Int J of Sci and Math Educ (2016) 14:263–280
DOI 10.1007/s10763-015-9681-y

Collaboration Scripts for Enhancing Metacognitive Self-regulation and Mathematics Literacy

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Received: 28 February 2015 / Accepted: 1 September 2015 / Published online: 16 September 2015

Abstract This study designed a set of computerized collaboration scripts for multi-touch supported collaborative design-based learning and evaluated its effects on multiple aspects of metacognitive self-regulation in terms of planning and controlling and mathematical literacy achievement at higher and lower levels. The computerized scripts provided a sequence of guidance for structuring intragroup and intergroup interactions and prompting individual metacognitive processes throughout the collaborative design phases based on the Think-Pair-Share method. Four intact classes of 80 fifth-grade students participated in this study. Employing a nonequivalent comparison group quasi-experimental design, this study examined whether or not applying the scripts better enhanced self-regulation and achievement in a technology-infused mathematics learning classroom. Multivariate analyses were conducted to reveal the effects on the aspects among the two sets of variables. The results showed medium effects on the controlling of metacognitive self-regulation and higher level achievement, whereas no significant effects were found for the planning aspect and lower level achievement between the groups with and without the collaboration scripts. The implications of this work in relation to metacognitive processes and technology-infused mathematics learning are discussed based on the results.

Keywords Collaboration script · Design-based learning · Mathematics literacy · Metacognitive self-regulation · Technology-infused learning environment

Introduction

In the last two decades, implementing project-based learning in mathematics courses has become more frequent in K-12 classrooms (e.g. Meyer, Turner & Spencer, 1997;

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Rogers, Cross, Gresalfi, Trauth-Nare & Buck, 2011). With a growing body of evidence suggesting that design and collaborative project approaches are beneficial to learning, there have recently been several attempts to introduce design-based learning (DBL), which is a particular form of project-based learning (Apedoe, Reynolds, Ellefson & Schunn, 2008) into mathematics classrooms (e.g. Ke, 2014; Silk, Higashi, Shoop & Schunn, 2010). To accomplish a project, students need to apply knowledge to formulate solutions and employ metacognitive skills to re-evaluate goals and regulate the solution process, and thus, their domain knowledge and metacognitive skills may be enhanced (Blumenfeld et al., 1991; Shin & McGee, 2003). Metacognitive processes play an important part in collaborative learning, as students mutually monitor and regulate their learning and the related activities, such as giving explanations, resolving cognitive conflicts, and elaborating on content (Iiskala, Vauras, Lehtinen & Salonen, 2011; King, 2007). However, these effective peer interactions are generally not spontaneous, especially without guidance (Collazos, Guerrero, Pino & Ochoa, 2002; Fischer, Kollar, Stegmann & Wecker, 2013). Employing collaboration scripts can structure group interactions and prompt the metacognitive processes by requiring students to follow a set of instructions prescribing how they should interact and collaborate (Dillenbourg, 2002; King, 2007). For instance, O'Donnell and Dansereau's (1992) "Scripted Cooperation" arranged students into dyads, and each student had to read the first text passage individually at first. Next, the script had one student summarize the text and the other detect and correct misconceptions. Both partners then elaborated jointly on the content of the text. After that, the dyads read the next segment in this manner and the roles were switched. Traditionally, scripts are given and administrated by teachers. With advances in technology, scripts can now be implemented via the interface of a computer-mediated environment. Computerized scripts can lighten teachers' load with regard to time management and distributing scripts to different group members (Dillenbourg & Jermann, 2007). On the other hand, multi-touch technology affords a computer-mediated collaborative environment that allows team members to interact simultaneously on the same task in the same place (Harris et al., 2009). Students can thus discuss their designs face-to-face and integrate their ideas around a shared space. In addition, multi-touch surfaces improve awareness of and participation in information sharing among team members to achieve a specific learning outcome (Basheri, Munro, Burd & Baghaei, 2013; Kharrufa, Leat & Olivier, 2010). It is considered that technology-infused environments focused on complex, multi-step tasks represent an opportunity for students to engage in metacognitive processes and cultivate their self-regulation ability, and to apply this to acquire knowledge (Bernacki, Aguilar & Byrnes, 2011).

To date, however, very few studies have reported the effects of using computerized collaboration scripts for technology-enhanced DBL in mathematics. Moreover, the use of multi-touch technology brings changes to DBL and may yield different results. The answer to such questions would not only add to the body of empirical evidence for the scripted collaboration approach in enhancing DBL, but may also contribute to greater knowledge of script design in technology-infused learning environments. The aim of this paper, therefore, is to investigate the effects of integrating the collaboration scripts into a multi-touch platform to enhance collaborative DBL. Specifically, this study concerned students' metacognitive self-regulation and mathematics literacy achievement in a multi-touch-enhanced learning context. The remainder of this introduction is divided into four sections. This is followed by some background information on previous research and a statement of the specific research questions, as well as the hypotheses.

