Journal Pre-proof

Exploring group interactions in synchronous mobile computer-supported learning activities

Martina Holenko Dlab, