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The Effects of Whole-class Interactive Instruction with Single Display Groupware for Triangles

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Abstract

Whole-class interactive instruction is an instructional approach in which all of the students in a class create knowledge together in an interactive way, mediated by the teacher. The current mixed-method study compared the effects of a specific implementation of whole-class interactive instruction, Single Display Groupware (SDG), with traditional classical instruction of geometry, for 69 third grade students. In SDG students work in groups that share one area on a large display screen in front of the class. Each individual student in a group has a mouse and together the students in each group need to perform assignments by using “silent collaboration”. In the current study, the assignment for the students was to identify and create different kinds of triangles. Outcomes of interest were learning gains (quantitative) and effectiveness of "silent collaboration" (qualitative). Learning gains were significantly higher for students in the SDG condition than for students following traditional instruction. An analysis of emerging activity patterns showed that students found natural ways to silently collaborate.

Keywords: Collaborative learning, Geometry, Single Display Groupware, Whole class instruction

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Abstract

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Keywords

Collaborative learning; Geometry; Single Display Groupware; Whole class instruction

Introduction

Whole-class interactive instruction is a key feature of mathematics instruction in countries with the highest levels of mathematics achievement (Reynolds & Farrell, 1996) and also seems to be successful for students in lower SES ranges (Reynolds, Creemers, Stringfield, Teddlie, & Schaffer, 2002). Whole-class interactive instruction is a teaching method in which knowledge is created by all of the students in a class together in an interactive and collaborative way, mediated by the teacher.

Whole-class interactive instruction is *interactive* in the sense that it is: "… a two-way process in which pupils are expected to play an active part by answering questions, contributing points to discussions, and explaining and demonstrating their methods and solutions to others in the class" (DfEE, 2001, p. 26). This type of active processing of information is known to be important for acquiring meaningful knowledge (Mayer, 2002). In whole-class interactive instruction students also *collaborate* in working towards the solving of a common problem (Szewkis et al., 2011). In this way they learn from one another, because during their interactions cognitive conflicts arise, inadequate reasoning is exposed, disequilibrium occurs, and higher-quality understanding emerges (Slavin, 1996). Because the contributions and opinions of all students are equally valued and each student is encouraged to participate actively during the classes, a collective understanding is created (Graham, Rowlands, Jennings, & English, 1999). Students also feel responsible for each other's learning as well as for their own, with each group member accountable for the group's results (Dillenbourg, 1999; Slavin, 1990).

Several conditions must be met to reach effective whole-class collaboration. First of all, there must be a common goal to work towards (Dillenbourg, 1999). Having a common goal works as an incentive for students to help and encourage each other to make the maximum possible effort (Slavin, 1996). Second, there must be positive interdependence between peers, defined as “the perception that we are linked with others in a way so that we cannot succeed unless they do” (Johnson & Johnson, 1999, pp. 70-71). Students are more likely to provide each other with emotional and tutorial support when they recognize that their success is dependent upon the successes of their peers (Lowyck, Poysa, & van Merriënboer, 2003). Joint rewards and/or punishments, the third condition, can aid positive interdependence between peers (Axelrod & Hamilton, 1981). When every group member receives the same treatment, they will look to maximize their joint utility and therefore generate a scenario where collaboration will prevail (Zagal, 2006). Fourth, students need to be aware of their peers’ work (Janssen, Erkens, Kanselaar, & Jaspers, 2007; Zurita & Nussbaum, 2004) in order to engage in the activities in which they are needed most, where they can best aid the group (Janssen, et al., 2007). Fifth, it is important for there to be good coordination, defined as “the act of managing interdependencies between activities performed to achieve a goal” (Malone & Crowston, 1990, p. 361), and communication between peers (Gutwin & Greenberg, 2001). For good communication between peers, three social skills are required (Tarim, 2009): students must listen actively, be positive towards their peers, and participate actively. The sixth condition to be met is that peers must support each other (Lowyck, et al., 2003). Peer support is necessary for students to feel that they are in a safe environment in which they can freely express their ideas (Muijs & Reynolds, 2000) and is positive for students’ self-efficacy, goal-orientation, and the intrinsic value they place on the learning task (Lowyck, et al., 2003). Seventh, students need to be individually accountable for their contribution to the group work (Slavin, 1996). This prevents the hazard of certain group members not participating, and encourages students to teach and assess one another (Slavin, 1996).