Metacognition for Mathematics Literacy

Over the past three decades, growing attention has been paid to the issue of metacognition in mathematics education (Schneider & Artelt, 2010; Schoenfeld, 1992). Metacognition means the active monitoring and consequent orchestration of one's cognitive processes (Flavell, 1976) and is also concerned with self-regulation, which involves metacognitive strategies for planning, monitoring, and modifying one's cognition (Lee & Wu, 2013; Pintrich & De Groot, 1990). Metacognitive self-regulatory activities include planning, monitoring, and regulating (The Organisation for Economic Co-operation and Development 2013; Pintrich, Smith, Garcia & McKeachie, 1991). Planning aims to make the material easier to comprehend by activating related prior knowledge, monitoring is to assist a learner in integrating the material with prior knowledge and understanding the material, and regulating deals with the continuous adjustment of a learner's cognitive activities (Pintrich et al., 1991). Planning activities put emphasis on analyzing tasks and setting goals, while the monitoring and regulating activities described in the literature could be viewed as the aspect of controlling because these activities place value on keeping track of one's cognitive processes.

We have focused on the control and self-regulation aspects of metacognition on the MSLQ, not the knowledge aspect. There are three general processes that make up metacognitive self-regulatory activities: planning, monitoring, and regulating. Planning activities such as goal setting and task analysis help to activate, or prime, relevant aspects of prior knowledge that make organizing and comprehending the material easier. Monitoring activities include tracking of one's attention as one reads and self-testing and questioning: These assist the learner in understanding the material and integrating it with prior knowledge. Regulating refers to the fine-tuning and continuous adjustment of one's cognitive activities. Regulating activities are assumed to improve performance by assisting learners in checking and correcting their behavior as they proceed on a task.

Making good use of metacognitive strategies allows for the transfer of mathematical literacy into new contexts. Mathematical literacy is defined as "an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts" by OECD (2013, p. 25) and also refers to the ability of students to analyze and communicate ideas as they pose and interpret solutions to mathematical problems (U.S. Department of Education, 2014). Traditionally, the teacher serves as an external monitor and encourages discussion behaviors to foster students' metacognitive skills during problem solving in a mathematics class (Schoenfeld, 1992). In the last decade, several studies have used the metacognitive guidance such as self-questioning in terms of "What is the problem all about?" for face-to-face and online discussion, in order to enhance students' mathematics literacy and self-regulated learning (e.g. Kramarski, Mevarech & Arami, 2002; Kramarski & Mizrachi, 2006). Kramarski & Mizrachi (2006) found that the seventh-grade students with the aid of metacognitive guidance outperformed those without such guidance on different aspects of mathematics literacy in terms of computation skills, mathematical problem solving, and reasoning, as well as on self-regulated learning regarding problem-solving strategies. Although this research gave more responsibility to the students themselves, the teacher still had to model the metacognitive guidance for the whole class. It is thus worth considering the development of computerized metacognitive guidance as a way to address manpower shortages with regard to monitoring the whole class in such activities. Few empirical studies, however, have reported on the effects of such a system in mathematics learning, especially with regard to examining its possible influence on different aspects of mathematics literacy achievement, either at higher or lower levels.

Design-Based Learning

Design-based learning (DBL) is an educational approach centered on student-designed projects, engaging students in solving ill-structured, real-world problems to acquire domain knowledge (Gómez Puente, van Eijck & Jochems, 2013). DBL is concerned with Papert's theory of constructionism, which advocates leaning through design and participating in construction activities (Han & Bhattacharya, 2001). That is, new knowledge is developed when a learner is engaged in the construction of an external and sharable artifact (Fessakis, Tatsis & Dimitracopoulou, 2008; Papert, 1990). DBL emphasizes hands-on learning and collaboration (Apedoe et al., 2008; Gardner, 2012). Student designers co-construct their artifacts representing the learning outcome to accomplish the design project (Han & Bhattacharya, 2001). In the last decade, DBL has been applied as a way of introducing science and engineering concepts in secondary schools, and empirical studies have shown that it is effective in increasing students' subject-related achievement (e.g. Apedoe et al., 2008; Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman, 2004). More recently, several studies attempted to introduce DBL into mathematics classrooms (e.g. Silk et al., 2010; Ke, 2014), and Silk et al. found that students could connect new mathematical concepts with their designs and learn them at a deep level.

