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RESEARCH ARTICLE

Computerized collaboration scripts and real-time intergroup competition for enhancing student collaboration and learning with multi-touch tabletop displays

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Abstract
This study introduced computerized collaboration scripts with an intergroup competition mechanism to foster students' within-group collaboration in a multi-touch tabletop classroom, investigating whether the scripting effects could be further improved by integrating intergroup competition. As such, this study utilized an experimental design to investigate the effects of intergroup competition on student teamwork performance, collaborative skills and learning achievement. A real-time intergroup competition mechanism was designed and integrated into a scripted multi-touch platform that supported collaborative designs. Forty-nine fifth-grade students from two classes at an elementary school in Taiwan were assigned to distinct groups, with and without intergroup competition. The participating students were required to accomplish a tessellation-related design project in small groups on a multi-touch platform. The findings showed that the students learning with the scripts under intergroup competition on multi-touch tabletop displays demonstrated better teamwork performance, collaborative skills and learning achievement than their counterparts who did not experience intergroup competition. These findings provide empirical evidence as to the effectiveness of integrating collaboration scripts with intergroup competition to computer-supported collaborative learning in multi-touch technology enhanced classrooms, delivering a better understanding of how learning with computerized collaboration scripts can be improved and how group awareness is related to this learning setting.

Keywords Multi-touch tabletop · Group awareness · Intergroup competition · Collaboration script · Computer-supported collaborative learning · Multi-touch classroom

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Introduction

Background

Multi-touch tabletops (such as that shown in Fig. 1, for instance), which provide a shared platform for co-located collaborative work, are increasingly being used to support collaborative learning activities (Beauchamp et al. 2019; Mercier et al. 2017). Students can carry out common learning tasks, collect or share information, and design and construct their work with other team members on a multi-touch platform using the intuitive shared interface, as well as discuss their ideas face-to-face (see, e.g., 10–11-year-old pupils in Higgins et al. 2012; fifth graders in Ioannou, 2019). In an earlier study, Harris et al. (2009) investigated the use of multi-touch technology in a collaborative design task for 7–10-year-old primary school students working in groups of three. The results showed that tabletop technology did influence the nature of the children's discussion and suggested that a multi-touch tabletop is suitable and helpful for a student team to perform collaborative design tasks. Over the past decade, research has indicated that multi-touch tabletops can increase students' awareness of others' actions/activity in face-to-face collaboration, allowing them to quickly understand each other's ideas and actions, and providing a shared platform for co-located collaborative work (Martinez-Maldonado et al. 2015). For explanations and conflict resolution processes to occur, learners need to be aware of the extent or content of other's knowledge; it is assumed that multi-touch tabletops support behavioral group awareness, as learners can observe each other's actions and activity during collaboration (Schnaubert & Bodemer, 2019). This technology alters co-located computer-supported collaborative learning (CSCL) activities by changing the nature of their interaction, and therefore the interaction among and between group members (Mercier et al. 2017). Although this technology offers different ways of interacting, both the conflicting actions between users that can occur on shared interfaces, as well as the lack of explicit guidance for argumentation and collaboration, are major challenges for learning together using multi-touch devices (Martinez-Maldonado et al. 2015). There is thus a need for collaboration and group awareness tools to incorporate instructional practices that structure group tasks and support collaborative processes and products to enhance teamwork and learning in this multi-touch learning environment.

Fig. 1 A multi-touch tabletop

In CSCL environments, two types of tools have been proposed to support regulating collaborative learning: scripting tools and group awareness tools (Miller & Hadwin, 2015). The first one includes collaboration scripts, which specify how students should collaborate and solve problems, structuring interactions by engaging students in well-defined instructions (Dillenbourg, 2002). In scripted collaboration approaches, scripts aim to foster intragroup interactions, elicit and regulate knowledge-productive interactions such as explanation and conflict resolution (Dillenbourg & Jermann, 2007). In the past decade, a few studies have proposed scripted approaches to multi-touch tabletop collaboration for students to assist in their collaboration and interaction (e.g., Clayphan et al. 2014). The second one, group awareness tool, collects, aggregates, and reflects information back to students to facilitate collaboration (Miller & Hadwin, 2015). An intergroup competition mechanism could be used as a group awareness tool, such as designing intergroup communication widgets to promote interactions and enhance the awareness of other teams' performance in CSCL (Romero, 2012). To date, however, instructional practices of the combination of scripting tools (e.g., collaboration scripts) and group awareness tools (e.g., intergroup competition mechanism) are still limited but worth developing to support regulation in CSCL, especially in multi-touch collaborative learning. In order to support and regulate students to collaborate and interact with their group members and to better deal with the intergroup relationships in a multi-touch classroom, this study attempted to design and incorporate an intergroup competition mechanism in a scripted approach to foster collaboration within groups and in-classroom learning, examining whether applying this mechanism enhances students' performance on teamwork, collaborative skills and learning achievement.

Multi-touch supported collaborative learning

Over the last decade, the use of multi-touch interfaces for collaborative learning has received considerable attention. Multi-touch tabletops have the unique advantage of being able to support small group and face-to-face collaborative learning and bridge the gap between computer-supported and face-to-face collaborative learning (Kharrufa et al. 2010), providing a different approach to CSCL, allowing several students to simultaneously use the same input device and interact face-to-face when designing and constructing artifacts (Ioannou, 2019).

Multi-touch tabletops provide users with intuitive operations and a shared interface for co-located collaborative design (Ioannou et al. 2015). The shareable interface enables co-located students to co-construct digital content, share, discuss, and reflect upon each other's ideas, as well as their design (Martinez-Maldonado & Goodyear, 2016). Using such platforms encourages students to collaborate and create an environment wherein they can integrate their ideas and discuss their findings (Basheri et al. 2013). Moreover, multi-touch tabletops support students' mutual awareness of each other's actions and the progress of their collaborative design (Martinez-Maldonado & Goodyear, 2016). Group members can switch between roles, explore ideas, and have an awareness of what each other was doing under the condition of horizontal table display usage (Rick et al. 2011). Therefore, multi-touch tabletops for collaborative learning can be said to have considerable potential in a face-to-face CSCL context, though more work is needed to develop their application in K–12 education.

Collaboration scripts

Collaboration scripts can be regarded as a type of social scripts, describing how to structure and sequence discourse and collaborative activities (Morris et al. 2010). The effective collaborative processes elicited by computer-supported collaboration scripts usually bear a positive relation to individual learning outcomes (Vogel et al. 2017). Some studies have proposed scripted approaches to multi-touch tabletop collaboration for students within face-to-face and computer-mediated environments (e.g., Chen & Chiu, 2016; Clayphan et al. 2014). Chen and Chiu (2016) focused on the script effects regarding metacognitive self-regulation and higher levels of mathematics literacy of elementary school students, while Clayphan et al. (2014) designed CSCL scripts to support tabletop brainstorming for university students. The scripts Clayphan et al. developed provided prompts and confirmation dialogues for each brainstorming stage, wherein they reported that these scripted approaches were effective in terms of the number of ideas produced and reasonable categories created. To date, however, the application of computerized collaboration scripts to structure elementary student interactions and collaboration in multi-touch supported collaborative learning has not yet been explored in much detail within the extant literature. More scripted research needs to be done in order to better deal with both intergroup relationships and within-group relationships.

Intergroup competition

Intergroup competition refers to a strategy dealing with intergroup relations in order to promote intragroup collaboration and learning by means of competition between groups. Theoretically, encouraging intergroup competition can lead to potent within-group collaboration (Dickinson et al. 2013). Some studies advocated the effectiveness of intergroup competition to foster teamwork performance and student learning achievement. Unlike competition between individuals, intergroup competition provides the motivational impetus which is necessary for groups to compensate for some of the process losses that often occur (Oldham & Baer, 2012). Specifically, Oldham and Baer claimed that "competition may serve to weld groups together into tight-knit social units in which members view each other as interdependent and in which the distinction between self- and group-interest becomes blurred—all of which are likely to boost within-group collaboration" (p. 393)

Intergroup competition usually takes place in the form of rank-order competition (Reuben & Tyran, 2010), with rankings based on group performance (scores) in the activity. Intergroup competition mechanics, such as giving points and establishing a leaderboard, may offer the right incentives to make students go the extra mile during a collaborative learning course (Massey et al. 2006). In a networked gaming learning environment, Yu et al. (2008) utilized real-time team competition by having dyads formed by 10-year-old students compete against other pairs by answering questions within the game to aggregate scores. Their study, however, focused on the comparison of face-to-face and anonymous conditions on students' affective states, such as satisfaction and motivation. With the rapid development of information technology, multi-touch platforms can now provide a (face-to-face and computer-mediated) communication medium for intergroup competition with a real-time environment, enhancing awareness of other teams' performance. Research on structuring student interactions in CSCL using computerized collaboration scripts, and on promoting peer collaboration and learning with technology supporting intergroup competition, is still in its infancy; its possible design and effectiveness need further research and evaluation.

Research questions and hypotheses

This study set out to examine whether applying intergroup competition when learning with CSCL scripts on multi-touch tabletop displays enhances the effects on teamwork performance, collaborative skills, and learning achievement. According to the research purpose, this study sought to answer the following primary question: Does intergroup competition in scripted multi-touch collaborative learning enhance elementary students' teamwork performance, collaborative skills, and learning achievement? In addition, in order to provide a qualitative perspective to support quantitative findings, this study also sought to understand elementary students' perceptions about this learning approach.

Based on the literature and considerations discussed above, the following research hypotheses were formulated: In a scripted multi-touch collaborative learning activity, elementary students completing an activity with intergroup competition will demonstrate significantly better teamwork performance (*H1*), collaborative skills (*H2*), or learning achievement (*H3*) than those not using intergroup competition.

Method

Design and participants

This study employed a quasi-experimental comparison group design to evaluate the effects of intergroup competition in a scripted multi-touch collaborative learning activity. The independent variable incorporated a real-time competition approach consisting of two levels, with and without intergroup competition; the dependent variables included teamwork performance, student collaborative skills, and learning achievement. In considering the influence of students' prior ability/knowledge on their measurement, this study used their pretest performance as covariates to adjust their posttest performance in the analysis of collaborative skills and learning achievement.

