members (Kao et al., 2008), whereas in shared concept mapping learners jointly create a single group concept map through synchronous and direct interaction (Chiu, 2004; Komis et al., 2002; Roth & Roychoudhury, 1993). Stoyanova and Kommers found that the shared concept mapping was superior to the distributed concept mapping in individual knowledge acquisition and transfer of knowledge from a group to individuals. For more active participation of all group members, previous studies also encouraged learners to prepare a concept map individually before the shared concept mapping (Molinari et al., 2009; van Boxtel et al., 2000). Van Boxtel and her colleagues (2000) found that learners were more engaged in questioning activities when they individually prepared a concept map before collaboration.

Second, concept-mapping tasks play an important role in CSCM. An instructor can allow students to decide all nodes and links in a concept map by themselves or provide a list of concepts and linking words to reduce their cognitive demands. Lim, Lee, and Grabowski (2009) found that fully generating a concept map was slightly more beneficial for knowledge acquisition than partially generating it (i.e., fill-in-the-blanks). The benefits of CSCM may be larger for a complex task of fully generating a concept map when compared to a simple task of filling in the blanks of a given concept map, which can be completed without the help of learning partners (Kirschner et al., 2011). In addition, learners may be more engaged in CSCM activities when the task is closely related to authentic problems and contexts (Chang, Sung, & Lee, 2003; Engelmann & Hesse, 2010; Liu, 2011). For instance, in a study by Chang et al. (2003), learners created, revised, and shared their concept maps for representing their knowledge and sharing hypotheses of authentic inquiry problems. It is therefore helpful for learners to carry out CSCM with a specific goal like solving a problem closely related to their interests.

Lastly, instructors need to design learning environments where students collaborate to construct concept maps. For CSCM, learners can interact with learning partners in face-to-face, online, or blended learning environments. The Internet and network technologies enable learners to collaborate asynchronously (Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008) as well as synchronously (Engelmann & Hesse, 2010; Komis et al., 2002). Online learning environments help to engage in reflection, critical thinking, and task-oriented discussion because verbal messages can be stored and retrieved whenever they are needed (Jonassen & Kwon, 2001). However, in online learning environments, learners encounter several difficulties in sharing their thoughts and challenging different viewpoints due to the lack of nonverbal cues (Ruberg, Moore, & Taylor, 1996) and delayed responses of unmotivated group members in asynchronous online learning (De Simone et al., 2001). In a synchronous CSCM activity, Chiu and Hsiao (2010) found that approximately 70% of student groups passively participated in the activity or primarily paid attention to social topics unrelated to the CSCM task. By contrast, in a face-to-face environment, learners can negotiate meanings of concepts and their relationships by using nonverbal cues like physically touching concept nodes and drawing a concept map to show what a person intends to say (Roth & Roychoudhury, 1993). It is important to design CSCM learning environments in a way to optimize the affordances of online and face-to-face learning environments and to meet the needs of learners.

From the previous studies above, the current study created three design principles of the CSCM activity. First, learners should develop individual concept maps before integrating them into a group concept map through shared interaction. Second, an authentic problem or task should be integrated with the CSCM activity. Lastly, online and face-to-face learning environments should be used flexibly according to the needs of learners and the purpose of the CSCM task.

The purpose of this study is to gain an in-depth understanding of the CSCM activity in mathematics pre -service teacher education by applying a case study method. By analyzing multiple data sources, this study inviestigates how learners (i.e., pre-service teachers) interact with each other in CSCM and how they perceive the benefits and limitations of the activity. Because CSCM was seldom applied for learning to teach mathematics in pre-service teacher education, this study intends to identify themes in regards to benefits and limitations of CSCM, as well as knowledge building processes in the activity, which can be beneficial for improving the design of CSCM.

Methods

Participants. Thirteen pre-service teachers (1 male and 12 females) participated as part of their coursework in the secondary mathematics method course at a Midwestern university in the United States of America (USA). All participants were third-year Caucasian American undergraduates and lacked prior experience with any concept mapping software. Before the CSCM activity, participants took a training session for an understanding of concept maps and the use of the concept mapping software (CmapTools). Participants were randomly assigned into six groups (5 dyads and 1 triad) for the CSCM activity. The course instructor, an assistant professor with 13 years of secondary mathematics teaching experience, participated in developing tasks and resources for the current study as well as implementing the CSCM activity.