Teachers have a mediating role in this whole process. They should guide and actively monitor the progress of the students, which will allow them to help those that require extra attention (Muijs & Reynolds, 2000). They should address each student's needs, adapt activities quickly in reaction to students' responses, use errors and misconceptions as a teaching point for the whole class and keep students on task for longer periods of time (Muijs & Reynolds, 2001). They also need to be aware of where pupils are in the development of their understanding of the material being taught (Graham, et al., 1999). It is important for teachers to know when students are ready to learn new material and to engage in new activities. When they fail to assess students properly, students are taught new things without being prepared (Graham, et al., 1999).

Technology can be important in supporting whole-class interactive instruction. Single Display Groupware (SDG) is a technology in which a single display is shared by multiple collocated users, each with their own input device (Moraveji et al., 2008). It is especially useful when developing a collaborative activity where interaction among all members of a large group within the classroom is desired (Pavlovych & Stuerzlinger, 2008). Studies have shown that the use of SDG in education has a positive impact on participation, student engagement and task performance (Infante, Hidalgo, Nussbaum, Alarcón, & Gottlieb, 2009; Scott, Mandryk, & Inkpen, 2003) as well as on collaboration and motivation (Inkpen, Ho-Ching, Kuederle, Scott, & Shoemaker, 1999), in order to encourage collaboration that could be inhibited by social barriers When using SDG, students perceive more fairness because no one is left out (Inkpen, et al., 1999); they work simultaneously on a single screen instead of taking turns (Infante, et al., 2009; Inkpen, et al., 1999) which provides them with a common focus (Infante, et al., 2009); and they are all able to control the screen, allowing shared leadership and forcing them to participate and be responsible for their own learning (Infante, et al., 2009).

Despite the benefits of SDG, there are only a few studies on how this technology could be used in classrooms to increase student participation (Liu & Kao, 2007). The work that has been done on this topic focuses primarily on analyzing the impact of different factors such as interference that occurs among participants (Tse, Histon, Scott, & Greenberg, 2004), group size (Inkpen et al., 2005; Ryall, Forlines, Shen, & Morris, 2004), comparisons with other technologies, and input effectiveness (Hansen & Hourcade, 2010).

Among the uses of SDG in large-group mathematics is the work undertaken by (Alcoholado et al., 2012) in which SDG was used to teach arithmetic. In their study, the teacher did not engage in interactive instruction and students did not collaborate but worked individually in personal spaces without interacting with their classmates, and the teacher acted as a mediator of individual rather than whole-group work. Alcoholado, et al. (2012) showed that the students' knowledge increased significantly and that the approach was most effective for the weaker students.

In order to analyze the work performed as a group, it is possible to recognize task work, each task's required actions, and teamwork, the actions done by the group to complete the task (Pinelle, Gutwin, & Greenberg, 2003). In the current study we will further investigate the value of SDG for mathematics instruction and also incorporate collaboration between students, though in a specific, silent, mode. This "silent collaboration", that is related to teamwork, has been explored before in a different domain (teaching Spanish) by Szewkis, et al. (2011). SDG was used in their study, but because it required collaboration among students who were seated far away from one another in the large classroom, a negotiation mechanism based on non-spoken suggestions was defined, known as "silent collaboration". Silent collaboration is a type of collaboration "in which students – through suggestions and exchanges performed through the dynamics provided by the software – must compare their ideas to those of their classmates" (Szewkis, et al., 2011, p. 561). In the work by Szewkis, et al. (2011), SDG with silent collaboration was proven to be effective for supporting learning in large classrooms where students are spread out.

In the current study, we investigated how SDG and silent collaboration can be applied to teach geometry, specifically about triangles. Our first (quantitative) research question concerned the effectiveness of SDG compared to traditional instruction and our second research (qualitative) research question concerned the way silent collaboration takes place naturally.

Method

Experimental Design

Two conditions were included in the study: an experimental condition (n = 33) that learned about triangles using specifically designed software, SDG for Triangles, (SDGT, for a full explanation see the section on SDGT) and a control condition (n = 36) that followed the regular lessons. Students in the experimental condition worked with their regular teacher in their usual classroom so as to avoid changing their regular environment.