Eight fifth-grade classes in a public elementary school located in a satellite town in northern Taiwan were invited to participate in this study, and two intact classes consisting of fifty-three students, aged 10 to 11, were willing to take part. This study arranged students to accomplish a tessellation-related design project, which was particularly designed for upper elementary students based on the mathematics curriculum guidelines of the Ministry of Education and corresponded to the competence indicators of plane geometry for this learning stage. The two participating classes could be considered to possess similar intellectual abilities, as Taiwan's public elementary schools adopt S-type grouping, which can divide the school students into academically balanced classes when they enter the fifth grade according to their overall academic achievement in the fourth grade. Considering the generalizability of the findings, data were not collected on the three students who were highlighted by the school's counseling office and their class tutor as having learning disabilities. Students with learning disabilities are not typically in the normal class grouping within the public primary education system in Taiwan, and they are often given individualized education programs in public schools; in addition, one student who had a disability card for health impairments would be excluded from the analyses, because these data were better off not being used to test hypotheses about the target population. That is, the data for four students was incomplete, and 49 students would thus enter the analyses. This study randomly assigned one entire class to the scripted group with intergroup competition (viz., the experimental group, 25 students) and the other class to the scripted group without intergroup competition (viz., the comparison group, 24 students). There was no significant difference between the experimental and comparison groups with regard to their previous semester's math final exam scores, $t(47) = -1.37$, $p = .179$, and their previous semester grades in mathematics, $t(47) = -.64$, $p = .522$.

Environment

This study featured a multi-touch learning platform setup (one for each team, as shown in Fig. 2) in a computer classroom at the participating school. The platform was composed of a medium-sized multi-touch tabletop connected to a networked Windows desktop computer with a keyboard. According to the empirical experience of our pilot study and previous research (Chen & Chiu, 2015, 2016), this setup was capable of enabling a small group of students to simultaneously conduct the tessellation design project together. An intergroup competition mechanism was designed and integrated into a multi-touch learning platform with collaboration scripts based on previous research (Chen & Chiu, 2016), which involved regulatory activities that engaged students in a design project for each learning stage (clarifying the problem, gathering information, and constructing an artifact). Students were asked to use the transformations of translation, rotation, and reflection to combine or arrange the tessellated patterns, and to mark each kind of vertex junction with the degrees of the interior angles of regular polygons, draw the lines of symmetry of each type of regular polygon they used, and describe the transformations they applied in the tessellated pattern.

A set of collaboration scripts was designed to structure the students' interactions and collaborations in multi-touch collaborative learning for both groups. The two functional types of individual- and group-level scripts were provided in sequential order. These collaboration scripts specified individual- and group-level sequencing procedures for each stage. For example, in the beginning of the clarifying stage, the script was displayed on the platform: "Please read the design project individually, and list the design specifications"; after this was done on the platform, the script guided the team members through

Fig. 2 The multi-touch classroom environment

face-to-face, reciprocal questioning. As Fig. 3 depicts, the script provided a team member's name and that student was then asked to articulate one's thoughts with regard to the listed specifications, and also requested the other members by name to question what the partner said. Each team member had to confirm the individual button (bearing the student's name) in the corner upon completing the reciprocal questioning. This student-centered, continuous questioning and answering process included regulatory activities that engaged students in a design project. Finally, the script required the team members to work together to relist the design specifications according to the content and opinions that they put forward.

The above computerized collaboration scripts and intergroup competition mechanism were implemented using Visual Studio as the development tool and MariaDB as the database system, including a digital, real-time leaderboard embedded in the multi-touch platform. The competition mechanism evoked competition between groups by building positive goal and reward interdependence among group members. Table 1 presents the design of the leaderboard, which consisted of a design aspect and a collaboration aspect, showing each team's design scores derived from peer assessments (in which student teams could view and graded other teams' products) and collaboration scores derived from field observer assessments (in which field observers could grade each team's teamwork performance). The design and collaboration rankings were determined based on the design and collaboration scores, respectively. As depicted in Fig. 4, the leaderboard, which functioned as a pop-up window on the multi-touch platform and could be viewed at any time during the collaboration process, showed the top three teams with their design scores and collaboration scores, and students' own team's scores, and attempted to extend the group awareness to intergroup level awareness for each stage/session.

Activity

A scripted multi-touch collaborative learning activity was implemented in students' computer classroom. Both the experimental and comparison group students conducted a design project in collaborative teams using the multi-touch platform with collaboration scripts,

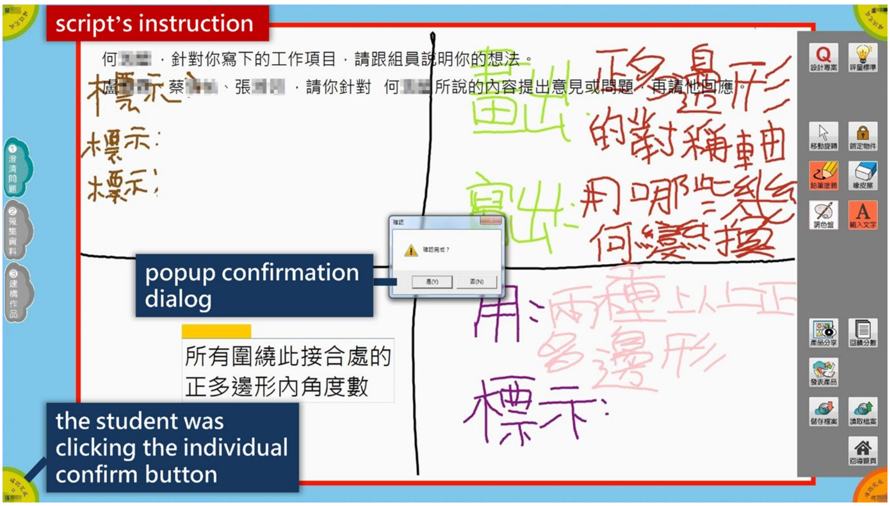


Fig. 3 Group-level collaboration scripts for reciprocal questioning about their work