Tasks and Learning Materials. Participants received a lesson-planning task that was designed to provide an authentic context and a goal of CSCM. The lesson-planning task required participants to develop a lesson plan for teaching twenty-one 10th grade students a way to identify and define an exponential function from a table. It was assumed that students were taught graphs of exponential functions in the previous lesson. The task also required writing a lesson plan with justifications in terms of learning objectives, learning materials, instructional processes, and assessment. Participants were allowed to use resources in a textbook and the Internet while developing a lesson plan.

In this study, participants individually constructed concept maps to represent their lesson plans with CmapTools and then collaboratively integrated them into a group concept map in a computer room. As shown in Figure 1, concept maps represented a lesson plan with nodes of classroom activities, tasks, learning contents, tools, and learning materials. Links in a concept map described a relationship between two nodes and a procedure of classroom activities. In addition, annotations were used to explain and elaborate a concept map with rationales, examples, student difficulties, and details of learning and teaching activities. The instructor provided participants with a handout which included an instruction of the concept mapping activity, examples of concept maps, and a concept map rubric before they individually constructed concept maps. In addition, the instructor helped participants to understand student difficulties in solving an exponential function problem by analyzing student work examples with participants in a classroom.

Participants integrated their concept maps into a group concept map. The CSCM activity consisted of three steps: (a) explaining individual concept maps to a learning partner(s), (b) comparing individual concept maps and then selecting a concept map to be developed as a group concept map, and (c) collaboratively revising the selected concept map through negotiating the meanings of concepts, links, and annotations. To support this activity, the instructor provided a worksheet including prompts that helped to identify similar and dissimilar