The SDGT software can support four working groups per computer and display screen, with up to ten students per group. However, in previous experiments using this software, groups with more than seven students experienced difficulties with coordination, particularly when constructing triangles. To facilitate student coordination in the experimental condition the whole classroom was divided in groups such that these have up to six students in each. For the display, two screens were used with two computers, as shown in Figure 1. The two screens together formed one large screen containing workspaces for up to eight groups; from these in this experiment only six groups were used. The students in the experimental condition were randomly assigned to one of the six groups in each of the sessions.

Students in the control condition worked on the same content and curricular objectives as those in the experimental condition, but via traditional teaching methods. The teacher mainly taught the theoretical concepts to the students by using a (conventional) whiteboard.

Each student worked individually, answering the teacher's questions as they were asked. When applicable, the exercise was carried out on a completely individual basis using pencil and paper. There was no active follow-up or general feedback from the teacher once the session had finished.

Participants

The participants were 8-9 year old students from two third grade classes in a state subsidized school located in Santiago, Chile. The experiment was carried out with 78 students. However, nine students missed session(s) and/or a test, which is why a total of 69 students were taken into account in the statistical analysis. Of the 69 students, 33 participated in the experimental condition and 36 in the control condition. The experimental condition included 21 girls and 12 boys, and the control condition included 17 girls and 19 boys.

Instructional design

An integrated instructional design was applied to realize our instruction. Four main elements played a role in this design: a) the SDGT software; b) students' activities with the software in relation to the curricular objectives for geometry; c) the teacher's activities; and d) the way collaboration between students was shaped.

Single display groupware for triangles

SDG for Triangles (SDGT) is an application for interactive teaching that allows all of the students in a class to work simultaneously on identifying, classifying and constructing triangles. Figure 1 illustrates students in a classroom working with SGDT. The application is suitable for common computers or laptops that can have a projector attached to them and that have at least one USB-port so as to connect multiple mice to the computer with the help of hubs; one mouse for each student and one for the teacher.

Fig. 1. Students and the teacher in the classroom working with SDGT

SDGT with one screen can currently be used for classes with a maximum of forty students. As explained in the section on Curricular Goals and Student Activities, activities are typically completed in four smaller groups of up to ten students, per screen and computer. Students are identified by a unique combination of cursor symbol and color, where the color represents the group. At the beginning of each session, a special activity in which students move their cursors to the corresponding symbol allows them to determine which symbol/color combination is theirs.

The screen is divided into four separate workspaces (Figure 2). Students are able to move around freely within their group's workspace but they cannot go outside of it. Teachers can move their cursor anywhere on the screen and have more options than the students, because they play a major part in controlling the class flow and the students' learning process. The menu at the top of the screen allows the teacher to choose a specific type of activity, display information, or freeze all the mice.