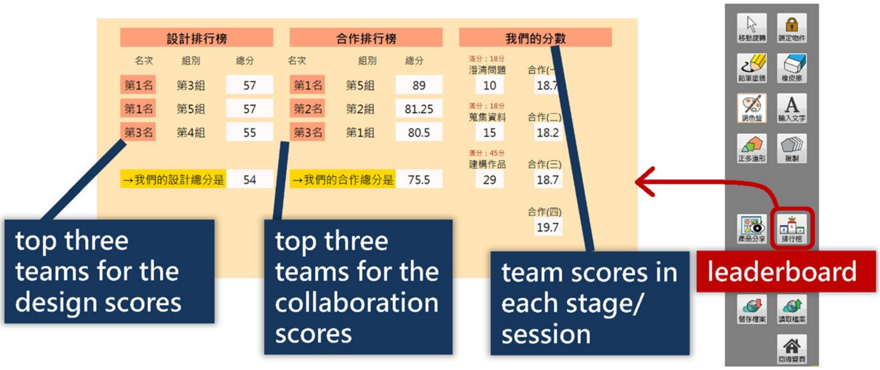


Fig. 4 The leaderboard on the multi-touch learning platform

Table 1 Design of the leaderboard

Aspect	Source	Description
Design	The design scores of each team were derived from peer assessments, in which student teams could view and grade other the uploaded products of other teams.	The leaderboard displayed design rankings of the top three teams and their accumulated scores, and the scores of students' own teams for each stage (as shown in Fig. 4).
Collaboration	The collaboration scores of each team were derived from field observer assessments, in which field observers could grade each team's teamwork performance[a].	The leaderboard displayed collaboration rankings of the top three teams and their accumulated scores, and the scores of students' own teams for each session (as shown in Fig. 4).

[a]The field observers in this study graded once every six minutes; thus, there were a total of five grades in each 40-minute class session (discounting the extra time needed to explain things at the outset)

whereas the students in the experimental group were told that they could view the real-time leaderboard to check which teams were currently in the top three and the design and collaboration scores of their own teams during class. The instructor, who was majoring in information and computer education, explained the criteria for the products to all students in the first five minutes of each design stage. Table 2 provides a description of the student activities in each design stage, as well as the time spent working on them. After the teams had uploaded their work to the intergroup shared area, both the experimental and comparison groups could view the other teams' uploaded products and were required to grade the assigned teams' products, whereas only the experimental group students could check the leaderboard during class time. Figure 5 is a photograph of the students participating in the scripted activity.

Data collection and analysis

Quantitative data were collected on student teamwork performance, collaborative skills, and learning achievement. In addition, a questionnaire was administered to provide

Fig. 5 Team members working together to complete the designed artifact

qualitative data from student perspectives for the multi-touch collaborative learning study. To test for differences between the experimental and comparison groups, this study employed Mann–Whitney *U* tests to analyze teamwork performance (given the relatively small number of student groups) and analyses of covariance (ANCOVAs) to analyze student collaborative skills and learning achievement. All quantitative analyses were carried out using SPSS, version 26.

Teamwork performance

The "Peer Collaboration and Teamwork" rubric developed by Markham et al. (2003) was expanded and used to evaluate the teamwork performance of each student group participating in this activity. This teamwork rubric involved three indicators: leadership and initiative (weighted 25%), facilitation and support (weighted 25%), and contributions and work ethic (weighted 50%). This study expanded this rubric to a five-point scoring rubric in which the performance ranged from *unsatisfactory* to *advanced*. For example, to reach the *advanced* level in contributions and work ethic, a group member not only "worked hard on the project most of the time," but also "made up for work left undone by other group members to complete the project."

Three field observers, majored in information and computer education, independently evaluated the teamwork performance of each team during each class session. The observers were trained in advance, first by acquainting them with the criteria of the rubric (see Markham et al. 2003, p. 69), then applying/mapping the criteria to actual examples using four recorded video clips from the pilot study. Two clips featured a student team that performed poorly in peer collaboration and teamwork, while the other two clips featured another team that performed adequately. The three observers judged their teamwork performance for each indicator in different design stages, then discussed the rating rubric to clarify the criteria until they reached consensus. The consensus gradings covered almost every level in the three indicators. During the experiment of this study, the teamwork performance measure was live: one observer graded one indicator of the rubric for each team;

Table 2 Students' activities with/without the intergroup competition during the three design stages

Design stage	Activity in design stage		Duration
	Comparison group (with collaboration scripts but without intergroup competition)	Experimental group (with both collaboration scripts and intergroup competition)	
Clarifying the problem	Students clarified the problem individually, then discussed the needs with team members to propose a list of design specifications and subsequently graded the assigned teams' proposed specifications.	In addition to the work completed by the comparison group, students could check the real-time leaderboard at any time during class.	One week, 40 minutes
Gathering information	Students collected the information individually, then discussed it with team members to propose a page of gathered information and subsequently graded the assigned teams' proposed information.	As stated above.	One week, 40 minutes
Constructing an artifact	Students developed solution alternatives individually, then discussed these with team members to propose an artifact and subsequently graded the assigned teams' final artifacts.	As stated above.	Two weeks, 80 minutes

Note. The comparison group students could view their own team's scores, but the multi-touch platform did not provide the leaderboard for them in other words, each indicator was rated by the same observer. The field observers graded every student group once every six minutes; thus, there were a total of five grades in each class session in which these five grades were totaled to constitute a team's indicator performance. Before the treatment, there was a one-session practice activity for all participant teams and these trained observers graded students' teamwork performance as an additional field training which was not counted toward the formal teamwork performance. While entering the treatment sessions, the observers were not told which class was the experimental or comparison group, and were asked not to intervene in the activities of students. All students were specifically not told that they were being evaluated nor asked who was scoring.