In such scenarios, the design processes generally include defining the problem, gathering information, exploring alternatives, constructing, and evaluating the solution (Doppelt, Mehalik, Schunn, Silk & Krysinski, 2008). Students need to use the metacognitive strategies and self-regulation as they work through the phases, monitor progress, and revise artifacts (Blumenfeld et al., 1991). It has been argued, by Kolodner et al. (2003), that students working with a design-based approach condition outperformed a set of comparison students in metacognitive skills. However, not all students are able to monitor and regulate their learning and need additional metacognitive support to enhance learning (Hadwin & Winne, 2001). Puntambekar & Kolodner (2005) provided pen-and-paper metacognitive prompts, which guided students to reflect on the design activities in order to learn science from them. Nonetheless, such guidance seems unable to prompt the metacognitive processes needed to regulate students' joint learning by structuring the interaction within or between groups in the design processes. Indeed, the use of metacognitive supports for collaborative DBL as a research topic has not yet been explored much in the literature.

Collaboration Script

A script is an instructional means that illustrates the convergence between socio-constructivism and instructional engineering (Dillenbourg & Jermann, 2007), which refers to a method that supports the cycle of a learning system from analysis to evaluation (Paquette, 2004). Collaboration scripts are used to sequence and support the task-related interactions of learning groups by constraining student interactions and inducing a sequence of activities (Kollar, Fisher & Hesse, 2006). In scripted collaboration approaches, scripts are used to elicit and regulate knowledge-producing interactions, such as explanations, conflict resolutions, and mutual regulation, and, in turn, these activities will induce metacognitive processes in students (Dillenbourg & Jermann, 2007; King, 2007). Accordingly, managing students' interactions deals with supporting the metacognitive activities related to their interactions and collaboration (Soller, Martínez, Jermann & Muehlenbrock, 2005).

The effective collaborative processes elicited by collaboration scripts have a positive relation to individual learning outcomes (Kollar et al., 2014). As research has shown, students' metacognitive skills are facilitated by the guidance provided by peer interactions in an ill-structured problem-solving task (Ge & Land, 2003). In addition, such a script controls the peer interactions and, consequently, affects student achievement (Berg 1994; Weinberger, Ertl, Fischer & Mandl, 2005). The findings of studies examining the effects of collaboration scripts on students' domain-specific learning outcomes have been mixed. For instance, Weinberger et al. (2005) reported a positive effect at post-test on individual knowledge acquisition, whereas Kollar et al. (2014) found no significant effects on the acquisition of mathematical argumentation skills. Recently, Clayphan, Kay & Weinberger (2013) designed computerized collaboration scripts for university students' multi-touch tabletop brainstorming. It was found that the students considered this approach was effective for brainstorming and helped them learn how to do so. However, there are few studies that have used comparison group designs to ascertain the effects of using computerized scripts for face-to-face and computer-mediated activities, especially for collaborative multi-touch learning activities. In addition, there seems no general consensus for the effects of collaboration scripts on different aspects of metacognitive self-regulation and different levels of mathematics literacy achievement. In an attempt to supplement the findings of the earlier studies, this study thus aimed to assess students' metacognitive self-regulation and mathematics literacy achievement, in that the focus is on the planning and controlling aspects of self-regulation, and higher and lower levels of the achievement.

Research Questions and Hypotheses

In view of the preceding research purpose, this study was designed to answer the following research question: After students complete a multi-touch supported DBL activity with or without collaboration scripts, are there any differences in metacognitive self-regulation (planning and controlling) and mathematics literacy achievement (higher and lower levels) between the two conditions? Based on the theoretical positions adopted in this study and the status of the field, as reviewed previously, the following hypotheses were generated: Students conducting the multi-touch supported DBL activity with collaboration scripts outperform those without the scripts on various aspects of metacognitive self-regulation, including planning (hypothesis 1a) and controlling (hypothesis 1b). Additionally, the students with collaboration scripts have better mathematics literacy achievement than those without the scripts in terms of higher level achievement (hypothesis 2a) and lower level achievement (hypothesis 2b).

Method

Design and Participants

To explore the research question, this study employed a nonequivalent comparison group quasi-experimental design. The independent variable incorporates a scripted collaboration approach in multi-touch supported DBL, which includes two levels: with and without collaboration scripts. Students were arranged to accomplish an ill-defined, plane geometry-related design project in collaborative teams. The dependent variables included students' metacognitive self-regulation and mathematics achievement literacy.