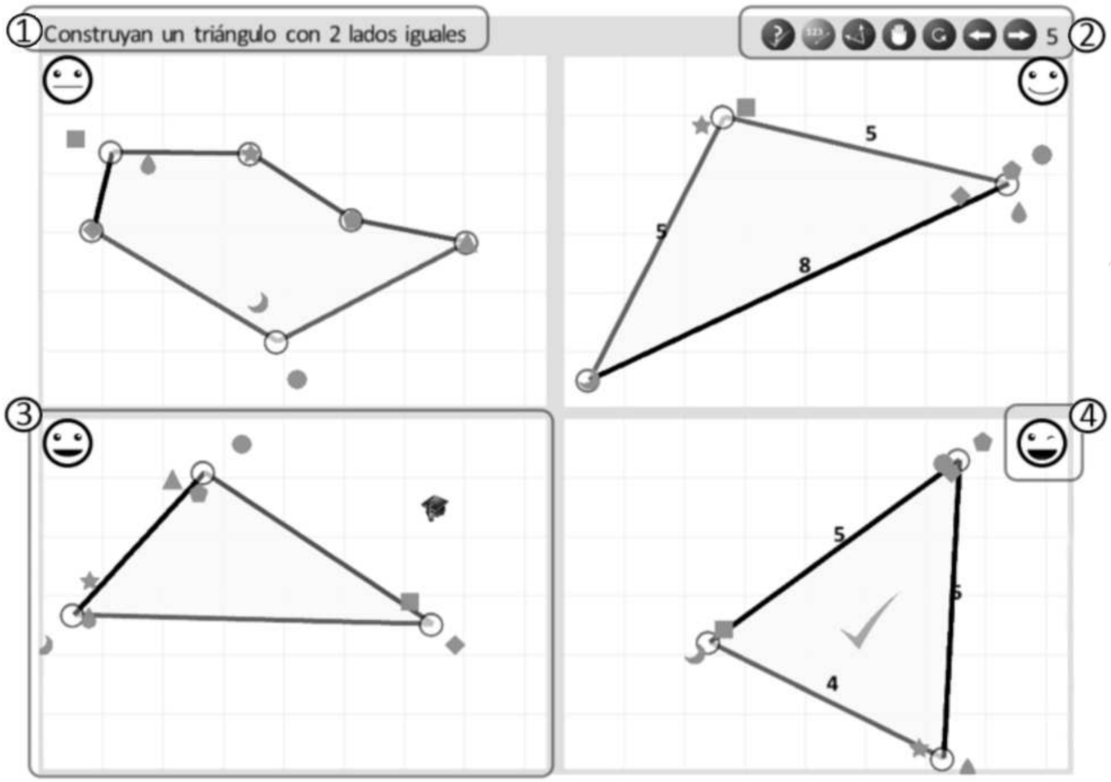

Fig. 2. General view of the display screen showing a specific activity type (5, Table 2).

As shown in Figure 2, the screen is composed of four elements:

(1) Group workspace: four workspaces are defined in which students in a group can freely move their cursors to complete their activities (element 3 in Figure 2).

(2) Instruction: the assignment is provided on the top left side of the screen (element 1 in Figure 2). Students can see what they need to accomplish at all times.

(3) Teacher tools: a set of teacher tools is given on the top right side of the screen (element 2 in Figure 2). The activity is indicated with an activity number (5 in the example given in Figure 2).. To the left of this is a set of buttons that are only accessible for teachers and that allow them to: go to the next or previous activity or slide, restart the activity with all cursors set to their initial position, stop the movement

of all cursors, and provide students with additional information such as revealing the angles, revealing the length of the sides, or revealing the correct answer.

(4) Group feedback: a smiley in the outer top corner of each workspace indicates how well the group is performing (element 4 in Figure 2). The smiley has eight states; from a neutral face (upper left, Figure 2) to a very happy face with a wink (bottom right, Figure 2). Group feedback is given graphically by indicating how close the group has come to achieving the goal of the activity, e.g. , in Figure 2 all cursors have to be appropriately positioned to reach the final smiley face. When the goal of building the assigned triangle is reached, a check appears in the center of the workspace to indicate that the activity has been completed correctly (bottom right in Figure 2).

Curricular goals and student activities

SDGT was developed to help third grade (8-9 year old) students learn about triangles. For this application to be suitable for the educational system, it needed to match the curricular requirements established by the Chilean Ministry of Education (MINEDUC, 2011). The main operations third-grade students needed to be able to perform were the identification and construction of triangles, which were also the two main types of activities: construction and identification activities. In construction activities students move their cursors within the 2D workspace in order to collaboratively satisfy a specific geometric condition. All of the cursors of the group are automatically connected to each other with line segments to form a polygon. When two cursors are close enough together a vertex is formed, allowing the formation of figures with three or more vertices. A group can only successfully create the assigned type of triangle when each student participates collaboratively. Alternatively, in identification activities, students moves their cursors to the object they want to select. The group is only successful when all students are on the correct object(s).

Table 1 summarizes the student goals to be achieved and associated activities to be completed, and the corresponding operations that make up the system. All of the activities contain multiple exercises that follow the curricular objectives, providing the students with opportunities to practice the different goals. We experimentally observed that for the kids, Activities 2, 4 and 6 had a similar level of difficulty, as 1,3 and 5 did; however 1,3 and 5 were more difficult than 2, 4, and 6. On the other side, within an identification activity (Activities 2, 4 and 6) the triangles became harder to identify as the activity progressed. .

