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Employing intergroup competition in multitouch design-based learning to foster student engagement, learning achievement, and creativity

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ABSTRACT

This study developed an intergroup competition mechanism and integrated it into a multitouch platform for collaborative design-based learning (DBL) to enhance elementary school students' engagement, learning achievement, and creativity. A total of 58 elementary school students in 2 sixth-grade classes participated in the study over a period of 9 weeks. A quasi-experiment was conducted to examine the effects of the intergroup competition mechanism. The two classes were divided into an experimental group (a class of 28 students in collaboration with intergroup competition) and a comparison group (another class of 30 students in collaboration without intergroup competition), and the students in both groups were required to carry out a tessellation design project with their partners on the multitouch platform. Statistical analyses revealed that students under the intergroup competition condition had significantly better student engagement, learning achievement, and creativity than those under the no-competition condition. The results suggest that the computerized intergroup competition mechanism is effective in enhancing student engagement, learning achievement, and creativity. On the basis of the results, considerations in relation to the intergroup competition mechanism and the enhanced cognitive processes in multitouch DBL are discussed.

1. Introduction

Design-based learning (DBL) has been seen as a promising approach for science, technology, engineering, and mathematics (STEM) education over the past decade, as it engages students in learning subject content and finding creative solutions in ways that stimulate creativity through hands-on learning and team collaboration (Gardner, 2012; Mehalik & Schunn, 2006). With advances in technology, multitouch systems, based on touchscreens, provide collaborative design with a new shared interface, namely a face-to-face and computer-mediated platform where team members can discuss and implement their design ideas, while simultaneously interacting on the same task, in an intuitive way (Basheri, Munro, Burd, & Baghaei, 2013; Harris et al., 2009). Although the multitouch technology has brought many changes to DBL, few studies have investigated the mechanisms dealing with intergroup relations in this context, as the learning process of DBL is both within and across teams (Gómez Puente, van Eijck, & Jochems, 2013). If we have a better understanding of the mechanisms that can

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engage collaborative teams and facilitate students' content learning and creative processes in multitouch DBL, then this would help to maximize the effectiveness of this learning approach. Since using design competitions in design projects may boost within-group collaboration and engagement (Kundu & Fowler, 2009; Massey, Ramesh, & Khatri, 2006), this study aimed to evaluate whether integrating intergroup competition into multitouch DBL can enhance student engagement, learning achievement, and creativity. The rest of this introduction consists of background information on DBL and intergroup competition, as well as their effects on learning, the use of technology in DBL, and intergroup competition, and finally the specific research questions.

1.1. Design-based learning

DBL is a teaching and learning method that can be applied across the K–12 curriculum (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Nelson, 2004; Strobel, Wang, Weber, & Dyehouse, 2013), based on constructionism and grounded in the processes of inquiry and reasoning toward designing innovative artifacts and solutions (Gómez Puente et al., 2013; Han & Bhattacharya, 2001). The design process typically consists of four main phases: problem understanding, information gathering, solution generation, and evaluation (Puntambekar & Kolodner, 2005). Chang, Peng, Lin, and Liang (2015) proposed a similar design process that can generally be divided into three major phases: analysis stage, ideation stage, and implementation stage. The design tasks encourage students to apply both domain knowledge and skills when doing project work (Ke, 2014; de Vries, 2006). Students have to use their prior knowledge in an open-ended exploration to learn subject concepts and enhance their related achievements (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008). Studies have found that DBL can promote students' academic achievement (e.g., Ellefson, Brinker, Vernacchio, & Schunn, 2008). In addition, the design process applies and builds a design team's creativity (Trilling & Fadel, 2009), which refers to the 'capacity to produce novel ideas, generate new solutions, and express oneself in a unique manner' (Abraham, 2016, p. 609). Students are expected to demonstrate creative thinking in their design products and the design process (Barak & Doppelt, 1999; Doppelt, 2009). Creative thinking comes about through the design process, in which various creative strategies or techniques of thinking, such as idea generation and idea manipulation, are used. The cognitive processes associated with creativity are called creative cognition (Smith, Ward, & Finke, 1995; Ward, 2007), which is concerned with the use of creative thinking strategies or creative techniques (Rogaten & Moneta, 2015).

In recent years, the emergent technology of multitouch surfaces, which provides multiple users with intuitive and dynamic interactions (Battocchi et al., 2010), is being promoted as a new avenue to support a student team in collaborative design tasks so that members can capture and build on ideas together (e.g., Basheri et al., 2013; Chen & Chiu, 2016). Multitouch surfaces allow team members at the same place to interact simultaneously around a shared space, discuss their products or findings face-to-face, and integrate their solutions in a computer-mediated collaborative environment. Despite the support of multitouch technology, DBL is typically a team activity (Doppelt et al., 2008). It is argued that design projects can get learners engaged in various communicative activities such as communicating ideas and results with team members or sharing their products with the class (Ke, 2014; Kolodner, 2002). Recent research in this area has emphasized the need for facilitating the learning process in DBL practices; however, such studies tended to focus on supervising students in applying knowledge to design artifacts or carrying out meaningful integration between the content knowledge and products (e.g., Gómez Puente, van Eijck, & Jochems, 2013; Ke, 2014). Simply put, the support offered in this context has mainly been for the process of knowledge construction. More thus needs to be known about the mechanisms that can foster within-group collaboration and engagement in DBL tasks.

1.2. Intergroup competition

Competition is established on the basis of comparing one's own performance with that of others doing the same task (Coakley, 1994). On the basis of the social interdependence theory, intergroup competition occurs when a group of individuals work together to compete with other groups (Goldman, Stockbauer, & McAuliffe, 1977). In competitive activities, the reward is typically winning (Deci, Betley, Kahle, Abrams, & Porac, 1981), and the social rewards for winning an intergroup competition are, for example, group pride and a positive social identity (Bornstein & Erev, 1994). Some of the elements that can invoke competition include the use of points and leaderboards (Rapp, 2015b). Introducing points or leaderboards to a learning task is a general gamification strategy (Seaborn & Fels, 2015). Points can be obtained by the students assessing others' work (Hammer, Ronen, & Kohen-Vacs, 2012), or by being given to the students by the teachers (Chou & Lin, 2015). Providing students with points or scores is a common approach to directly motivate students in gamified learning environments (Denny, 2013, pp. 763–772; Goehle, 2013; Li, Grossman, & Fitzmaurice, 2012). Moreover, leaderboards serve as a basic mechanism of competition in many computer games, and can be included in school courses to increase student motivation because students see their progress instantly (Domínguez et al., 2013; Silva, 2010, pp. 61–62).