Collaborative skills

The Collaborative Skills Scale developed by Chiu et al. (2006) was modified and expanded to assess students' collaborative skills. The scale consisted of 32, five-point Likert-type items composed of 25 positively worded statements and 7 negatively worded statements. For instance, "I am willing to share what I know with the team members" is a sample item, and "When team members are in conflict, I am willing to provide advice to solve the problem" is another sample item. The participants indicated their use of collaborative skills by selecting one of five choices: *always*, *often*, *sometimes*, *seldom* and *never*. The Cronbach's α for this scale was .95 in this study.

Learning achievement

The achievement test covered learning content related to the design project, including content related to plane geometry. The appropriateness of this test was confirmed by a senior mathematics professor who is an expert in student mathematics education. For example, a sample item is "Which of the following statements is wrong? a) A pentagon has five lines of symmetry. b) All the lines of symmetry of a hexagon intersect at one point. c) A graph with four lines of symmetry is a square. d) A diagonal of a square is also a line of symmetry." A pilot test was implemented with another 90, thirteen-year-old Taiwan students. The discrimination indices were all above .3. Three items were deleted since their difficulty indices were below .2 or above .8. There were nine items for the formal test, consisting of five multiple-choice questions and four word problems. The reliability coefficient (*KR20*) calculated using the Kuder–Richardson Formula 20 was .78.

Students' perceptions of the activity

A questionnaire with two open-ended questions (1. Would you like to participate in this kind of learning activity on the multi-touch platform in the future? Why or why not? 2. What thoughts and suggestions do you have for this activity?) was conducted to understand students' perceptions of the activity. The qualitative data would be presented in tabular form, including quotations from participants and the frequency of yes/no responses.

In addition to the above quantitative data and student perception data, with students' permission, their intragroup interactions (including cursor/pointer highlight and spotlight) were recorded using a screen recorder. Video recordings of higher and lower teamwork performance groups (the top and bottom third of both conditions) were selected and transcribed verbatim as additional data for discussing the dependent variables and/or group awareness to provide a more in-depth understanding of students' interactions with their partners for carrying out the design project collaboratively on the multi-touch platform.

Procedure

The experiment was conducted over a period of seven weeks. The entire procedure for both the experimental and comparison groups was administered by the same instructor, including a practice activity (one week), pretest (one week), treatment activity (four weeks), and posttest (one week). Students operated in teams of three or four, following the script instructions to accomplish the design project on a multi-touch learning platform with or without intergroup competition, while the schoolteachers did not intervene in the student activities, serving only to maintain the order of students when necessary while paying attention to the safety of students during their learning activities. The procedure for conducting this experiment is presented in Fig. 6.

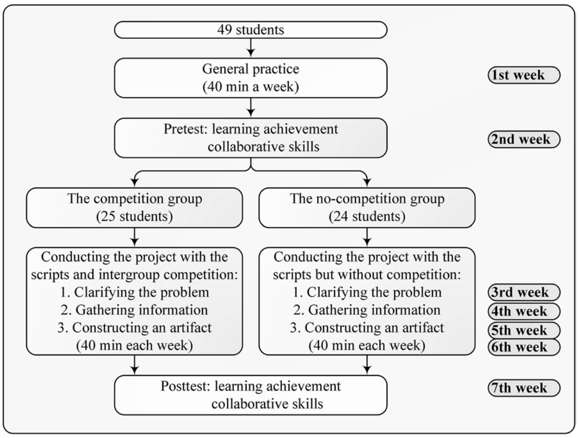
1. Practice (first week). Prior to the formal experiment, the instructor used a 40-minute class to enable the participants to practice the process of collaborative design using the multi-touch platform. All the participants within each class were assigned to temporary teams based on their scores in the previous semester's math final exam and using S-type grouping. Each team was required to work together and create a designated pattern comprised of regular polygons by using the general functions of the multi-touch platform

2. Pretest (second week). The participants were given pretests on learning achievement in the second week, as well as the collaborative skills scale. The pretest items were not mentioned or reviewed during the following treatment period

3. Treatment (third, fourth, fifth, and sixth weeks). The students within each class were arranged in formal teams formed by S-type grouping based on their scores in the pretest of learning achievement. Each team was asked to follow the script instructions to accomplish the design project on the multi-touch platform with or without intergroup competition, according to the assigned condition. The project lasted four weeks, with three design stages in four weekly sessions (40 min each)

4. Posttest and questionnaire (seventh week). All participants completed the learning achievement test and the collaborative skills scale in the seventh week after the four-week

Fig. 6 The experimental procedure of this study



treatment. Finally, the questionnaire for students' perceptions of the activity was conducted to understand students' perceptions of the activity

Results

A post-hoc power analysis was performed to justify the sample size of this study. The threshold for statistical significance was set at .05 in this study. The statistical power was computed using G*Power 3.1, and the power of this study was .8, indicating that the sample size was sufficient to find meaningful significant differences. Additionally, in considering the independence of the data, this study calculated the intraclass correlation coefficients to measure possible variation between student teams. For collaborative skills, the coefficients for the experimental and comparison groups were .01 and $<.001$, respectively. For learning achievement, the coefficients for the two groups were both $<.001$. The intraclass correlations were quite small, and no significant effects were found ($p>.05$) for the variances, hence the general linear models (such as ANCOVAs) could be performed (Wen & Chiou, 2009).