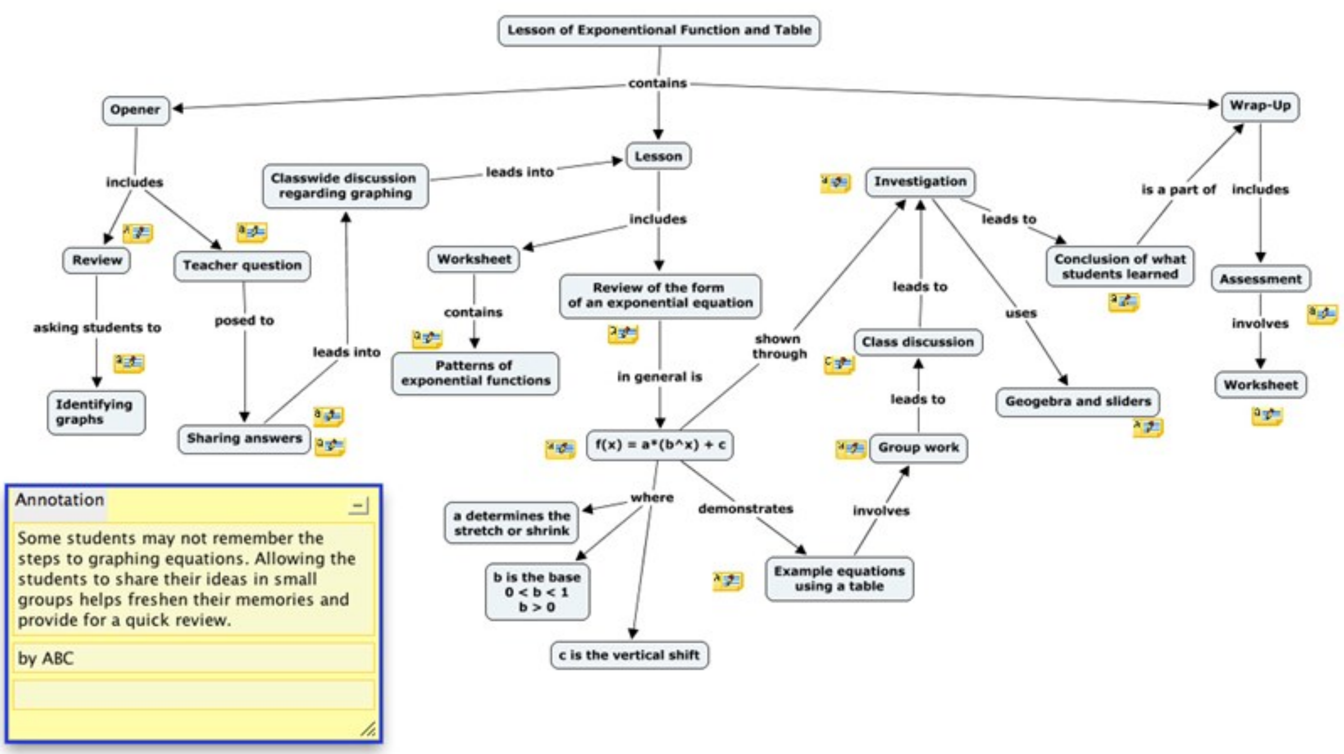

Figure 1. Digital concept map of a lesson plan

Table 1. *Peer Interaction Categories*

Category	Description
Externalization	Articulating thoughts to a learning partner
Elicitation	Asking a question or provoking a reaction from a learning partner
Agreement	Accepting the contribution of a learning partner to move on with the task
Integration	Taking over, integrating, and applying the perspective of a learning partner
Challenging	Disagreeing, modifying, or replacing the perspective of a learning partner
Meta	Planning, monitoring, and coordinating the CSCM task
Off-task	Talking about a topic unrelated to the CSCM task

features between individual concept maps and to justify why a particular concept map was selected for CSCM.

Procedure. Before the CSCM activity, participants were asked to individually create a lesson plan about mathematical reasoning with conditional statements. The pre-lesson planning task was given to examine participants' initial lesson-planning performance. A different topic was selected from the lesson-planning task carried out after the CSCM activity to prevent the practice effect, although the two tasks had the same requirements. In addition, participants learned the principles of concept maps and practiced using CmapTools for two regular class periods.

The CSCM activity was carried out in three phases for two weeks. First, participants received the lesson-planning task and searched for the information and resources that were necessary for teaching the exponential function. Second, participants individually constructed a concept map to represent a lesson plan with CmapTools and shared it using CmapServers, which allowed participants to create, modify, and share their concept maps online (Novak & Cañas, 2008). Lastly, participants integrated individual concept maps into a group concept map through discussions in a computer room for 75 minutes. Participants shared a computer with their learning partner(s).

After the CSCM activity, participants individually created a lesson plan based on their group concept map and took a survey about their perception of CSCM. In addition, six participants recruited from different groups were interviewed in regard to their perceptions of benefits and limitations of the CSCM activity. Each person was interviewed individually for approximately one hour.

Data Collection and Analysis. Multiple data sources were employed to investigate research questions. In the phase of integrating individual concept maps into a group concept map, discourses between learning partners were all recorded and transcribed for the analysis of peer interaction patterns. Transcripts of audio records were segmented into idea units, and two researchers independently coded the idea units according to the seven categories in Table 1. The coding scheme was developed based on the studies by Weinberger and Fischer (2006) and Hmelo-Silver and Barrows (2008). Inter-rater reliability (Cohen's kappa) ranged from .91 to .94, and disagreements were all resolved through discussions.

Lesson plans were collected before and after the CSCM activity. Two researchers later independently assessed the quality of lesson plans with the lesson plan rubrics that were developed based on Boston and Smith (2009) and Panasuk and Todd (2005). For each category of tasks (an understanding of mathematical concepts and meanings behind procedures), instruction (effectiveness of instructional strategies for achieving learning objectives), students (instruction based on students' prior knowledge and difficulties), and justification (well-elaborated reasons to support instructional decisions), lesson plans were rated from 0 to 3 points. Inter-rater reliability (Cohen's kappa) ranged from .74 to .94, and all disagreements about the qualities of lesson plans were resolved through discussions.

The survey conducted after the CSCM activity included five items about satisfaction (e.g., "I am satisfied with the concept mapping activities," "I am disappointed with the way the concept mapping activities worked out") and seven items about participation in CSCM (e.g., "We challenged each other's ideas," "All group members participated in creating a group concept map") in a 5-point Likert scale ranging from "strongly disagree" to "strongly agree." The reliability of survey items (Cronbach's alpha) was .84 for the satisfaction items and .79 for the participation items.