Intergroup competition can be integrated into collaborative learning environments as a motivating strategy (Yu, Han, & Chan, 2008). It is generally agreed that when the group membership is stable, then intergroup competition can motivate students to make valuable contributions to their in-group, and hence promote within-group collaboration (Bornstein & Erev, 1994; De Dreu, Dussel, & Ten Velden, 2015). Interdependent team members and blurred distinctions between individual and group interests are likely to boost student engagement (Oldham & Baer, 2012, pp. 387–420), which deals with 'the quality of effort that students themselves devote to educationally purposeful activities that contribute directly to desired outcomes' (Hu

& Kuh, 2002, p. 555). Individuals engaged in their work are more willing to experiment with ideas, thereby facilitating creativity (Zhou & Shalley, 2003, pp. 165–217). Oldham and Baer (2012, pp. 387–420) pointed out that intergroup competition has the potential to foster creativity by giving the learning process the motivational impetus that is necessary for groups to work together. Furthermore, Baer, Leenders, Oldham, and Vadera (2010) found that an intermediate level of intergroup competition induced groups to produce ideas of greater creativity, whereas fierce rivalry undermined creativity by limiting the extent that groups engaged in collaborative idea generation and decision-making. More empirical research, nevertheless, is needed to verify whether intergroup competition has a direct impact on students' creativity. On the other hand, Wood, Campbell, Wood, and Jensen (2005) found that university students developed course-related knowledge through making their group products better for the competition. Yu (1999) reported that fifth-grade students working together as part of an intergroup competition had better achievements related to their science class than those working without intergroup competition, although some of her other studies contradicted one another. For instance, Yu's (2001) later work found that collaboration with intergroup competition engendered worse science achievement than collaboration without intergroup competition in another set of fifth-grade students. Since the effects of intergroup competition on learning achievement are somewhat inconsistent in the literature, this issue deserves further attention with regard to whether the positive outcomes found in collaborative learning environments resulted from competition between groups.

There have been several attempts to introduce intergroup competition into university engineering design classrooms. The empirical results showed that intergroup competition encouraged design teams to make an extra effort during a problem-based learning course (Massey et al., 2006) and to add more flair to the resulting design products (Kundu & Fowler, 2009). However, few studies have employed comparison-group designs to evaluate the effects of introducing intergroup competition to DBL activities. More research thus needs to be conducted to draw conclusions about the impact of intergroup competition in DBL, especially on K–12 students. With advances in computer and network technologies, computer platforms can not only afford intergroup competition a computerized and real-time competition environment (Yu et al., 2008), but also enable enhanced awareness of the performance of other teams (Romero, 2012, pp. 15–34). In the context of collaborative, serious computer games, Romero (2012, pp. 15–34) noted that a competitive gamified system allows teams to compare their scores and rankings with other teams, and thus know how likely they are of winning the competition. One of the key issues in designing competitive systems with gamification elements, such as points and leaderboards, is to create positive social interactions (Rao, 2013). Rapp (2015a) encouraged comparisons between groups when designing for intergroup competition in an interactive system. This works by promoting a challenge against the game where each group strives to achieve this (Rapp, 2015a). Another issue that can arise with the use of points and leaderboards is that this may reduce students' intrinsic motivation (Nicholson, 2012, pp. 223–230). Nicholson (2012, pp. 223–230) thus suggested creating an engaging scenario and interesting activities instead of only relying upon points and leaderboards, and thus intrinsic motivation can be enhanced.

1.3. Purpose

Although there have been a number of studies on DBL, these tend to focus on middle or high school students. As discussed in the above literature review, intergroup competition can serve as a motivating strategy for team work and has potential benefits to facilitate student engagement, learning achievement, and creativity, yet little research has been done on introducing intergroup competition to collaborative DBL either in a face-to-face alone or computer-mediated context. In addition, the multitouch technology now affords a different way of interaction and learning. This study was thus conducted to investigate the influence of employing intergroup competition in a multitouch DBL activity on sixth-grade elementary students in terms of engagement, learning achievement, and creativity. Accordingly, this study sought to answer the following questions: (1) When elementary school students collaborating with team members to conduct a multitouch DBL activity, do students under the intergroup competition condition have better engagement than those under the no-competition condition? (2) After elementary school students collaborate with team members to conduct a multitouch DBL activity, do students under the intergroup competition condition have better learning achievement than those under the no-competition condition? (3) After elementary school students collaborate with team members to conduct a multitouch DBL activity, do students under the intergroup competition condition have better creativity than those under the no-competition condition?

2. Method

A quasi-experimental, nonequivalent comparison-group design was employed. The independent variable was whether students collaborated with or without intergroup competition in the multitouch DBL activity. The dependent variables included student engagement, learning achievement, and creativity. First, student engagement was determined by the extent of individual students' active and deliberate involvement in the DBL activity and in activities that promote higher quality learning. Second, students' learning achievement was measured through test results. Third, students' use of creative cognition in studying was assessed as their degree of creativity.

2.1. Participants

Fifty-eight sixth-grade students (aged 11–12 years) from two intact classes at a public elementary school in Taipei, Taiwan, were invited to participate in the multitouch DBL activity. The students had three years of formal education in basic computer operations. This study assigned one class to the group with intergroup competition (experimental group, 14 boys and 14 girls) and another class to the group without intergroup competition (comparison group, 15 boys and 15 girls). When these students entered fifth grade the school divided them into academically balanced classes by *S*-type grouping based on the average of their overall academic achievement in the fourth grade. Moreover, the mean scores of a math midterm held one day prior to the treatment for the experimental and comparison groups were 74.41 ($SD = 12.67$) and 75.95 ($SD = 15.23$), respectively, with no significant difference found between the two groups by an independent samples *t*-test, $t(56) = -0.42$, $p = 0.68$.