Descriptive statistics for teamwork performance, collaborative skills, and learning achievement for the experimental and comparison groups are presented in table 3. A repeated measures analysis of variance indicated that there was no significant difference between the pretest and posttest of collaborative skills within the experimental group, $F(1,24)=1.47$, $p=.237$, as well as within the comparison group, $F(1, 23)=2.66$, $p=.116$; a significant difference, however, was found between the pretest and posttest scores of learning achievement within the experimental group, $F(1, 24)=13.40$, $p=.001$, but no significant difference was found between the pretest and posttest scores within the comparison group, $F(1, 23)=.83$, $p=.371$. The following results present the treatment effects on teamwork performance, collaborative skills, and learning achievement, as well as summarizing student perceptions of the learning activity.

Table 3 Descriptive statistics of overall measures for the experimental and comparison groups

Measure		Experimental group ($n^a = 25$; $n_g^b = 8$)		Comparison group ($n = 24$; $n_g = 8$)	
		M	*SD*	*M*	*SD*
Teamwork performance	overall	81.25	3.04	65.84	3.17
	leadership and initiative	78.13	3.64	66.88	4.73
	facilitation and support	77.63	4.47	64.75	5.39
	contributions and work ethic	84.63	3.25	65.88	2.03
Collaborative skills	pretest	127.72	16.62	128.29	17.96
	posttest	130.20	15.32	124.04	19.25
Learning achievement	pretest	27.76	6.35	25.58	9.86
	posttest	34.16	10.56	26.96	6.68

Note. Maximum possible score of teamwork performance = 100, collaborative skills = 160, and learning achievement = 65

[a]The number of students

[b]The number of student groups

Teamwork performance

For the treatment effect on overall teamwork performance, this study employed a Mann–Whitney *U* test to test for differences between the experimental and comparison groups. The *U* test revealed a significant difference in the teamwork performance of the competition group and the no-competition group, $U = 64.00$, $z = 3.36$, $p < .001$, $r = .94$ as a large effect. *H1* was thus supported, indicating that students completing the scripted activity with intergroup competition can demonstrate significantly better teamwork performance compared to those not experiencing intergroup competition. Regarding the indicators of teamwork performance, the experimental group significantly outperformed the comparison group in the indicators of leadership and initiative ($p = .001$), facilitation and support ($p = .001$), and contributions and work ethic ($p < .001$).

Collaborative skills

For the treatment effect on overall collaborative skills, an ANCOVA was performed with the posttest measure of collaborative skills as a dependent variable, and the pretest performance on the collaborative skills as a covariate. No significant differences were found between the two groups in their pretest: $t(47) = -.12$, $p = .908$. The test for the assumption of homogeneity of regression slopes was not violated in collaborative skills; $F(1, 45) = .21$, $p = .649$. The ANCOVA was then conducted to analyze the difference between the two groups' posttest performance on collaborative skills. The ANCOVA revealed a significant difference between the two groups; $F(1, 46) = 4.40$, $p = .041$, $\eta_p^2 = .09$ as a medium effect (M_{adj} for competition = 130.42; M_{adj} for no-competition = 123.81). The results thus support *H2*, which proposed that students complete the scripted activity with intergroup competition can demonstrate better collaborative skills compared to those without intergroup competition.

Learning achievement

For the treatment effect on overall learning achievement, this study performed an ANCOVA with the posttest measure of learning achievement as a dependent variable, and the pretest scores on the achievement as a covariate. No significant difference was found between the two groups in the learning achievement pretest: $t(47) = .92$, $p = .361$. The assumption of homogeneity of regression was not violated; $F(1, 45) = 2.99$, $p = .091$. The ANCOVA showed a significant difference between the competition and no-competition groups; $F(1, 46) = 7.52$, $p = .009$, $\eta_p^2 = .14$ as a large effect (M_{adj} for competition = 33.52; M_{adj} for no-competition = 27.62). Therefore, *H3* was supported, indicating that students working with intergroup competition in the scripted activity can have better learning achievement than those not working with intergroup competition.

Table 4 Examples of quotes from the questionnaire regarding student perceptions about the activity

			Would you like to participate in this kind of learning activity on the multi-touch platform in the future? Why or why not?	What thoughts and suggestions do you have for this activity?
Experimental group	P-1-1	Yes	This kind of activity is very special and interesting. I also learned a lot of knowledge in the process, and it can also promote the friendship between friends.	I think the time is too short, and it can be longer.
	P-2-3	Yes	It can increase the experience of teamwork.	I feel all good.
	P-3-1	Yes	I feel that this class has taught me a lot of mathematics and I have more interaction with my classmates.	I hope I can have the opportunity to use the touch screen again next time. You can come to class again!
	sum	Yes: 24 (96.0%); No: 1 (4.0%)		
Comparison group	C-2-2	Yes	You can do things about mathematics by yourself.	The team can be more collaborative.
	C-5-2	Yes	I like group discussions very much, and I can learn from other students' strengths, which is not bad.	It's fun, but it can be more interesting.
	C-6-2	No	Boring.	Organizing event.
	sum	Yes: 21 (87.5%); No: 3 (12.5%)		

$N = 49$. Students' original complete qualitative responses (in Traditional Chinese) of this study are available from the corresponding author on reasonable request

Students' perceptions of the activity

Example quotations from the questionnaire for research participants are presented alongside yes/no response frequencies, as summarized in Table 4, which will be discussed in the following section.