Semi-structured interviews were carried out in order to identify benefits and limitations of CSCM. Interview transcripts were analyzed based on the grounded theory approach (Glaser & Strauss, 1967). Three researchers individually identified categories from interview transcripts and then compared their categories to synthesize different viewpoints on the interview data. They repeatedly labeled and discussed the relationships between categories until saturation was achieved. After articulating the properties of categories and their relationships, the researchers coded the interview transcripts again with final categories and subcategories that emerged from raw data.

Findings

Collaborative Knowledge Building in CSCM

Participants integrated two or three concept maps into a group concept map through discussions. According to the survey (5-point scale), participants perceived that they were actively engaged in the CSCM activity (M = 4.2, SD = .35). As shown in Table 2, discussion messages included an average of 161.8 idea units. Group F, with three participants (total 251 idea units), discussed more actively than other groups with two participants. When participants externalized their thoughts about the concept maps (28%), their learning partner was likely to ask a question (14%), accept the opinion (16%) or integrate it with his or her own opinion (9%). In addition, participants often planned, monitored, and coordinated CSCM processes (17%). However, the low percentage of challenging messages (4%) indicated that participants were not actively engaged in conflict-oriented consensus building.

A sequential analysis was conducted to examine whether a particular message was likely to follow a given message (Bakeman & Gottman, 1997). Transitional probabilities of target messages following a particular given message were calculated and then z-scores of transitional probabilities were tested at the significance level of .05. Figure 2 shows the transitional probabilities between discussion messages in which challenging, meta, and off-task messages were excluded because they were not significantly related to other message types. After a participant stated a new idea about a concept map, his or her learning partner was likely to ask a question (transitional probability = .2), agree on the idea (.23) or integrate it with other ideas and instances (.17). Elicitation was likely to be followed by externalization (.54) and agreement (.23). After pre-service teachers agreed with each other about an issue of their group concept map, their discussion was likely to shift to a new issue through externalization (.42). In addition, integration tended to be followed by elicitation (.22), agreement (.24), and the other integration (.21). These peer interaction patterns show that small groups were engaged in quick consensus building and integration-oriented consensus building (Weinberger & Fischer, 2006) rather than conflict-oriented consensus building.

Peer interaction patterns were compared across six groups. According to Teasley (1997), transactive interaction in which learners elaborate or challenge the reasoning of a learning partner positively influences individual learning outcomes. In this study, some groups (Groups B, C, E, and F) showed more transactive interaction patterns than other groups (Groups A and D), whose aggregate percentages of integration and challenging messages were below the mean percentage (13%). In Group A, for instance, participants quickly built a consensus about their group concept map (22%) without further integration (2%) or challenging (3%) messages and frequently chatted about topics irrelevant to the concept-mapping task (25%). In the following excerpt (Figure 3), for instance, two participants shared their thoughts about a lesson plan along with simple agreements. As a result, they quickly made decisions about their group concept map, but they did not deeply negotiate the meanings of concepts, links, or annotations.

By contrast, Group C showed more transactive peer interaction patterns. The percentages of integration (10%) and challenging (7%) messages were above the mean percentages. In the following discourse (Figure

Table 2. *Discussion Messages*

Group	Externalization	Elicitation	Agreement	Integration	Challenging	Meta	Off-task	Total
A (n=2)	35(22%)	12(8%)	34(22%)	3(2%)	4(3%)	29(19%)	39(25%)	156
B (n=2)	49(30%)	31(19%)	28(17%)	22(13%)	4(2%)	20(12%)	9(6%)	163
C (n=2)	31(27%)	10(9%)	14(12%)	11(10%)	8(7%)	20(17%)	21(18%)	115
D (n=2)	39(35%)	21(19%)	19(17%)	6(5%)	4(4%)	17(15%)	7(6%)	113
E (n=2)	52(30%)	21(12%)	22(13%)	18(10%)	8(5%)	30(17%)	22(13%)	173
F (n=3)	63(25%)	44(18%)	35(14%)	30(12%)	10(4%)	47(19%)	22(9%)	251
Mean	44.8(28%)	23.2(14%)	25.3(16%)	15(9%)	6.3(4%)	27.2(17%)	20(12%)	161.8