Concerning the student group size in DBL, it is found that students typically work in groups made of two to four persons (e.g., Doppelt, 2009; Ellefson et al., 2008; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005; Mehalik, Doppelt, & Schunn, 2008; Perrenet & Adan, 2002). Apedoe, Ellefson, and Schunn (2012) have suggested that the optimal group size for DBL is three or four persons, and no significant differences between the two group sizes were found on student learning and performance. Therefore, this study assigned students within each class to groups of three or four by using *S*-type grouping based on the students' scores in a mathematics achievement test administered shortly prior to this study. The students were thus divided into balanced, heterogeneous teams. Detailed information about the composition of individual groups is provided in Table 1.

2.2. Assignment and environment

2.2.1. Design assignments

Each student team was required to collaborate to conduct a DBL project. An open-ended, authentic design project was used in this collaborative design activity, placing students in the scenario as designers and requiring them to craft a tessellation pattern of a playground surface for a children's playground. Tessellation design integrates mathematics and art, and is connected to students' real-world experience (Ward, 2003), e.g., the paving of tile floors and the hexagonal tiling of honeycomb. The final group product (a design drawing) of this project should meet the following requirements: (1) using two or more regular polygons to compose the tessellation, (2) finding the measures of the polygon interior angles for each kind of tessellation vertex, (3) drawing the lines of symmetry for each type of regular polygon, and (4) describing the transformations (e.g., translation, rotation, or reflection) used in the tessellation. Conducting this tessellation design project engaged students in a geometric investigation of transformations and polygons, and developed their understanding of the interior angles of regular polygons, lines of symmetry, and transformation geometry, from collaborative hands-on processes.

Students would carry out the design project through three crucial stages: clarifying the problem, gathering information, and constructing an artifact. These design stages were derived from the literature on DBL (Atman et al., 2007; Doppelt, 2005; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner, Gray, & Fasse, 2003; Puntambekar & Kolodner, 2005), as elementary school students, especially in Taiwan, are generally not familiar with the design process. The first stage, ‘clarifying the problem,’ is to define the problem and formulate the need for the design; the second stage, ‘gathering information,’ is to collect and organize important information needed to solve the problem; and the third stage, ‘constructing an artifact,’ is to develop ideas and create a learning artifact.

This study followed general DBL approaches in which the students would review (i.e., view and discuss) the design products of their peer groups (Kolodner et al., 2003; Puntambekar & Kolodner, 2005). A benchmark for the product of each stage was provided on a multitouch learning platform (for details, see Section 2.2.2) for both experimental and comparison groups. The product benchmark was developed by referring to the criteria for the products of design projects or project-based learning (Dettman, 2005; Frank & Barzilai, 2004; Markham, Larmer, & Ravitz, 2003). The appropriateness of this benchmark was confirmed by two experienced researchers, who both hold master degrees in information and computer education and have rich experience in DBL, as well as tessellation-related activities. This benchmark has three sections in accordance with the three design stages: (1) a ‘clarifying the problem’ section, which contains two dimensions: defining the problem and formulating the need for the design; (2) a ‘gathering information’ section, which also contains two dimensions: identifying key information and organizing data; and (3) a ‘constructing an artifact’ section, which involves five dimensions: tiling with a repeating pattern, incorporating different types of regular polygons, calculating the interior angles of regular polygons, graphing the lines of symmetry of regular polygons, and illustrating the transformations. Three-level criteria for each dimension were given in the benchmark. For instance, the highest level criterion for the “defining the problem” dimension was: ‘The problem was clearly and unambiguously stated.’

Table 1
Composition of individual groups.

Student group		Experimental group[a]	Comparison group[b]
		Numbers	Numbers
Triad	(one boy and two girls)	2	1
	(two boys and one girl)	2	1
Quad	(two boys and two girls)	4	6

[a] $n = 28$.
[b] $n = 30$.

2.2.2. Classroom environment and the multitouch platform

This study placed eight mid-sized (three 23-inches and five a27-inches) multitouch screens in a computer classroom at the participants' school, and arranged a multitouch screen for each student team. To utilize the horizontal surface and enable more equitable interactions with a multitouch surface, in principle the 23-inch screens were used for the groups of three, while the 27-inch screens were used for the groups of four. However, since the number of multitouch screens was limited and the number of experimental and comparison group's student triads and quads was different, one triad used a 27-inch screen and one quad a 23-inch screen. Nevertheless, according to the empirical experience of our pilot study (Chen & Chiu, 2015), both screen sizes are capable of enabling up to four students to learn together simultaneously.

Each multitouch screen was connected to a Windows 7-operated desktop computer in which a multitouch system for tessellation design (Chen & Chiu, 2016) was installed, and this constituted the multitouch learning platform. The multitouch platform was used to support the multitouch DBL activity. As shown in Fig. 1, this platform could support multiple team members conducting tessellation design drawings face-to-face on the same multitouch display. Team members could create personalized tessellations with different regular polygons on the collaborative workspace by utilizing the tools of regular polygon and transformation geometry, as illustrated in Fig. 2.

2.3. Intergroup competition mechanism

For the experimental group, a digital mechanism of intergroup competition, including team scores and a leaderboard, was designed and integrated into the multitouch platform to evoke intergroup competition by establishing positive goals among team members. The computerized mechanism was coded in C♯ (C Sharp) using MariaDB 5.5 as a database system. Table 2 presents the design of the intergroup competition mechanism.

The team scores consisted of design and collaboration scores. First, the design scores were obtained by students giving product scores for each design stage. Using the platform, team members would work together to give scores to three randomly assigned teams' products (with each team having an equal chance of being assigned) according to the product benchmark, on a three-point scale corresponding to the three-level criteria: *good* (3 points), *fair* (2 points), and *poor* (1 point). The design score can be seen as a consensus score, which needs a general agreement among team members. A team's design score for each stage would be accumulated during the competitive activity and serve as the basis of design ranking on the leaderboard.

Second, the collaboration scores were determined by the observer assessment in terms of teamwork performance, which refers to the quality of a team's peer collaboration and teamwork during collaborative learning processes. In considering students' intrinsic motivation and to avoid intense intergroup competition, the collaboration scores were given for the student teams' actions or behaviors, and no punishments were given. On the basis of Markham et al.'s (2003) teamwork rubric, three field observers, who majored in education-related fields, independently evaluated each team's teamwork

Fig. 1. Team members working together around the multitouch platform.