Table 1
Activities to be completed

(Activity #) Student goals		Student actions
(1)	Construct a triangle	Students move their cursors within their workspace to collaboratively construct any triangle
(2)	Identify triangles in real life	Students individually move their cursors towards the figure they believe is a triangle
(3)	Construct a triangle and identify the different parts of this triangle	Students collaboratively build a triangle (3a). After the triangle is accepted by the system they individually move their cursors towards a specific part of the triangle; side, vertex, or angle (3b)
(4)	Identify specific types of triangles based on the number of equal sides	Students individually move their cursors towards the figure they believe to be the correct type of triangle (equilateral, isosceles, or scalene)
(5)	Construct specific types of triangles distinguished by the number of equal sides	Students collaboratively construct a given type of triangle (equilateral, isosceles, or scalene)
(6)	Identify specific types of triangles	Students individually move their

	based on their angles	cursors towards the figure they believe to be the correct type of triangle (right-angled, acute, obtuse)
(7)	Construct specific types of triangles distinguished by their angles	Students collaboratively construct a given type of triangle (right-angled, acute, obtuse)

Teacher activities

The teachers played a pivotal part in the study. They received information about the topics to be taught, the amount of time they had for each activity, and both teachers (experimental and control conditions) received additional face-to-face instructions regarding the classroom orchestration. In order to become more familiar with the software and its orchestration, the experimental condition teacher reviewed and practiced with the software and its orchestration three times prior to the experiment.

In order to guide the teacher of the experimental condition in the integration of the software into her teaching practices, an orchestration was defined (Nussbaum, Dillenbourg, Fischer, Looi, & Roschelle, 2011) for all of the topics regarding triangles. The seven activities, as defined in Table 1, were alternated with slides that allowed the teacher to define the concepts with which the students then immediately worked. Table 2 describes the corresponding orchestration for Activity 4, "identifying triangles according to their sides". An orchestration was also offered to the teacher of the control condition who was using the traditional methodology. Both orchestrations were printed out and handed to the teachers before the experiment began. They received oral instructions on how to use the orchestration.

In both orchestrations (for the experimental and control conditions), the structure of the sessions was presented to the teacher. In a first stage, the students in both conditions needed to practice the concept of triangles by identifying abstract geometric objects and triangles in real life. In a second stage, the concept of triangles needed to be defined. In the experimental condition the students and the teacher were to do this together, whereas in the control condition the teacher was to explain the concept to the students. Computer interactivity occurred only in the experimental condition, in both conditions, however, student discussion was encouraged in order to talk about the concepts and to clarify any confusion. . Finally, students needed to participate in exercises to practice their knowledge and apply it to new situations. The experimental condition did these exercises collaboratively using the software, while the control condition did them individually using pen and paper.

As Table 2 illustrates, the orchestrations contained five elements: the session during which the activity is carried out; the amount of time the teacher must allow the students to work on a (sub) activity or instruction; the objective of the sub-activity; the instructions the students need to receive in order to carry out the sub-activity; and the explanation of the sub-activity for the teacher.

Table 2 shows part of the orchestration for the experimental condition that took place during the experiment, starting with Activity 4 (defined in Table 1): identifying types of triangles according to the number of equal sides they contain. Once the first sub-activity had been carried out, the teacher was asked to present a PowerPoint slide in order to conceptualize the activity of classifying triangles. At the end of this presentation, the students were to continue with Activity 5, and so forth.

Table 2
Orchestration for identifying triangles according to their sides

Session	**Time**	**Objective**	**Student instructions**	**Teacher explanation**
2	5 min	To identify triangles according to the number of equal sides they have.	Collaboratively identify triangles that have three equal sides, two equal sides, or no	Indicate that triangles can be classified according to their sides. Ask students to identify triangles with three, two, or no equal sides. Show different types

			equal sides.	of triangles, using the software, to identify triangles according to their sides.
	3 min	To understand the classification of triangles according to their sides: equilateral, isosceles, and scalene.	Recognize the different classifications of triangles according to their sides.	Show the "Classifying triangles" PowerPoint presentation, while analyzing the corresponding classification.
	7 min	To build different triangles at the system's request: isosceles, scalene and equilateral triangles.	Build different types of triangles.	Tell the students to collaboratively build an isosceles, scalene, and equilateral triangle.

Meeting the collaboration conditions

In order to create a classroom environment conducive to collaboration, certain conditions must be met, as mentioned in the Introduction. Table 3 provides an overview of the conditions to be met and the manner in which these were realized in our instructional design. Here the activities of the learner and of the teacher as described in the previous sections come together.