Four intact fifth-grade classes from an elementary school located in northern Taiwan were involved in this study. The participants were 80 fifth-grade students, ranging in age from 10 to 11 years. All participants had 2 years of formal education in basic computer skills. In an attempt to minimize selection threats by preliminary matching (Cates, 1985), this study assigned experimental and comparison groups according to the class means of a math exam administered before the arrangement. That is, two classes were assigned to the group with collaboration scripts (22 boys and 19 girls), and two were assigned to the group without collaboration scripts (22 boys and 17 girls). This study then used the S-type grouping, which arranges individual scores from high to low in 'S' shape to assign student groups (Jang, 2010; Yang & Heh, 2007) based on the students' scores on the math exam to divide students within each class into balanced and heterogeneous groups, with three or four students in each group.

Scripted Multi-touch Collaborative Activity

A collaborative DBL activity was administered. The activity asked the participants to accomplish a design project that required them to design tile patterns for covering the playground surface of children's amusement park. The designed pattern must be a tessellation using two or more regular polygons, with no overlaps and gaps (i.e. plane tiling by regular polygons). The project also asked students to highlight the degrees of interior angles for each kind of vertex junction, draw the symmetry axes of the regular polygons they used, and describe the transformation geometry they applied in the tessellated pattern. The project was imported into a multi-touch learning platform developed by Chiu, Chen & Wu (2013), which supported group members carrying out tessellation-related design projects at the same time on the same display. Students could create tessellations by using the regular polygon tool and transformation geometry functions, such as translation and rotation. In addition, students could discover patterns and argue in favor of their designs within a face-to-face collaborative environment, as shown in Fig. 1. Students carried out the design project through three sequential phases derived from previous DBL studies (Apedoe et al., 2008; Doppelt et al., 2008; Fortus et al., 2004; Kolodner et al., 2003), including (a) "clarifying the problem," students specify

Fig. 1 Students working together to create designs in the computer-mediated environment

and write down design requirements for the project on the platform; (b) "gathering information," students collect useful information for solving the problem from the provided reference, and organize it on the platform; and (c) "constructing artifacts," students develop solution alternatives on the platform, and co-construct a learning artifact meeting the necessary requirements. Plane geometry-related information pages were provided to each student for reference, both on paper forms and the platform.

The collaboration scripts were designed for structuring students' interactions and collaboration in a multi-touch supported DBL and intended to induce metacognitive processes in individual learners through effective learning interactions. Based on the Think-Pair-Share method (Lyman, 1981) and the script levels of individual, group, and class (Dillenbourg & Hong, 2008), the collaboration scripts provided three functional types in a sequential order, including individual, intragroup, and intergroup. These three types of collaboration script paralleled the three processes of Think-Pair-Share. The collaboration scripts were embedded in the multi-touch learning platform. The individual scripts asked each student to develop their own thoughts in the individual workspace on the same display interface, as shown in the top left part of Fig. 2. The top right part of

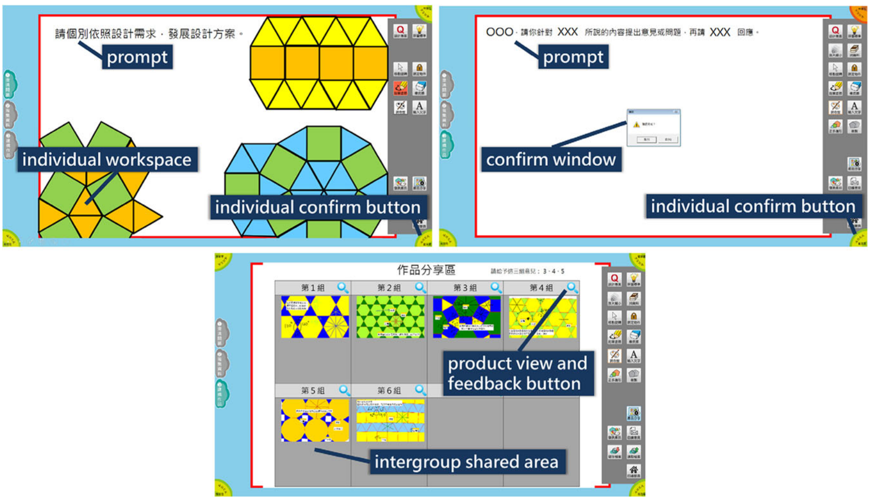

Fig. 2 Interface of the individual, group, and class level scripts

Fig. 2 shows how the intragroup scripts asked the students to explain their own ideas to their partners and discuss them using reciprocal questioning, within face-to-face discussions enhanced by computer-mediation. The intergroup scripts required students to share their products with the whole class, that is, to view other groups' products and give feedback in the intergroup shared area, as illustrated in the bottom part of Fig. 2.