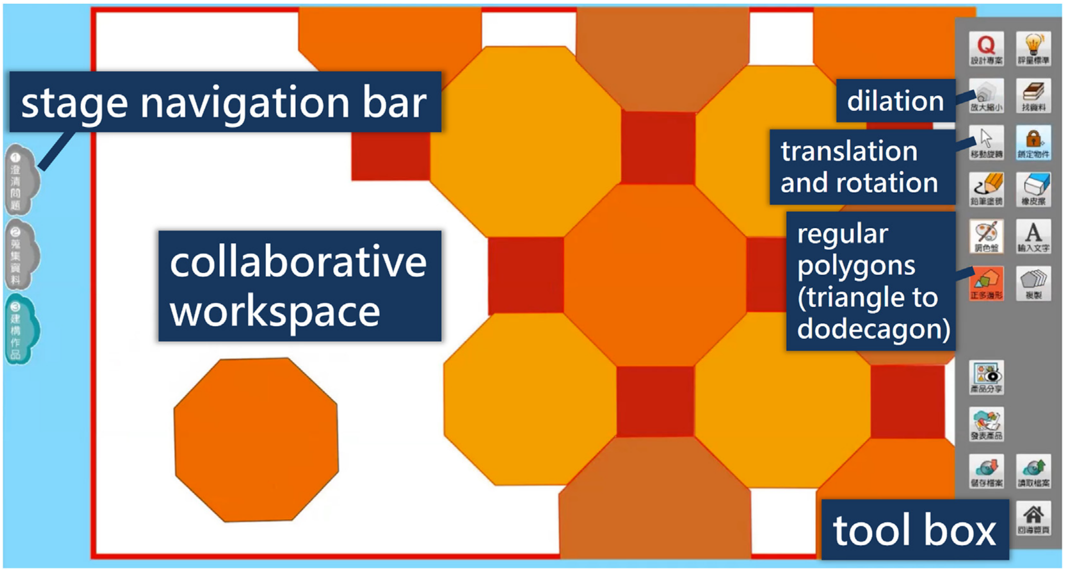

Fig. 2. The interface of the multitouch platform.

Table 2
Design of the intergroup competition mechanism.

	Aspect	Source	Description
Team score	Design	Derived from scores given by the other teams for a team's products	Team members work together to give scores to the assigned teams' products for each design stage.
	Collaboration	Derived from scores given by observers for a team's teamwork performance	Field observers grade each team's teamwork performance during the design process.
Leaderboard	Design	Based on each team's design scores	The leaderboard displays the ranking and design scores of the top three teams and students' own team.
	Collaboration	Based on each team's collaboration scores	The leaderboard displays the ranking and collaboration scores of the top three teams and students' own team.

performance as collaboration scores. This rubric involved three indicators: leadership and initiative (weighted 25%), facilitation and support (weighted 25%), and contributions and work ethic (weighted 50%). One observer would grade one indicator of the rubric for each group. Each indicator was rated on a five-point scale in which the performance ranges from 1 point, *unsatisfactory*, to 5 points, *advanced*, by the same observer. For example, one of the *advanced* criteria for the "leadership and initiative" indicator is that team members thoughtfully organized and divided the work. The field observers discussed the rating rubric to clarify the criteria before the formal experiment. With regard to the design scores, the collaboration scores were accumulated during the competitive activity and served as the basis of collaboration ranking on the leaderboard.

The design and collaboration scores of the students' own team were displayed in the upper left and right corners of the platform, respectively, as shown in the top left and right parts of Fig. 3. On the other hand, the leaderboard showed the top three teams with their design and collaboration scores, as well as the scores of students' own team for each stage, as illustrated in the center of Fig. 3.

Note. Both the team scores and leaderboard are presented using real-time data on the multitouch platform.

2.4. Students' activities with/without intergroup competition

The intergroup activities were designed for four 40-min weekly sessions. Table 3 provides a description of the students' activities in three design stages. The design assignments were conducted in open-ended, authentic, hands-on, and multidisciplinary design tasks. The first week was to define the problem and the goals in a realistic scenario with students as designers. In the second week, the students searched and collected useful information for the project. The third and fourth weeks were utilized to develop hands-on alternative solutions and then create a design drawing of tessellation, which is a specific connection between mathematics and art.

At the beginning of each stage, all students received the same instruction that explained the criteria for the product of that stage by the same instructor. The participants then began to carry out the tessellation design project in their own teams. For the experimental group, the students could check the leaderboard to see the current rankings and scores at any time during

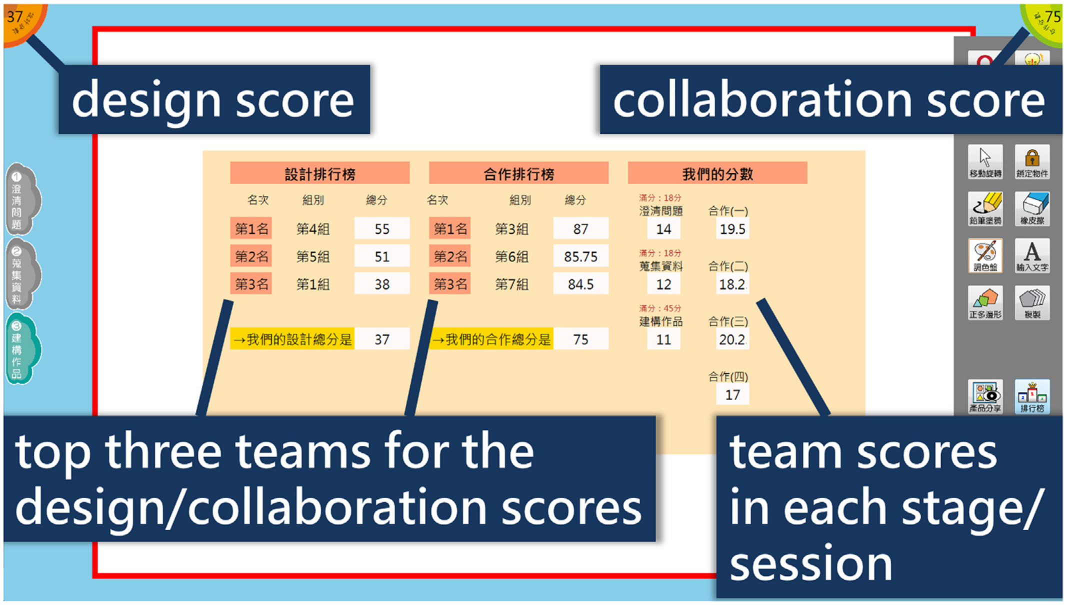

Fig. 3. The displayed team scores and leaderboard on the multitouch platform.