Discussion

This study designed and integrated a real-time intergroup competition mechanism into a collaboration script supported multi-touch learning platform, and examined the effects of introducing it into a multi-touch classroom. The findings show that the students of the experimental group had better teamwork performance, collaborative skills, and learning achievement, indicating that with the support of collaboration scripts, students working with intergroup competition performed significantly better than those who did not; as such, learning in a multi-touch classroom with CSCL scripts could be improved by introducing intergroup competition.

These results indicate that intergroup competition can increase within-group collaboration in a multi-touch classroom. This is possibly because the intergroup competition represented on the multi-touch table enhanced students' group awareness about their group performance (including their own group and other groups) from multiple sources (including design and collaboration scores) and thus stimulated their collaboration and learning. As shown in Table 5, in this example, the competition group students were checking their current design and collaboration scores on the leaderboard displayed on the multi-touch platform and comparing them to other teams. Within the intergroup setting of sharing design solutions with the class and monitoring the performance of other teams, the students in the class have the opportunity to notice and perhaps address potential problems that their own team did not foresee. This use for a digital leaderboard, which can be a source of motivation for competitive students (Domínguez et al. 2013), may enhance intragroup collaboration as well as intergroup awareness. This is reflected by the students' intergroup level awareness, and may promote teamwork performance and enhance student collaborative skills, which will be discussed as follows.

With regard to the teamwork performance, it is noteworthy that the differences between the competition and no-competition groups' "leadership and initiative" and "facilitation and support" performance were not as large as that in "contributions and work ethic." In addition, that the experimental group performed very well in "contributions and work ethic" may be attributed to the effects of intergroup competition, which motivated the competition group students to be less likely off-task and also motivated them to work hard on the project most of the time, as well as to the criterion "make up for work left undone by other group members to complete the project." Although students under conditions of both competition and no-competition followed the computerized script instructions to develop their digital design solutions on the shared interface, the competition group students tended to engage more actively in discussions with team members on the multi-touch learning platform regarding the collaborative task when designing the artifact to meet requirements, according to their teamwork performance judgement. As part of the competition effort, engaging in comparing and contrasting ideas using the multi-touch learning platform may help students to achieve better teamwork performance and collaborative skills. As shown in Table 6, the competition group students tended to engage in more active discussions with team members regarding the collaborative task on the multi-touch platform when designing

Table 5 Examples of group awareness in competition group student interactions

Team	Stage	Student	Content
Team 1	Constructing an artifact	A	Our (total design) scores are 42, and the (design) score (of "constructing an artifact" stage) is 21 points now. [referring to and touching their design scores on the multi-touch platform]
		B	And then this (collaboration) score (during this session) changes to 22, you see. [referring to their collaboration scores on the platform]
		A	We suck! [indicating their design scores]
		C	Their (the top third team, Group 7) total design scores… Wow! They are seven points different from ours. [referring to the team's design scores on the platform]
		C	Wow! Group 3 is amazing, all (both their design scores and collaboration scores) are on the leaderboard. [referring to another team's scores on the platform]
		C	We still have better collaboration scores (on the digital leaderboard)

Table 6 Examples of teamwork performance in competition and no-competition group student interactions

Team	Stage	Student	Content
Team 2 (Competition group)	Constructing an artifact	A	Find the right proportion…wait a minute, your triangle is not turned upside down. [referring to their digital design on the multi-touch platform]
		B	Yes, adjust it again.
		B	A little more adjustment, a little more adjustment. [adjusting the triangle on the platform]
		C	Probably okay.
		A	Smaller, smaller. [fitting the triangle to their digital design]
		B	Move, move, move, I'm moving now. [moving the triangles on the platform]
		A	The ratio should be enlarged a little more, the ratio is a little difficult to get.
		A	Nope, I have to shrink it further.
		C	Wait a minute, in fact, it's not done very well here because the size is different. [pointing out their design on the platform]
		C	Wait a minute, wait a minute. [arranging the pattern on the platform]
		A	Is it ready?
			(Working together to complete the tessellation on the platform)

Table 6 (continued)

Team	Stage	Student	Content
Team 3 (no-competition group)	Constructing an artifact	A	One person creates one (tessellation), you do this, go!
		B	Why? You use that…it will be very difficult to use, so many triangles. Do you know what kind of polygons you just made?
		A	1, 2, 3, 4… [counting the sides of a polygon on the platform]
		B	Stop counting!
		A	It's easy, it's easy, you tessellate it here. [dropping triangles on the tabletop surface]
		B	(Using) squares is easier. [placing a square on the screen]
		A	One person creates one (tessellation pattern), there. [moving the square closer to a team member]
		B	Okay, okay, okay, you do it. [erasing the square on the platform]
		C	Okay, you do it!
		A	No.
		B	Aren't you going to do the difficult one (tessellation)?
		A	I forget. How to tessellate?
		B	Hurry up. We're waiting for you!
		B	What are you doing? Why do you keep clicking (on the screen)? [two team members were placing squares and then octagons on the platform]