The collaboration scripts were applied to each phase of multi-touch supported DBL (i.e. clarifying the problem, gathering information, and constructing artifacts). Table 1 presents the three levels in the collaboration scripts. To take an example from the scripted "constructing artifacts" phase, first, students have to develop and propose design solutions independently (e.g. "Please develop your own design solution according to the design requirements individually."), then take turns to explain and discuss the proposed solutions within the group (e.g. "Jack, please explain your ideas regarding your design."), and share the final artifact between groups, including illustrating their own design rationales as well as giving and receiving feedback (e.g. "Please comment on the artifacts of these groups."). Students in the collaboration script condition received these computerized prompts that sequenced their discussions and interactions in all DBL phases, whereas students without the collaboration scripts did not receive any prompts to structure their collaboration. It is supposed that scripting of the interactions during learning would function as a catalyst that prompts metacognitive processes, therefore ensuring the intended learning takes place.

Measures

Metacognitive Self-regulation. A metacognition scale was created to measure students' metacognitive self-regulation after participating in the focal activity, based on Pintrich et al.'s (1991) Motivated Strategies for Learning Questionnaire (MSLQ) and Wu and Cherng's (1992) revised version of the MSLQ for Taiwanese pupils. This scale focused on the control and self-regulation aspects of metacognition, rather than on the

Table 1 Structure of the collaboration scripts for the multi-touch supported activity

Category	Level	Activity in design phase		
		A. Clarifying the problem	B. Gathering information	C. Constructing artifacts
1. Individual	Individual	A1. Understand the problem and list the design requirements independently	B1. View the provided reference and summarize the information independently	C1. Develop and propose design solutions independently
2. Intragroup	Group	A2-1. Explain one's listed requirements to team members in sequence	B2-1. Explain one's gathered information to team members in sequence	C2-1. Explain one's proposed solution to team members in sequence
		A2-2. Discuss each other's requirements by reciprocal questioning	B2-2. Discuss each other's gathered information by reciprocal questioning	C2-2. Discuss each other's solutions by reciprocal questioning
3. Intergroup	Class	A3. Share the proposed requirements and give other teams feedback	B3. Share the proposed information and give other teams feedback	C3. Share the final artifact and give other teams feedback

knowledge aspect. The items asked students to what extent they were better able to do metacognitive self-regulatory activities in terms of planning, monitoring, and regulating activities, as they learned mathematics after participating the research activity. For example, "After participating in this activity, I try to determine which concepts I don't understand well when studying for the mathematics course." was an item for monitoring. This employed a seven-point Likert scale in which the participants rated themselves from "not at all true of me" to "very true of me." This scale consisted of 12 items in which ten statements were positive, and two statements were negative. Since the two negatively worded items in the MSLQ were deleted in the Chinese version of the MSLQ, owing to the low item reliability values and a non-significant level for the factor loadings, this study treated the two items as detecting items, which would not be tallied for an individual's score. There were thus ten scored items (four for planning, two for monitoring, and four for regulating) in this scale. Students' responses on the seven-point scale would be added up to calculate the scores. The Cronbach's α was calculated to be .93. Monitoring and regulating items made up the "controlling" aspect, followed from those centered on controlling behaviors and cognitions.

Mathematics Literacy Achievement. A mathematics test was developed to measure students' mathematics literacy achievement in the literacy area "space and shape," with an emphasis on plane geometry. This test covered the content of angles of regular polygons, line symmetry, and transformation geometry. Referring to plane geometry-related items in the mathematics textbooks and midterm or final exams for upper elementary students, the preliminary test items were formulated by the researchers. The appropriateness of this test was confirmed by a senior mathematics professor, who is also a director of science education center and an expert with regard to middle school students' mathematics learning. This test consisted of 12 items, including six multiple-choice questions and six word problems. The test items covered understanding, applying, analyzing, and evaluating levels of the revised Bloom's taxonomy (Anderson et al., 2001), where the latter two levels could be thought to constitute a higher degree of mathematics literacy achievement in comparison with the first two. The following is an example of an applying level item, a multiple-choice question "Taipei city government is working on paving refurbishments for the 2017 Summer Universiade, and the government plans to select the same kind of regular polygon to pave the way. Which of the following regular-polygon tiles cannot be tessellated?" was used to assess concepts regarding the polygon angles. Students' answers to each question in this test would be scored and tallied to calculate the scores.

A pilot test was implemented with another 91 Taiwan students (aged 13–14) different from the participants, and the calculated reliability coefficient using the Kuder-Richardson Formula 20 (KR-20) was .82. The discrimination indices, calculated by subtracting the proportion of scores in the low-score group (bottom 27 %) from the proportion of those in the high-score group (top 27 %) for each item, were all above .3. However, three items were deleted since their difficulty indices were below .2 or above .8. There were, thus, nine items for the formal test, consisting of five multiple choice questions and four word problems. The maximum possible raw test score was 65 (25 points for the multiple-choice questions, and 40 points for the word problems). Analyzing (three items) and evaluating (two items) levels were grouped into "higher level," whereas understanding (two items) and applying (two items) levels were grouped into "lower level."