Table 3
Realization of collaboration conditions

Condition	Realization
Common goal	All students from one working group received the same instructions and they all had to carry out the same operation (constructing or identifying triangles).
Positive interdependence	All students from one working group had to work together in order to succeed. Without active participation and collaboration it was not possible to complete the assignments.
Joint rewards or punishments	Everyone worked for the same purpose and received the same feedback. Success or failure depended on the entire group and rewards or punishments were given accordingly to all group members in the form of smiley faces and comments by the teacher.
Awareness of peers'	Considering that all students shared the same display,

work	students could see what their peers were doing at all times. Groups could also see the performance of other groups.
Coordination and communication between peers	In order to be able to create triangles collaboratively students needed to work together, because all their cursors were connected to each other in construction activities to create the assigned figures, and the feedback smiley was only happy when all students contributed successfully. It was necessary for students to communicate and coordinate, which could be done silently during the activity by moving their cursors. Verbal communication was allowed in the group discussions held by the teacher.
Peer support	The teacher was asked to encourage the students to support each other and to respect each other when this did not occur naturally.
Individual accountability	Each student was accountable for the positioning of his or her own cursor, without which the group as a whole could not succeed. The result of each peer's actions was reflected in the feedback face that changed mood according to the number of students who were in the correct place. Because of the individual symbol that was assigned to every student, the teacher was able to see who was doing well, who was struggling and who was disrupting the lesson.

Procedure

After taking the pre-test, which all students took on the same day, both the experimental and control conditions participated in three sessions of 40-50 minutes each. Each session was carried out on a different day within the timespan of one week. Students in the experimental condition learned about triangles using the SDGT software specifically designed for this study while working in randomly assigned groups. Students in the control condition received regular classes using the traditional teaching method, and were taught the same topics, with the same activities (without the technology), as the experimental condition. To measure the knowledge acquired, both conditions took a post-test immediately after the final session.

In order to analyze how silent collaboration appears naturally, both screens were videotaped and later the corresponding exercises analyzed in detail by an observer so as to explore how students use their devices to communicate (Stewart, Raybourn, Bederson, &

Druin, 1998) and coordinate through silent collaboration (Tse, et al., 2004). In order to identify how often a given collaborative behavior occurred during each of the activities carried out by the students, student behavior was analyzed by the same single observer in each of the groups. The students' intentions were interpreted and labeled as a specific form of collaborative or non-collaborative behavior. These labels had already been defined as the result of a previous study, work performed by the same researchers. Where there were difficulties, a more in-depth discussion between the observer and two additional research team members followed until agreement was reached.

Measures

A test was created for this experiment to evaluate the students' growth in knowledge regarding triangles; it was used as the pre- and post-test. The test consists of open and multiple choice questions that measure the different concepts about triangles that third grades students should learn through participating in various activities specified in Table 1; there were 7 open questions and 8 multiple choice questions.. The open questions also included sub-questions, so that the maximum possible total score was 35 points across all 15 questions; one point per correct multiple choice question, and 0, 1, and 2 points for open questions, where 0 was wrong, 1 was incomplete and 2 was correct. To reach inter reliability in the scoring, a rubric was defined. Based on the results, the Cronbach's alpha for the post-test was 0.81 for constructing and recognizing triangles based on their sides (9 items), and 0.75 for constructing and recognizing triangles based on their angles (9 items).

Results

Student achievement

Table 4 shows the mean scores (max. 35) and standard deviations of the experimental and control conditions on the pre- and posttest. Both the experimental and control conditions significantly increased their scores ($p < 0.001$ in both cases).

Table 4

Descriptive statistics for learning gains, with scores for the pre-test and post-test

Condition	N	Pre-test		Post-test		Gain	
		Mean	SD	Mean	SD	Mean	Sig
Experimental	33	5.24	2.08	14.00	7.29	8.76	<0.001
Control	36	6.67	2.47	12.03	5.62	5.36	<0.001

To determine whether there was a significant difference between the gain scores of the two conditions, a one-way ANOVA was applied with the condition (control or experimental) as an independent variable and the learning gain from pre-test to post-test as a dependent variable. These results show that condition had an effect on learning gain ($F(1, 67) = 4.58$, p = .04), with the experimental condition showing a larger gain than the control condition.

Student activities

Any recurring behavior across one or more activities provided evidence of emerging patterns, as documented in Table 5. This table shows all activities for the six participating groups, the number of exercises carried out as part of each activity, the time spent on each activity, the number of occurrences of each detected pattern in each activity and the total number of occurrences of each pattern. It is important to note that multiple occurrences of one pattern could occur within the same exercise, as long as they represented the behavior of different students e.g., several students trying to help another student who was not collaborating. Additionally, the behavior of one particular student could show different patterns at different points during the exercise, for example, first playing individually with the mouse before subsequently collaborating with their peers in order to complete the exercise.