Note. The comparisons between the two conditions are presented with a higher teamwork performance group of each respective class, under the same design stage and script level the artifact that met the requirements, and also demonstrated better facilitation and support than did the no-competition group students. Although the no-competition group students with higher teamwork performance also worked hard on the design project, and one team member (student A) tried to provide leadership to the team by providing focus regarding the digital design on the multi-touch platform and direction for the project, the competition group students in this example demonstrated more willingness to help other team members, which would help create a more positive work environment. As a student in the competition group stated in the questionnaire, “it (the multi-touch collaborative learning activity) can also promote the friendship between friends,” while another competition group student noted that “I have more interaction with my classmates (during the multi-touch collaborative learning activity).” Appropriate pressure leveraged by intergroup competition motivates individuals into improving their performance (Rapp, 2017) and to put more effort into group activities in order to make their group perform better than others.

Regarding the collaborative skills measured in this study, the experimental group outperformed the comparison group on grounds that intergroup can enhance group cohesiveness and productivity, and promote collaboration within the group (Dickinson et al. 2013; Oldham & Baer, 2012). Moreover, this study also found that both the competition and no-competition group students’ collaborative skills did not improve significantly. The finding of the current study does not seem to correspond with some previous research (e.g., Radkowitsch et al. 2020; Vogel et al. 2017) which found that CSCL scripts facilitate students’ collaboration skills. There are differences, however, between the “collaborative skills” in this study and Vogel et al. “collaboration skills,” which included argumentation skills and peer assessment skills. Nevertheless, this finding seems compatible with Radkowitsch et al. (2020) finding that CSCL scripts may have a negative influence on learners’ motivation, as some Collaborative Skills Scale items regarding student reflection and feedback are related to students’ attitudes/motivation. Considering the fact that collaboration scripts may undermine learners’ motivation levels, but intergroup competition may improve learners’ intrinsic motivation levels (Tauer & Harackiewicz, 2004), the effect of the combination of computerized collaboration scripts with intergroup competition for multi-touch collaborative learning on students’ (intrinsic) motivation deserves further investigation.

With respect to students’ learning achievement, this study found that the competition group had significant improvement, but the no-competition group had no significant improvement. Since both groups followed the computerized collaboration scripts, these results are not fully in accord with Vogel et al. (2017) finding that scripted students can acquire knowledge about the topic discussed within the group, as well as Radkowitsch et al. (2020) finding that CSCL scripts can facilitate domain-specific knowledge. It may be inferred that the scripts used in this study focused on the arrangements of individuals and peer interaction (i.e., individual- and group-level scripts), thus having the domain-unspecific character of collaboration scripts (see Kollar et al. 2014). Additionally, the scripts used in this study did not have an arrangement like those of the previous research (Chen & Chiu, 2016) which asked students to write down their design rationale and give qualitative feedback to other groups’ designs. Therefore, future design of CSCL scripts with the intergroup competition strategy may strengthen the domain-specific arrangements or instructions. In addition, the result suggests that the intergroup competition mechanism encouraged the experimental group students to be more active in the learning process and have deeper thinking and elaboration of domain-specific knowledge in positive team collaboration. Examples of student perceptions were, for example, a competition group student who stated in the questionnaire that “I feel that this class has taught me a lot of mathematics … I hope I can have the opportunity to use the touch screen again next time.” Moreover, another competition group student stated that "It (this course) is rare and interesting. I like it very much. I hope I can take more courses like this to fill myself with knowledge." In comparison with the students in the group without intergroup competition, those working under competitive conditions had higher teamwork performance and better within-group collaboration - this was enhanced by the competition mechanism that was used throughout the design and collaboration process, which consequently improved their learning achievement.

Several limitations to this study need to be acknowledged. First, since the number of student teams was limited, this study employed the nonparametric technique to compare the experimental and comparison groups' teamwork performance. Second, the participants in this study were 10 to 11 year old elementary students, and thus the findings may not be generalizable to students at higher levels, such as secondary school or college students. Continuous research is encouraged to introduce the scripted approach with intergroup competition in CSCL to different educational stages. Future research could also include an additional age group to investigate whether there are differences in age groups and to increase research relevance, as the sample size for this study was small.

Conclusion

This study designed and integrated a real-time intergroup competition mechanism into a multi-touch platform to better deal with intergroup relations in scripted collaborative learning, and a quasi-experiment was conducted to evaluate the effects of intergroup competition. The findings indicate that with the support of collaboration scripts, students collaborating with intergroup competition outperformed their non-competitive counterparts in multi-touch collaborative learning with regard to teamwork performance, collaborative skills, and learning achievement. The present study extends prior research of CSCL scripts and group awareness in CSCL (e.g., Miller & Hadwin, 2015) to multi-touch collaborative learning, extends the group awareness concept to intergroup level awareness, and confirms the positive effects of scripted collaboration with intergroup competition. Instructors could adopt such an approach to engage students in teams and attain better performance and achievement in a multi-touch learning context

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Data availability The data generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflicts of interest The authors have no competing interests to declare that are relevant to the content of this article.

Ethical approval All procedures performed in this study involving student participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The investigators obtained consent from the participating school and classroom teachers for experimentation. All of the students were informed that their participation was entirely voluntary, and that their responses would be confidential.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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