Procedure

This study was conducted over a period of 8 weeks in a technology-rich classroom at the participants' school. The whole procedure, including the treatment activity (6 weeks), test (1 week), and questionnaire (1 week) to the students, was administered by the same instructor. During the treatment activity, students in the same team were assigned to a multi-touch platform. Team members stood next to each other to carry out the design projects.

Treatment. First, all the participants received two practice sessions, each lasting 40 min and conducted at a 1-week interval. The first session was to create a geometric pattern with their team members by using the general functions (e.g. regular polygon tools) of the multi-touch platform. A week later, in the second session, students were required to conduct a simplified DBL project via the multi-touch platform (i.e. design a digital tessellation). During this session, the experimental group students carried out the project with the computerized collaboration scripts on the multi-touch platform, whereas the comparison group conducted the project without the scripts. Second, each team member was arranged to accomplish the formal design project on the multi-touch learning platform with or without the computerized collaboration scripts according to their assigned condition. The formal project occurred over 4 weeks, with three design phases in four weekly classroom periods (40 min each period). The first and second phases (clarifying the problem and gathering information) each lasted for 1 week, and the third phase (constructing artifacts) was conducted over 2 weeks.

Assessment. The mathematics test was administered for 30 min to all participants within a week after the experimental treatment. As the metacognitive self-regulation scale was used to measure changes in the students' metacognitive activities with regard to regular mathematics classes after the treatment, and metacognition might not change one's activities within a week (Lameijer, 2011), the students were asked to fill out the scale 2 weeks after the treatment activity. It took approximately 5 min for students to finish the scale. Students completed the test and questionnaire individually in pen-and-paper forms.

Results

Four students' data was excluded from the analysis, including three students with learning disabilities and one student who missed two practice sessions. In addition, another four students' data were marked as missing values because the researchers screened every student response by using the scale's negatively worded statements and found their responses were all the same or in a repeated pattern. The missing values were handled by listwise deletion. For all statistical analyses and tests, the significance level was set to .05. Table 2 presents the descriptive statistics, including the means and standard deviations for the metacognitive self-regulation and mathematics achievement literacy of the experimental and comparison groups. Considering the possible risk of clustering of the data, this study calculated the intraclass correlation coefficients (ICCs)

Table 2 Means and standard deviations for the dependent variables under the two conditions

Measures	Experimental (*n*=35)		Comparison (*n*=37)	
	M	SD	M	SD
Metacognitive self-regulation	63.63	10.40	58.30	11.75
Planning	21.77	4.15	19.81	4.71
Controlling	33.34	5.43	29.11	7.17
Mathematics literacy achievement	40.23	11.90	39.30	13.43
Higher level	28.51	8.18	25.92	8.56
Lower level	11.71	5.68	13.38	6.24

to measure the variations between classes. The calculated ICCs for the experimental and comparison groups were both <.001. For mathematics literacy achievement, the ICCs for the two groups were .02 and <.001 respectively. The intraclass correlations were quite small, and no significant effects were found (p > .05) for the between-class variances. These results suggest that the general linear models can be used for multivariate analyses. Since this study focused on students' metacognitive self-regulation in terms of planning and controlling after participating in the experimental and comparison treatment activity, a multivariate analysis of variance (MANOVA) would be used to detect whether a significant difference existed among the variables. Additionally, in considering the influence of prior knowledge on student achievement, this study included students' prior achievement as a covariate to adjust the mathematics test scores in the analysis of mathematical literacy. Students' math midterm exam scores prior to the treatment were used as a pre-intervention covariate, and no significant differences were found between the two groups, $t(70)=-0.70$, $p=.489$. Therefore, a multivariate analysis of covariance (MANCOVA) would be performed to evaluate the differences between the higher and lower levels of mathematics literacy achievement, with the math midterm exam as the covariate.

Metacognitive Self-regulation

This study employed MANOVA to determine whether there were significant differences between the group with and without collaboration scripts among the two aspects (planning and controlling), as the aspects of the metacognitive self-regulation had a high correlation (r = .85, p < .001). The testing results of Levene's tests for each aspect and Box's M statistic for the variance-covariance matrix showed the assumptions were not violated, Box's M = 8.01, F(3, 982,677.56) = 2.59, p = .051. The test statistic Wilks's lambda = .89, F(2, 69) = 4.34, p = .017, and partial η^2 = .11, indicating a medium significant MANOVA effect was found. When ANOVA tests were carried out, significant differences were found between the two groups in terms of controlling, F(1, 70) = 7.91, p = .006, partial η^2 = .10, indicating a medium effect. The average of the controlling aspect was significantly higher in the experimental group (M = 33.34, SD = 5.43) than in the comparison group (M = 29.11, SD = 7.17), and so hypothesis 1b is supported. However, there was no significant difference in terms of the planning, F(1, 70) = 3.50, p = .065, partial η^2 = .05. Hypothesis 1a is thus not supported from our data.