each design session. The field observers graded each team's teamwork performance independently every 6 min during the students' operation, and thus, there were a total five grades in each session (see Table 3, for example, OA1-1 to OA1-5). The observers did not interfere in the activities carried out by the students. After uploading team product of each stage to the platform (during the period of OA1-5, OA2-5, and OA4-5), team members in the experimental group had to give the assigned teams design scores for their products in addition to the work the comparison group did. For example, at the end of the third stage, Group 2 gave scores to the uploaded products of Groups 1, 4, and 8 under the criteria of the product benchmark, as shown in Fig. 4. The students were told to score the products fairly and objectively, as the instructor and observers would check whether the scoring was done in a serious way. At the end of the last class, the instructor took 10 min to summarize the project content, i.e., tessellation, regarding the concepts of the interior angles of polygons, lines of symmetry, and transformation geometry, for both experimental- and comparison-group students. No material rewards or extra marks were given to the teams placed on top of the leaderboard.

2.5. Measures

2.5.1. Student engagement

The Student Engagement in Technology Rich Classrooms survey developed by Gebre, Saroyan, and Bracewell (2014) was translated into Chinese and used to measure student engagement in the multitouch DBL activity. The dimensions measured in the survey are cognitive and applied engagement, social engagement, reflective engagement, and goal clarity. The following is an example of an item for social engagement, "I engage in discussion with other students on the same table." As three items in the social dimension of the original survey relate to after-class activities that may not fit the experimental conditions of this study, two items were deleted and one item statement was modified. The appropriateness, meaningfulness, and usefulness of the modified survey were confirmed by a senior professor and a researcher on our research team with expertise in both technology-enhanced learning and computer-supported collaborative learning. The modified survey consisted of 17 five-point Likert-type items in which all statements were positively worded, and the participants made their responses by selecting one of five choices: *always* (5 points), *often* (4 points), *sometimes* (3 points), *seldom* (2 points), and *never* (1 point). This study screened every response to check whether the students' responses were all the same or in a repeated pattern. The responses in the Likert scale were then summed to create a total score. Cronbach's α value of this instrument was 0.91 in this study.

2.5.2. Learning achievement

A mathematics test was developed to determine students' prior knowledge and achievement in mathematics. This test included the content related to interior angles of regular polygons, lines of symmetry, and transformation geometry. The test items were constructed according to the revised Bloom's taxonomy (Anderson et al., 2001), including the understanding, applying, analyzing, and evaluating levels. This test consisted of five multiple-choice questions and four word problems. For example, a multiple-choice question "Taipei city government is working on paving refurbishments for the 29th Summer

Table 3
Activities in the three design stages.

Stage/Characteristic	Timing	Activity in the design stage		
		Experimental group[a]		Comparison group
Clarifying the problem (week 1)	5′	The instructor explained the criteria for the products of this stage.		The instruction was same as that used with the experimental group.
open-ended; authentic	6′		Team members specified and wrote down the design requirements on the platform.	Students' activities were the same as those in the experimental group.
	12′	OA1-1		
	18′	OA1-2		
	24′	OA1-3		
	30′	OA1-4	Team members checked that the other teams' products met the criteria, and gave scores to the assigned teams' products.	Team members checked that the other teams' products met the criteria.
	36′	OA1-5		
	40′			
Gathering information (week 2)	5′	The instructor explained the criteria for the products of this stage.		The instruction was same as that used with the experimental group.
open-ended	6′		Team members collected useful information for solving the problem from the provided references, and organized it on the platform.	Students' activities were the same as those in the experimental group.
	12′	OA2-1		
	18′	OA2-2		
	24′	OA2-3		
	30′	OA2-4	Team members checked that the other teams' products met the criteria, and gave scores to the assigned teams' products.	Team members checked that the other teams' products met the criteria.
	36′	OA2-5		
	40′			
Constructing an artifact (week 3)	5′	The instructor explained the criteria for the products of this stage.		The instruction was same as that used with the experimental group.
open-ended; hands-on; multidisciplinary	6′		Team members co-constructed a learning artifact meeting the design requirements on the platform.	Students' activities were the same as those in the experimental group.
	12′	OA3-1		
	18′	OA3-2		
	24′	OA3-3		
	30′	OA3-4		
	36′	OA3-5		
	40′			
(week 4)	6′	OA4-1		
	12′	OA4-2		
	18′	OA4-3		
	20′		Team members checked that the other teams' products met the criteria, and gave scores to the assigned teams' products.	Team members checked that the other teams' products met the criteria.
	24′	OA4-4		
	30′	OA4-5		

Note. OA = observer assessment.
[a] The team scores including design and collaboration scores were always displayed on the platform. Experimental group students could check the leaderboard during class.

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? (With four choices)" was an applying-level question to assess the concept of the interior angles of a regular polygon. Students' answers would be scored to calculate the test scores. The total score of this test was 65 points, of which the multiple-choice questions and the word problems accounted for 25 and 40 points, respectively. This achievement test was pilot-tested on another 90 students (aged 13–14 years) who were different from the participants. The Kuder–Richardson reliability index (*KR20*) was calculated to be 0.81. The item difficulty indices were between 0.2 and 0.8, and the discrimination index for each item was above 0.3. The students were required to finish this test within 30 min.

2.5.3. Creativity

The short Use of Creative Cognition Scale (UCCS) (Rogaten & Moneta, 2015) was translated into Chinese and used to assess students' use of creative cognition before and after participating in the focal activity. This unidimensional instrument had five items derived from the Cognitive Processes Associated with Creativity scale (Miller, 2014) and provided a holistic score. The UCCS is reported as having good construct and concurrent validity (Rogaten & Moneta, 2015). Various cognitive processes associated with creativity would be assessed in the UCCS, including idea manipulation, idea generation, imagery, and metaphorical/analogical thinking. For instance, an item "While working on something, I try to generate as many ideas as possible" was used to measure the frequency of using the idea generation cognitive strategy. Students' responses were recorded on a five-point scale ranging from 1 point, *never*, to 5 points, *always*. This study checked whether the students' responses were in a repeated pattern. Cronbach's α coefficients for the pretest and the posttest were 0.84 and 0.80, respectively, which were close to the value (0.82) reported in Rogaten and Moneta's study. As Cropley (2000) noted in a review of creativity tests, the internal consistencies of these commonly reach 0.8.