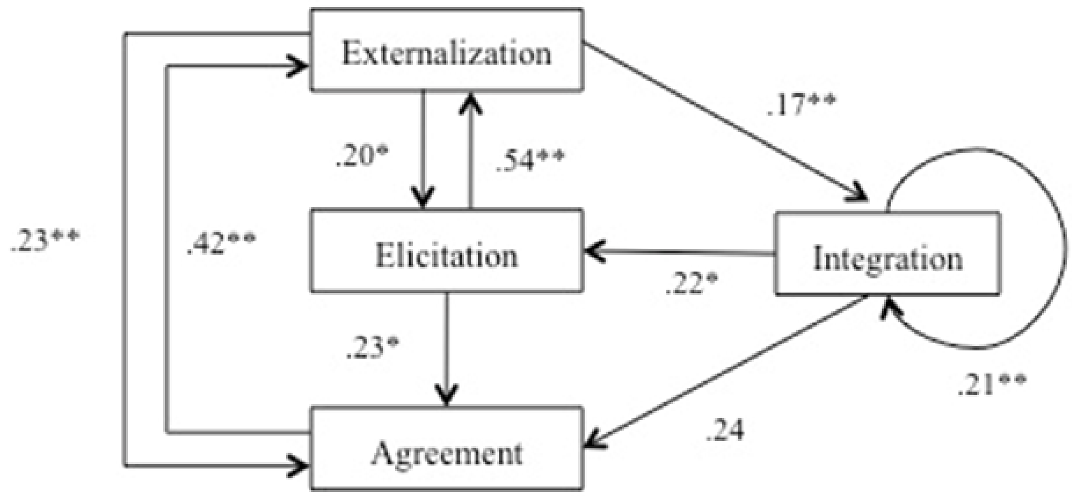

Figure 2. Sequence of peer interactions (* $p < .05$, ** $p < .001$)

4), for example, pre-service teachers challenged and integrated their opinions about student activities in a lesson plan. C1 initially planned to provide student groups with mathematics problems and later asked a question to C2 to garner her opinion about an alternative plan to collect data from students. The two participants reciprocally agreed, challenged, and integrated their thoughts. Their collaboration created a new plan of allowing students to make their own table with a common ratio.

Group C was more actively engaged in transactive peer interaction than Group A. Consistently, an interview with C1 revealed that he negotiated different viewpoints with his learning partner without any defensive attitude: "We could honestly agree which one was the better idea instead of being really defensive."

Benefits and limitations of CSCM

The lesson-planning performance was assessed with rubrics in terms of tasks, instruction, students, and justification. As shown in Figure 5, there was no significant difference in the task quality between pre- and post-lesson plans, $t\ (12) = 1.59$, $p = .137$. However, CSCM was beneficial for the lesson planning performance in regards to instruction, $t\ (12) = 2.21$, $p = .047$, students, t

1. A2:	I started with a review of graphs, questions too. I did like when they walked into the room, they would get a card. It would either have a graph or formula on it, and they would have to find the person that was their match.	Externalization
2. A1:	Oh, that's cool.	Agreement
3. A2:	I got that idea actually from the pre-service math teacher conference this past weekend. So, we did it with like cartoons, but it was kind of cool. That was how we found our group. We both started with a review of graphs of exponential functions.	Externalization Externalization
4. A1:	Okay. I know the next part that I did after the warm up. I guess I assumed that they didn't do much with tables before, so I had them make tables from the given exponential function. Then, they started to look at patterns there.	Agreement Externalization
5. A2:	That's a good idea.	Agreement