Mathematics Literacy Achievement

This study used MANCOVA to determine group differences in the higher (analyzing and evaluating) and lower (understanding and applying) levels of mathematics literacy achievement, as a significant correlation ($r = .52$, $p < .001$) existed between the two levels. The assumption of equality of variance was tested by Levene's tests, with the results indicating that equal variances held for each dependent variable. The assumption of homogeneity of the variance-covariance matrix was tested using Box's M statistic, and the results showed that the assumption was satisfied, Box's $M = 1.26$, $F(3, 982{,}677.56) = 0.41$, $p = .749$. The MANCOVA results revealed that the mathematics literacy achievement for higher and lower level questions differed significantly between the two research groups, Wilks's lambda = .91, $F(2, 68) = 3.48$, $p = .036$, and partial $\eta^2 = .09$. ANCOVA was thus conducted on each dependent variable as a follow-up test. The results showed that the two groups were significantly different in higher level questions, $F(1, 69) = 4.32$, $p = .041$, and partial $\eta^2 = .06$, suggesting a medium effect size, but not significantly different in lower level questions, $F(1, 69) = 0.89$, $p = .348$, and partial $\eta^2 = .01$. The average of higher level questions was significantly higher in the experimental group (adjusted $M = 28.92$, SD = 8.18) than in the comparison group (adjusted $M = 25.53$, SD = 8.56). The results thus support hypothesis 2a, but do not support hypothesis 2b.

Discussion

Metacognitive Self-regulation

The results indicate that students who received computerized collaboration scripts in the collaborative design phases (clarifying the problem, gathering information, and constructing artifacts) differed significantly from those without the scripts on overall metacognitive self-regulation. This seems compatible with Dillenbourg and Jermann's (2007) argument that collaboration scripts are expected to be internalized as metacognitive skills. The results also suggest that the students with the scripts outperformed those without the scripts on the controlling rather than the planning aspect of self-regulation, and this is not in contradiction with the finding of Kramarski & Mizrachi (2006) that students with metacognitive guidance achieved better self-regulated learning, which tended to lay more emphasis on controlling and regulating their problem-solving processes, than those without, although the environments in each study were different.

The computerized collaboration scripts applied in this study provided guidance for structuring group interaction to elicit effective peer interactions, such as asking questions, providing feedback, making suggestions, and sharing ideas. These peer interactions would facilitate students' metacognitive skills as they made justifications, monitored and evaluated the solution process (Ge & Land, 2003), which might contribute to improving their controlling aspect of metacognitive self-regulation. In comparison to students without the collaboration scripts, students receiving the scripts seemed to engage in more cognitive and metacognitive activities during the collaborative design processes. The effects of the collaboration scripts may be deconstructed in terms of the three categories (individual, intragroup, and intergroup) of the scripts, which closely paralleled the Think-Pair-Share process for collaborative learning. During the "Think" period in each design phase, although the scripted students were required to come up with solution alternatives in an individual workspace of the multi-touch platform, the related planning activities, such as goal setting and task analysis, were mainly structured in the design phase "clarifying the problem," while the other two design phases "gathering information" and "constructing artifacts" did not focus on planning. This might account for the positive, but not significant, results of the planning aspect. Nevertheless, in this scenario, students had opportunities to think independently and were able to draw on prior experiences and knowledge to monitor their thinking. Prompting students to concretize their ideas on multi-touch platforms made their thinking available to them for monitoring, revision, and reflection. While the students were directed to the "Pair" period, students were provided with more opportunities to elaborate, interpret, and coordinate information with their partners. Students' discussion was sequenced by reciprocal questioning, which engaged them in metacognitive thought (Krishnamurthi 2012). The collaboration scripts prompted the students to articulate their design solutions within their groups, and this peer interaction helped them become more aware of what they knew (Ge & Land, 2003). In addition, this continuous questioning and answering process involved regulatory actions that assisted students in correcting their design products. With respect to the "Share" period guided by the collaboration scripts, the scripts could prompt the metacognitive processes of reflecting on the completed actions and products, as noted by Clayphan et al. (2013) for a scripted tabletop brainstorming activity. Additionally, the metacognitive processes were also induced by reviewing other groups' artifacts and receiving their feedback in the intergroup shared area since error detection and awareness of performance level are considered to be metacognitive activities (O'Donnell & Dansereau, 1992).