Each group of students completed 32 distinct exercises and as there were six groups, a total of 192 exercises were carried out (see Table 5). In some activities, various exercises of the same type were completed, e.g., in Activity 7, students sequentially constructed an acute triangle, a right angle triangle and an obtuse triangle (three exercises for Activity 7, Table 5). Occurrences of construction activities are marked in *light gray,* while occurrences of identification activities are marked in *dark grey* in Table 5. All of the activities (and their exercises) are collaborative, as described in the Curricular Goals and Student Activities section, and their successful completion required all group members to participate. Table 5 shows the number of successfully completed exercises, which provides evidence that collaboration was effective in 87.5% of exercises (i.e., 168 out of 192). In 12.5% of the exercises (24 out of 192) the proposed objectives were not met or required direct input from the teacher in order to complete the assigned task.

It is important to note that in order to successfully accomplish the exercises all students had to identify all requested triangles in the identification activities, or work together to successfully construct the requested triangle within the construction activities. However, even though activities required collaboration among all group members, non-collaborative patterns were identified during the realization of the exercises. It is for this reason that a distinction has been made between collaborative and non-collaborative patterns regarding student behavior.

The non-collaborative patterns identified in this analysis coincide with individual actions not necessarily oriented towards meeting the goal of the exercise. The non-collaborative patterns observed correspond to three types of actions. The first type of action observed was *copying peers*, but without leading to successful completion of the exercise, i.e., by either copying an incorrect object, or copying a correct triangle when further triangles remained to be identified. The second type of action was *trial and error,* i.e., seeking for improvement in the group's feedback (e.g., a smiley face) by moving the mouse over different objects. The third type was *entropy*, i.e., randomly moving the mouse around out of boredom or despair. This final pattern was particularly common in construction activities if the students failed to organize themselves after a certain amount of time. *Copying peers* and *trial and error* only applied to identification activities, as analyzing their presence in construction activities would have been very subjective.

The following collaborative patterns were observed: *marking the correct location*, i.e. moving the mouse persistently over a relevant figure, or over the vertex of the triangle needing construction; *marking the peer who is in the wrong place,* i.e. moving the mouse persistently over the symbol of a peer in the wrong place or not participating in the activity (generally until the latter reacts and begins to participate); and *marking the peer who is in the wrong place and marking the correct location,* i.e. a combination of the two previous patterns. All of these patterns are efforts to catch the attention of other group members, so that all students within a group cooperate in meeting the objectives. The most common collaborative pattern is *marking the correct location*, with 96 occurrences distributed across 72 exercises out of 192 (37.5%). Here, students look to help their peers complete the collaborative activity through positive interdependence, rather than simply pointing out what a peer is doing wrong in the exercise. This latter case is seen with *marking the peer who is in the wrong place,* something that occurred just 13 times out of 142 observed collaborative patterns. Students seem to have a tendency towards being a model for their peers rather than correcting them.

Besides the aforementioned patterns, other activities were identified in some isolated cases. One example is adapting to a peer who does not wish to participate in construction activities, which occurred on numerous occasions during the first activity. In this activity, the students were able to coordinate themselves in the construction of the required triangle, leaving the isolated peer to one side on one of the vertices. Another behavioral trait that emerged in various identification exercises consisted of one student waiting for their partners to take their positions at correct answers before moving the mouse himself; the student then simply hovered the mouse over one of the selected options.

Table 5

Non-collaborative and collaborative patterns. Occurrences in construction activities are in light gray, while occurrences in identification activities are in dark gray.