Figure 3. Quick consensus building in Group A

1. C1:	Since we are working in groups of 2 to 3 on a problem list I have prepared, give them additional practice making equations from tables. So instead of a list that I've prepared, do you think we could collect some data?	Externalization Elicitation
2. C2:	Yeah. I mean it would have to be.	Agreement
3. C1:	To make it a little more worthwhile instead of just doing problems?	Elicitation
4. C2:	Yeah, but if you were collecting data it would have to be something that you need to control to start exponential functions.	Agreement Challenging
5. C1:	That's true.	Agreement
6. C2:	Like after I got to working on mine, I was thinking because you couldn't just plug in random data.	Externalization
7. C1:	Ok so have them make their own table that would show…	Integration
8. C2:	The table would have to have a common ratio. That would be the stipulation.	Integration

Figure 4. Transactive peer interaction in Group C

(12) = 4.38, p = .001, and justification, t (12) = 2.94, p = .012. In the post-lesson plan, pre-service teachers applied more effective instructional strategies for achieving learning objectives (M = 2.62 vs. 2.08) and considered students' prior knowledge and difficulties (M = 2.38 vs. 1.46) more than in the pre-lesson plan. In addition, participants more effectively justified their instructional decisions in the post-lesson plan, compared to the pre-lesson plan (M = 2.54 vs. 2). As such, these results show that CSCM instructional strategies helped pre-service teachers to construct higher quality lesson plans.

Although lesson-planning performance improved through CSCM, participants conveyed both positive and negative perceptions toward the CSCM activity. The survey showed that participants neither agree nor disagree on the statements of satisfaction (M = 2.8, SD = .84). From interviews with six participants, their perceptions of CSCM were identified and categorized in regard to benefits, limitations, and suggestions for the activity. As shown in Table 3, benefits of CSCM included four major categories: mathematical knowledge for teaching, helpfulness of concept mapping, usefulness of CmapTools, and collaborative knowledge building. Limitations of CSCM also included four major categories: redundant tasks, low motivation of learners, ineffective collaboration, and obstacles in concept mapping. Lastly, there was a suggestion about instructional

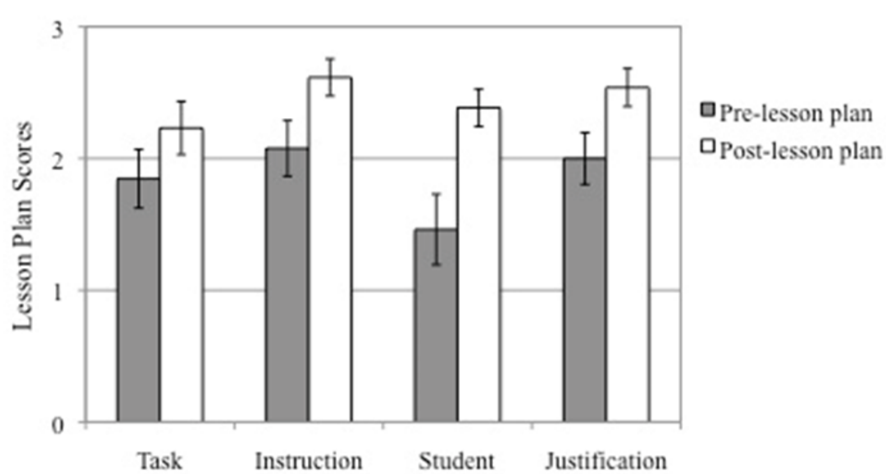

Figure 5. Means and standard error bars of lesson plan scores

Table 3. *Perception of SCCM activity*

	Major and minor categories	Frequent	Sometimes	Rare
	Benefits of CSCM			
1. Mathematical knowledge for teaching	Mathematical knowledge of an exponential function	x		
	Instructional strategies in mathematics class	x		
	Student difficulties in solving exponential function problems		x	
2. Helpfulness of concept mapping	Using concept maps for mathematics learning and teaching	x		
	Visualizing and organizing ideas	x		
	Helpful for lesson planning		x	
3. Usefulness of CmapTools	Easily using CmapTools		x	
	Enhancement of concept mapping performance			x
4. Collaborative knowledge building	Sharing multiple perspectives	x		
	Identifying differences between concept maps	x		
	Getting a great idea from a learning partner	x		
	Challenging ideas and correcting errors			x
	Limitations of CSCM			
5. Time-consuming tasks	Lack of time for the time-consuming task		x	
	Redundant tasks		x	
6. Low motivation	Preference toward outlines			x
	Preference toward individual concept mapping			x
7. Difficulty in concept mapping	Lack of understanding about the role of annotations		x	
	Difficulty in making labeled links			x
	Lack of knowledge about students			x
	Lack of knowledge about an exponential function			x
8. Ineffective collaboration	Lack of disagreement and negotiation		x	
	Unhelpfulness of discussing and comparing concept maps		x	
	Ineffective strategies to resolve disagreements			x
	Suggestion to improve CSCM			
9. Instructional support	More options that learners can select		x	
	More guide on concept mapping			x
	More feedback of an instructor			x