Mathematics Literacy Achievement

The results suggest that the group with computerized collaboration scripts achieved better learning outcomes than that without the scripts in higher level (analyzing and evaluating) instead of lower level (understanding and applying) questions. While O'Donnell (1999) noted that scripted collaboration can promote student achievement through peer learning, more recently Kollar et al. (2014) suggested that collaboration scripts do not suffice to support domain-specific knowledge acquisition. Our findings are not too surprising, for the character of the collaboration scripts in this study was not domain-specific. Nevertheless, as Hsu, Yen, Chang, Wang & Chen (2014) discussed in their review regarding self-regulated learning studies, promoting metacognitive strategies through collaborative learning has been effective with regard to acquiring domain knowledge in several studies, even though the metacognitive prompts used in these were not domain-specific. The findings of this study give some credence to those of Kramarski & Mizrachi (2006), which reported positive effects of metacognitive guidance on students' mathematical reasoning in relation to mathematics literacy in collaborative learning, where reasoning skills could correspond to higher level tasks, such as analyzing (Clark, 2015).

According to the revised Bloom's taxonomy, analyzing and evaluating levels can be considered as higher order thinking. Since the outcome of a project and actions such as designing and constructing are categorized in the highest level of the revised Bloom's taxonomy, "creating," it is anticipated that participants are able to demonstrate better higher order thinking outcomes in terms of mathematics literacy achievement. Compared to the unscripted group, the collaboration scripts provided the scripted group with more opportunities to interact in relation to the mathematics content in order to solve the problem. In the face-to-face scripted collaboration, the students had to take turns to explain their phased products and discuss them through reciprocal questioning, and this may have affected the student subsequent achievement. The individual cognitive processes appropriate to the learning task at hand are induced through the use of collaboration scripts because the scripts force the student to clarify the concepts and often relate the content to each other's knowledge or even generate new alternatives on the multi-touch platform. On the whole, the individual students could refer to each other's ideas on the platform and explanations prompted by the computerized scripts to carry out the design project and restructure their own knowledge, and thus, their higher level achievement was enhanced. In addition, students were expected to self-regulate their collaborative learning in the scripted collaboration. As such, the scripted students appeared to show greater mathematics literacy achievement than the unscripted students, who might engage in fewer self-regulative behaviors, as discussed by Bernacki et al. (2011), which noted that more self-regulated learners tend to acquire more knowledge when using technology-enhanced learning environments.

Conclusions

This paper has addressed the issue of metacognition in a multi-touch technology infused environment and extends prior research on the effects of collaboration scripts to a new technological context in mathematics domain. This study designed computerized collaboration scripts based on the Think-Pair-Share method for multi-touch supported DBL and investigated whether integrating the scripts is an effective approach to facilitate various aspects of the students' metacognitive self-regulation and mathematics literacy achievement in an elementary mathematics classroom. The results indicate that the students working with the support of collaboration scripts demonstrated better metacognitive self-regulation in the controlling aspect and mathematics achievement in higher level questions than did the students without the scripts. However, since no statistically significant differences in the planning aspect of metacognitive self-regulation and lower questions of mathematics literacy achievement between students with and without the scripts were found, caution should be taken in generalizing these findings. The results also cannot be applied to learners who collaborate in a distance learning context since the collaboration scripts in this study scripted both face-to-face interaction and computer-mediated activities. It may be of interest for future research, on the other hand, to explore the different effects between the use of computerized scripts in face-to-face and computer-mediated collaborative learning and those given by a live teacher. In addition, the participants in this study were 10 to 11 years old Taiwanese pupils enrolled in mathematics classes, and thus, the findings may not be generalizable to students in higher grades, as well as to other subject domains.

Given the fact that the students finished both the metacognition scale and mathematics test after participating in the scripted collaboration activity, this study did not examine the causal relationship between metacognitive self-regulation and mathematics achievement. Future studies could assess the interplay between students' metacognition and academic achievement on the basis of the reported relationships (cf. Schoenfeld, 1992; Stoffa, Kush & Heo, 2011) in a technology-infused learning environment or determine if any mediating effects exist. Moreover, future research can keep track of the mid- or long-term development of metacognitive self-regulation. An additional avenue of further investigation is to compare what students stated in the metacognition scale and how much their learning behaviors have actually changed in reality, although this would require a qualitative or a mixed method approach.

Acknowledgments The authors thank the Editor and anonymous reviewers for their remarkably constructive comments. This research was supported by the Ministry of Science and Technology, Taiwan (R.O.C.) under Grant No. NSC 101-2511-S-003-033-MY3.

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