Number of Activity			1	2	3a	3b	4	5	6	7	TOTAL
Number of Groups			6	6	6	6	6	6	6	6	6
Number of collaborative exercises in each activity			1	9	1	3	6	3	6	3	32
Collaborative exercises that were successfully accomplished			**6**	**52**	**4**	**16**	**28**	**13**	**32**	**17**	**168**
Collaborative exercises that were not successfully accomplished			**0**	**2**	**2**	**2**	**8**	**5**	**4**	**1**	**24**
Effective Time (minutes)			*3*	*11*	*2*	*5*	*10*	*10*	*6*	*5*	*52*
Pattern		*Type of activity*	Max. number of occurrences (one per student per group per exercise)								
Non-collaborative	***Copying peers***	*Identification*	-	2	-	2	15	-	23	-	**42**
	Trial and error	*Identification*	-	4	-	2	16	-	17	-	**39**
	Entropy	*Identification and construction*	3	8	4	3	18	15	9	10	**70**
Collaborative	***Marking the correct location***	*Identification and construction*	4	19	2	7	13	20	21	10	**96**
	Marking the peer who is in the wrong place	*Identification and construction*	2	3	1	0	1	2	3	1	**13**
	Marking the peer who is in the wrong place and marking the correct location	*Identification and construction*	0	6	2	3	7	3	10	2	**33**

Discussion and conclusions

The main goal of this work centered on assessing the effectiveness of interactive instruction and classroom collaboration and on how silent collaboration takes place naturally.

While students in both the control and the experimental conditions significantly increased their scores from the pre- to the post-test, this difference was significantly larger in the experimental condition, showing the effectiveness of our approach. In order to analyze the way silent collaboration takes place naturally, we identified collaboration patterns that emerged spontaneously in an environment in which peers are not necessarily physically adjacent and are not always able to verbally communicate with each other, also known as silent collaboration (Szewkis, et al., 2011). This concurs with Liu and Kao (2007), who argue that the use of shared displays produces an improvement in non-verbal interaction, such as hand signaling in reference to individual answers, thereby achieving a natural interaction between peers. Considering that each student has their own interaction device (mouse), the activity forces students to become involved in the group activity even if they do not want to, and become an active participant in the process (Infante, et al., 2009). This was reflected in students' behavior, with 168 out of a total of 192 exercises (87.5%) successfully completed.

Tse, et al. (2004) suggest that people naturally divide their work across the workspace so as not to interfere with others. However, our study shows students openly intervening their classmates' work, whether it be to help them finish the task or simply because they lose interest in the exercise. In the former case, the interference did not lower productivity as Tse, et al. (2004) would suggest. On the contrary, the multiple mice allowed the students to avoid ineffective communication (Liu & Kao, 2007); students were able to undertake collaborative and non-collaborative behavior within the same exercise. For example, when identifying a correct triangle they would then mark it so as to help their group members.

These results have the following impacts: in analyzing teamwork, we demonstrated that it is possible to achieve synchronous collaboration among students who, in a classroom, are at a distance from each other and cannot effectively communicate orally. The collaboration achieved comes through collaborative patterns that we define as silent collaboration. The implications of silent collaboration are not just relevant for the classroom, but also for online learning. A second relevant result is the impact that this has on classroom teaching. We demonstrated that interactive instruction is possible with an entire class, in a concrete educational context. This takes on great importance given that one of the greatest barriers to adopting SDG is that little educational content is available for applications in SDG(Heimerl, Vasudev, Buchanan, Parikh, & Brewer, 2010).

Despite its overall success there are still improvements to be made to the software and class orchestration. One of these concerns the fact that the time required by different groups to successfully complete an activity varied greatly. This resulted in long periods of waiting for groups that finished earlier than the specified orchestration time, during which they interrupted their classmates on many occasions, e.g. yelling or interrupting the teacher while she was giving feedback to the groups that were still working. In order to avoid this, a new activity of the same kind and level could be offered to the faster groups that are waiting for the last group to finish, so that those students can avoid waiting and receive additional practice. When all of the groups have finished at least one exercise, the teacher could then freeze the screen, analyze the work that has been done so far, and then continue on with the next activity. This aims to avoid the situation of one group finishing early and having to wait too long for a slower group to catch up. Further, the application could be tested in a greater number of short sessions rather than a few long ones. This should lead to more concentrated, interactive, and attentive students.

Future work will examine if the same patterns of identification and construction have a general meaning. It would be useful to verify, if possible, whether or not the patterns of silent collaboration that we observed reemerge in different socio-cultural contexts and domains other than geometry and to possibly identify any new patterns that can be connected with the student learning.

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The Effects of Whole-class Interactive Instruction with Single Display Groupware for Triangles

Highlights

- We compared the effects of Single Display Groupware with traditional instruction
- The students in each group need to perform assignments using *silent collaboration*
- We made an analysis of emerging activity patterns on the screen
- Students found natural ways to collaborate silently
- Learning gains were higher for students in the SDG condition