2.6. Procedure

This study was conducted in nine weekly sessions that were administered or taught by the same instructor for each participating class during the spring semester of 2015 in the computer classroom. The procedure consisted of a practice

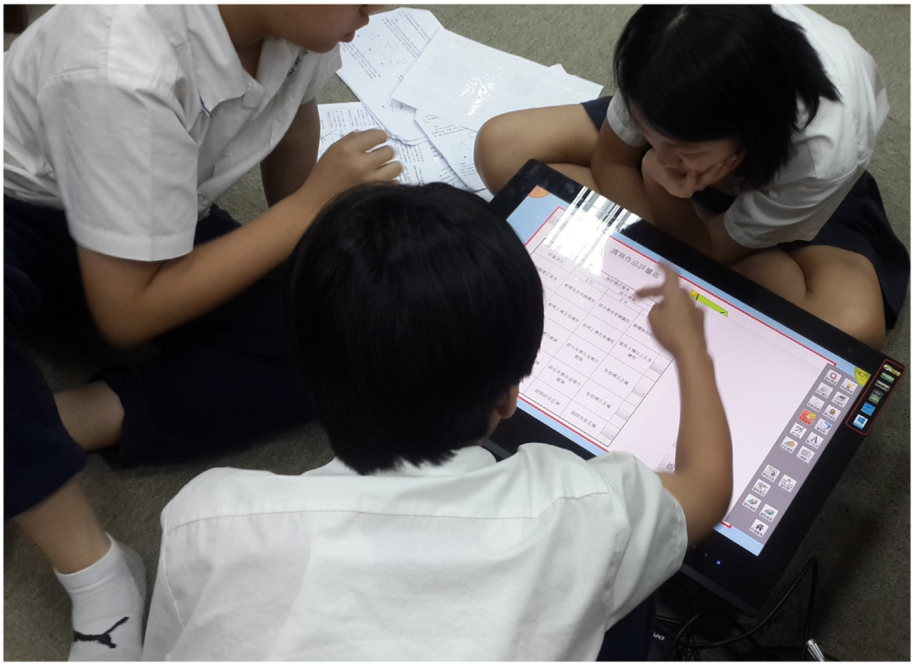

Fig. 4. Team members giving scores to the assigned teams' products under the criteria of the product benchmark.

activity, pretests, a treatment activity, and posttests. The pretest and posttest data were collected electronically using Google Sheets, although the mathematics test was carried out in a pen-and-paper format. Immediately following the administration of the posttests, a short informal interview was conducted with three students in the experimental group (high-, intermediate-, and low-prior-knowledge students) and three students in the comparison group (high-, intermediate-, and low-prior-knowledge students) to understand their perceptions of the multitouch DBL activity.

(1) *Practice activity (first week)*: The instructor spent a class enabling the students to practice the process of collaborative design using the multitouch platform. All students within each class were divided into temporary teams composed of three or four students and assigned by *S*-type grouping on the basis of the scores in the previous semester's math final examination. Each team was required to work together and create a digital, specified tree pattern comprising three types of regular polygons (triangular, square, and hexagon) by using the multitouch platform's general functions such as polygon and transformation.
(2) *Pretests (second and third weeks)*: The students were given the mathematics test on their prior knowledge in the second week, since the participants' school had arranged periodic assessments for students in the third week. The creativity scale was administered in the third week because of its short administration time.
(3) *Treatment activity (fourth to seventh weeks)*: The students within each class were arranged in formal teams (as described in Section 2.1 Participants) according to their pretest scores in the mathematics test. Each team was asked to complete the design project on the multitouch platform with or without the intergroup competition mechanism, depending on the assigned condition.
(4) *Posttests (eighth and ninth weeks)*: All participants completed the mathematics test and the engagement survey in the eighth week. Since the creativity scale was to measure students' tendency to deploy creative cognition in real-life contexts across situations and times (Rogaten & Moneta, 2015), this scale was administered in the ninth week.

3. Results

Two students with learning disabilities (one girl in the experimental group and one boy in the comparison group) and four students absent for the treatment activity in three weeks (one girl in the experimental group and one boy and two girls in the comparison group) were excluded from the analyses. This study used SPSS Statistics 22.0 to carry out the statistical analyses. The two-tailed α level for determining the statistical significance for all statistical tests was set at 0.05. A post-hoc power analysis was performed to justify the sample size of this study. The statistical power was computed using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007), and the power of this study was 0.81, indicating that the sample size was sufficient to find meaningful significant differences between the experimental and comparison groups' means on the dependent variables. Descriptive statistics are shown in Table 4, including means and standard deviations for the dependent variables of student engagement, learning achievement, and creativity after the treatment.

Table 4
Means and standard deviations of the dependent variables.

Dependent variable	Competition group ($n = 26$)		No-competition group ($n = 26$)	
	M	*SD*	*M*	*SD*
Student engagement	70.27	8.21	62.46	10.81
Learning achievement	41.15	9.48	34.81	12.19
Creativity	21.08	2.79	19.46	3.27

3.1. Student engagement

An independent samples *t*-test was used to analyze the difference between the competition and no-competition students with regard to the extent of engagement. The effect size associated with the *t*-test was taken to be eta squared (η^2). Normality and homogeneity of variance were tested for the residuals of the analysis. The normality assumption was assessed by the Shapiro–Wilk test, and no violation of the assumption was detected, $W(52) = 0.97$, $p = 0.24$. The homogeneity of variance assumption, which was evaluated by Levene's test, was not violated either, $F(1, 50) = 2.64$, $p = 0.11$. The *t*-test showed that there was a statistically significant difference in student engagement, $t(50) = 2.93$, $p = 0.01$, $\eta^2 = 0.15$, suggesting a large effect. The results indicated that the extent of student engagement of the competition group ($M = 70.27$, $SD = 8.21$) in the multitouch DBL activity was significantly greater than that of the no-competition group ($M = 62.46$, $SD = 10.81$).