Note. Frequent = 5-6 persons; Sometimes = 3-4 persons; Rare = 1-2 persons

supports for CSCM. The major categories included 2-5 minor categories, which were classified into "frequent," "sometime," and "rare" categories according to the number of interviewees who stated the same idea for each category.

Interviewees perceived that the CSCM activity was helpful for developing their knowledge of the exponential function, effective instructional strategies, and student difficulties in solving exponential function problems. In addition, they described helpfulness of digital concept maps as an instructional design for mathematics learning and teaching, representing ideas visually, and preparing a lesson plan. For instance, D1 perceived that concept maps helped her to organize lesson plans: "I think a concept map was a really good way to organize your thought process. Like, this is what I am going to do in the beginning, and this is what I am going to do in the middle." In addition, A2 perceived that concept maps were helpful for identifying students' difficulties: "Concept maps helped me see how students are going to think about it, and whether they are going to be confused." Interviewees also perceived the usefulness of CmapTools as an instructional design tool for constructing concept maps.

Interviewees frequently stated the benefits of CSCM for collaborative knowledge building. Participants perceived that it was helpful to share multiple perspectives on a lesson plan and to compare their individual concept maps. For instance, A1 described that her concept map included more student-centered activities and discussions, whereas her learning partner's concept map included more teacher-directed activities and problem solving practices. In addition, participants learned new instructional strategies from peers through discussions of what learning activities should be included in a group concept map of the lesson plan. For instance, F1 described that she learned a new instructional strategy from her group member when she said:

> I thought that half the students would have worksheet A and half would have B, but she actually has every two students have different worksheets. The students actually have to find one another and discuss what they are looking for … So, I thought that was a good assessment tool, and it is good for getting students to work together.

Perceived limitations of the CSCM activity included time-consuming tasks, low motivation of learners, difficulty in concept mapping, and ineffective collaboration. Four interviewees expressed a desire for more time in comparing and integrating individual concept maps: "There is not really time to develop a whole other lesson plan, like from it [an individual concept map] in the class period (A1)." They also pointed out the redundancy between creating a concept map and writing a lesson plan because annotations in a concept map included details of a lesson plan. In addition, two interviewees preferred making an outline to creating a concept map for the lesson plan: "It makes more sense to just have it written in an outline form and then it would be a lot easier to write up an actual lesson plan (F1)."

The low motivation of learners was related with the usability difficulties in developing a lesson plan with digital concept maps: "With a concept map, if you forget something, you have to alternate and change so many things on your concept map and move them all around because things have to be built up of one another (F1)." Some interviewees also perceived that it was difficult to know when annotations were necessary and how detailed they should be, although they rarely stated difficulties in creating concepts and links with CmapTools. Lastly, the lack of disagreement and negotiation was sometimes perceived as a limitation of the CSCM activity. This perception was consistent with a low percentage of challenging idea units (4%) in Table 2. In addition, three interviewees perceived that comparison of concept maps was not much helpful because their own concept map was similar with that of their learning partner.

Although interviewees rarely requested more instructional supports like feedback and resources, some interviewees wanted more options in creating a concept map and a lesson plan: "If he [instructor] would have given us another option and explained that option well, then I think a lot of us would have been more interested because we could have done it differently (C1)." Three interviewees expressed a desire to have more autonomy in deciding the format of a lesson plan (concept map vs. document) and a tool for collaborative lesson planning (concept map vs. outline).