3.2. Learning achievement

An analysis of covariance (ANCOVA), using the pretest scores of the mathematics test as a covariate by considering the influence of prior knowledge on students' posttest performance, was employed to analyze the difference between the experimental and comparison groups' mathematics posttest scores. The effect size measure for ANCOVA was taken to be partial eta squared (η_p^2). No significant difference existed between the two groups with regard to the prior knowledge, $t(50) = -0.88$, $p = 0.39$. The assumption of normality was not violated, $W(52) = 0.97$, $p = 0.29$, and the assumption of variance homogeneity was not violated either, $F(1, 50) = 0.94$, $p = 0.34$. Additionally, the assumption of homogeneity of regression was accepted, $F(1, 48) = 1.35$, $p = 0.25$. The ANCOVA yielded a significant difference for students' learning achievement between the two groups, $F(1, 49) = 6.67$, $p = 0.01$, and $\eta_p^2 = 0.12$, indicating a medium effect. The adjusted average posttest scores showed that the competition students ($M_{adj} = 41.66$, $SD = 9.48$) performed significantly better than the no-competition students ($M_{adj} = 34.30$, $SD = 12.19$).

3.3. Creativity

An ANCOVA was performed to determine whether a significant difference existed between the competition and no-competition groups in creativity. Before conducting the ANCOVA, students' creativity scores prior to the treatment were examined to see whether there was a significant difference between the two groups, and no significant difference was found, $t(50) = -0.92$, $p = 0.36$. The pretreatment score was entered as a preintervention covariate for adjusting the creativity scores measured after the treatment. The normality and variance homogeneity assumptions were tested, and no violations were found in either case: $W(52) = 0.99$, $p = 0.84$ for the Shapiro–Wilk test; and $F(1, 50) = 2.31$, $p = 0.14$ for Levene's test. The homogeneity of regression assumption was also tested, and the result was not significant, $F(1, 48) = 0.63$, $p = 0.43$. The ANCOVA revealed a significant difference by treatment for creativity, $F(1, 49) = 5.56$, $p = 0.02$, and $\eta_p^2 = 0.10$, indicating a medium effect. The results showed that the adjusted average of creativity scores was significantly higher in the competition group ($M_{adj} = 21.21$, $SD = 2.79$) than in the no-competition group ($M_{adj} = 19.32$, $SD = 3.27$).

4. Discussion

4.1. Student engagement

The results show that the students under the intergroup competition condition had significantly higher engagement during the multitouch DBL activity than the students under the no-competition condition. This is compatible with Tauer and Harackiewicz's (2004) finding that intergroup competition made students become more involved in the activity and with Romero's (2012) argument regarding learner engagement. The computerized intergroup competition mechanism used in this study, including leaderboard and team scores, provided real-time performance feedback so that the students could see their progress in the design process or how much they needed to catch up with other teams. The scores and leaderboard were closely connected to the collaborative design tasks, providing students with information concerning how well they were performing the task, hence the students would know whether they needed to devote more effort to the activity and where they could do better, and additionally, their intrinsic motivation was maintained or might even enhance as individuals might welcome (and indeed desire) such information (Zhou & Shalley, 2003, pp. 165–217). Competing for the top positions in the leaderboard may act as a spur to actively participating in the collaborative design tasks, and winning or not losing the competition against other teams might constitute a focal point for team members (Bornstein, Gneezy, & Nagel, 2002). In addition, the team scores may offer right incentives, motivating team members to go the extra mile for the design project. Although the use of points and a leaderboard can drive extrinsic motivation, it should be noted that extrinsic rewards can produce negative effects on intrinsic interest (Lepper & Greene, 2016; Newby & Alter, 1989), and furthermore material rewards tend to be more detrimental for children than young adults (Deci, Koestner, & Ryan, 1999). This study thus did not provide material rewards or extra points to the competition-group students. As Osterloh and Frey (2000) suggested, the most important condition for the trade-off between extrinsic and intrinsic motivation is the existence of intrinsic motivation in the first place.

In view of the social context of DBL, intergroup competition serves as a motivating strategy for team work (Gómez Puente et al., 2013). The competition approach engendered greater social interaction among team members around the multitouch table, such as checking the points and the leaderboard. By posing an external threat to the groups involved, intergroup competition heightens interdependency and cohesiveness within the groups themselves (Yu, 2001). As a high-prior-knowledge student in the experimental group indicated in the informal interview, the learning activity enabled them "to make a concerted effort to complete the tasks together with other classmates," while a low-prior-knowledge student stated that it encouraged them to "communicate with classmates and enhance team work." However, the within-group collaboration in the comparison group might not have been as good as the experimental group. A high-prior-knowledge student in the comparison group indicated that "I personally like this course, but it seems that many classmates do not, probably due to the collaboration of team members." This is in accordance with the instructor's observation, which showed that, in general, the competition students seemed to be more absorbed in the collaborative design tasks and demonstrate more collaborative attitudes and active involvement in the learning activity, compared with the students in the no-competition condition. The instructor also observed that the experimental-group students had better goal clarity, which implies their greater awareness of the goals of the classroom session and the relevance of the learning materials to the stated goals (Gebre et al., 2014) in each design session. In addition to social engagement and goal clarity, students' reflective engagement might also be enhanced by the intergroup competition mechanism. That is, students engaged in reflecting on their team's learning because their group performance was reflected in the design and collaboration scores that could be compared with other teams. Given the influence of awarding design scores enhanced by computer mediation, the students under the competitive condition appeared to have more occasions to use the multitouch platform to analyze information or compare ideas, as observed by the instructor and the observers that most team members seriously voted the outcomes of the other teams according to the criteria provided on the platform, thereby fostering their greater cognitive and applied engagement.

4.2. Learning achievement

Students in the intergroup competition condition performed significantly better on adjusted posttest scores than the students in the no-competition condition. This agrees with the findings of Wood et al. (2005), which showed that intergroup competition enhanced the development of related knowledge in an engineering design course. The results also lend some credence to those of Christy and Fox (2014), which found that leaderboards had a significant impact on undergraduates' math performance, although their study focused on different leaderboard conditions in a virtual classroom. The better academic performance of the students found under the competition condition seems to be indicative of the fact that a primary goal of competition between groups is to improve students' achievement in the subject domain. Further, the collaborative design task along with competition would motivate students to test and learn more ideas, as the competition scores were used as a measure of design success (Silk, Higashi, & Schunn, 2011) and positive social interaction when they carrying out the design project. Rewarding students with points for their actions or behaviors may help to foster friendly competition, which can be a strong motivator that helps to increase student learning performance (Burguillo, 2010; Denny, 2013, pp. 763–772). It is thus not surprising that the intergroup competition mechanism led to the better learning achievement seen among students in the competition group than in the no-competition group.

The constructivist view sees learning as being achieved via the students' knowledge construction that occurs through authentic and collaborative engagement in generative learning activities (Gebre et al., 2014). Kafai (2006) suggested that those students who engage in the design process receive the greatest learning benefits. Examples of the learning benefits were, for instance, a competition-group student (with intermediate prior knowledge) who pointed out in the informal interview that "I learned a lot of mathematics knowledge in this class, and I learned lots of things need teamwork." In contrast, two no-competition-group students (intermediate-and low-prior-knowledge students) only responded that the learning approach/activity was interesting. In comparison with the students in the no-competition group, those working under the competitive condition had higher engagement, and this was enhanced by the team scores and leaderboard mechanism that were used throughout the design process, and this thus improved their learning achievement.

4.3. Creativity

The students who were under the intergroup competition condition had significantly higher scores on creativity than those under the no-competition condition. That is, the competition-group students tended to use more creative cognition in studying. This finding is in accordance with Baer et al.'s (2010) results, which showed the positive effects of intergroup competition on students' creativity, but inconsistent with Cheville, McGovern, and Bull's (2005) proposition that students working in a collaborative environment without intergroup competition tend to be more creative than those who pursue ability-focused goals in a competitive environment, because they adopt task-focused goals and use deep cognitive processes. We argue, however, that students in a competitive relationship with other teams may also focus on task goals and be involved in even deeper creative cognitive processes, such as idea generation, in order to demonstrate better collaborative productivity than the rival out-groups. As Baer et al. (2010) noted, the motivating premise underlying the use of intergroup competition to stimulate creativity is that competition adds to the positive tension of challenge in a team. Nonetheless, caution should be taken if individuals operate with the goal of trying to win at all costs, as the controlling aspect of competition will be more salient, and their intrinsic motivation and creativity are likely to be diminished (Deci et al., 1981; Zhou & Shalley, 2003, pp. 165–217).

Another explanation for the superior use of creative cognition of the competition group may lie in giving design scores for intergroup competition employed in the three design stages. This action might act as a catalyst for stimulating student designers to look for new and adaptive ideas or facilitating the use of metaphorical and analogical thinking. A third factor to account for this result may be the influence of the competition group's enhanced engagement, which contributes to the development of creative ideas (Oldham & Baer, 2012, pp. 387–420). In fact, reflective engagement, such as thinking out loud to express ideas, involves the creative cognitive process concerning imagery (e.g., imagining a potential solution to a problem). Moreover, cognitive and applied engagement, such as engaging in comparing and contrasting ideas using the multitouch platform, might facilitate students' use of idea manipulation techniques (e.g., looking at a problem from a different angle to acquire an appropriate solution) to achieve more creative designs.

5. Conclusions

The issue of integrating intergroup competition into a design-based math, multitouch-enabled classroom was addressed in this study. This study designed and embedded a computerized intergroup competition mechanism in the multitouch learning platform, and conducted a quasi-experiment comparing sixth graders enrolled in the intergroup competition and no-competition conditions. The principle findings suggested the positive effects of intergroup competition on student engagement, learning achievement, and creativity. As the findings in this study indicated, intergroup competition could be a useful motivating strategy that can be introduced to collaborative DBL and built within a multitouch learning context. From another perspective, classroom teachers could adopt such an intergroup competition mechanism, combining team scores and a leaderboard, to engage elementary school students in a design team and thus achieve better learning outcomes in a technology-enhanced DBL context.

While this study has yielded findings that have both theoretical and practical implications, some limitations should be considered. First, the form of creativity studied in this paper places emphasis on students' use of cognitive processes associated with creativity (i.e., a kind of process creativity). Therefore, this finding may not be generalizable to other perspectives or types of creativity (e.g., product creativity). Second, since this study was carried out on group sizes of three and four students using mid-sized multitouch screens, it is possible that these findings may not be generalizable to other group sizes or using large multitouch tabletops/surfaces (e.g., SMART Table®). Additionally, this study was conducted in a Taipei elementary school, with 11–12-year-old pupils from two sixth-grade classes. Caution should be taken in generalizing these results to a broader range of students in higher grades, or to other populations. In addition to the above limitations, it is noteworthy that researchers or instructors, according to Attle and Baker's (2007) suggestions and Baer et al.'s (2010) findings, should control and adjust the intensity of intergroup competition to an intermediate level (e.g., de-emphasizing awards or showing only top positions on a leaderboard), otherwise intense intergroup competition may constrict within-group collaboration and thus undermine the effectiveness of this approach.

This study extended previous findings on the effects of intergroup competition to a new technological context of DBL and confirmed the positive effects of this method. This research also contributes to developing an appropriate mechanism for implementing real-time intergroup competition throughout the design process for elementary school students in a face-to-face classroom environment. Despite the fact that the students fairly reviewed and scored the design products of their peer groups, further research is required to determine whether this scoring mechanism would produce any detrimental effects on students, as students might unfairly review other groups' products in striving for ranking in an intergroup competition condition. In addition, although the gender factor might impact the effects of intergroup competition (see Baer, Vadera, Leenders, & Oldham, 2014), this study did not examine this factor due to the limited number of participants. Future research is therefore warranted to investigate the moderating role of gender on the effects of intergroup competition in computer-or multitouch-supported DBL contexts. Finally, it might be of interest in future studies to investigate the intergroup competition effects in a DBL setting by considering students' different interpersonal orientations or personality traits (e.g., extraversion, conscientiousness, and agreeableness), as teams composed of members low on the traits of extroversion and agreeableness seem to perform better under a competitive reward structure than those with high levels of these attitudes (Rapp, 2015b), and these diverse personality traits would also influence student designers' creativity (Chang et al., 2015).

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