Discussion

The current study designed the CSCM activity based on instructional design principles synthesized from previous studies. The instructional design principles were applied to the context of mathematics teacher education in which pre-service teachers developed a lesson plan on the exponential function. A case study was carried out for an in-depth understanding of collaborative knowledge building processes in CSCM as well as benefits and limitations of CSCM in mathematics teacher education. In this study, the CSCM activity was unique when it came to the object of CSCM (i.e., a lesson plan) because previous studies mainly focused on visualizing subject matter knowledge with a concept map (Bolte, 1999; Martin, 1994). In order to create a lesson plan with a concept map, pre-service teachers need to use both subject matter knowledge and pedagogical content knowledge.

This study found that participants (i.e., pre-service teachers) actively participated in CSCM for developing a lesson plan. Participants perceived their active participation in collaborative knowledge building through CSCM, and most discourses (88%) were closely related to the CSCM task. When compared to the study by Chiu and Hsiao (2010), the percentage of discourses pertaining to collaborative knowledge building (i.e., externalization, elicitation, agreement, integration, and challenging) was relatively high (71%). However, small groups were more engaged in quick consensus building and integration-oriented consensus building rather than conflict-oriented consensus building. Consistently, in the interviews, some participants perceived the lack of disagreement and negotiation as a limitation of the CSCM activity.

Future studies could employ instructional designs to increase conflict-oriented consensus building, which is beneficial for meaningful learning. Nussbaum (2008) asserted that "difference of viewpoints can trigger sociocognitive conflict, and when this conflict is resolved through discussion and hypothesis testing, better and more lasting learning is obtained" (p. 351). To facilitate conflict-oriented consensus building, an instructor could organize groups of learners who have different viewpoints from each other. In addition, it is recommended to use a CSCM instructional design tool that can automatically highlight different nodes and links between individual concept maps (Kao, Lin, & Sun, 2008).

However, learners who do not have social affinity with their learning partners may not be engaged in conflict-oriented consensus building even if they identify different viewpoints during CSCM. It is also necessary to promote a sense of community and trust among group members (Jones & Issroff, 2005; Rovai & Lucking, 2003) and to prevent learners from interpreting critiques as attacks or win-lose competitions (Rourke & Kanuka, 2007).

The present study explored both benefits and limitations of CSCM. Data analysis revealed the CSCM activity positively contributed to the lesson-planning performance. In addition, interviewees perceived that CSCM was beneficial for the development of mathematical knowledge for teaching and for collaborative knowledge building. These findings were consistent with previous studies that showed the effectiveness of collaborative concept mapping for articulating ideas, elaborating meanings, and sharing different viewpoints (Engelmann & Hesse, 2010; van Boxtel et al., 2000). In this study, the benefits of CSCM might be caused by the design principles of (a) integration of individual concept maps into a group concept map, (b) CSCM for authentic problem solving, and (c) blended learning environments for CSCM.

Beyond the instructional design tool, this study also found limitations of the CSCM activity (see Table 3). For the improvement of the activity, it is necessary to reduce redundant tasks and provide more autonomy in CSCM as well as facilitate conflict-oriented consensus building discussed above. Mayer and Johnson (2008) found that redundancy can be helpful for learning when repeated information fosters essential knowledge construction process without increasing extraneous processing. However, a redundant task may not be beneficial for learning when it increases extraneous processing without contributing to essential processing for knowledge construction. In order to prevent redundancy, it is recommended to write justifications of a concept map without details of a lesson plan that is already visually represented in the concept map.

In the current study, some participants suggested to provide more autonomy in deciding the format of a lesson plan and a tool for collaborative lesson planning. According to the self-determination theory (Ryan & Deci, 2000), autonomy supports are essential for promoting intrinsic motivation in learning. The lack of autonomy might be closely related to the low motivation of learners, which was also identified as a limitation of CSCM. It is necessary to support autonomy of learners by allowing them to select one of multiple options in regard to CSCM design elements. However, an instructor should be cautious when learners lack knowledge of the CSCM task because the increased cognitive load due to the autonomy can hinder novice learners from focusing on negotiation of meanings (Kalyuga, 2007). Thus, an instructor should control the autonomy level according to previous knowledge and experience of learners. In the future research, the design principles suggested in this study should be applied and evaluated in multiple contexts for pre-service teacher education.

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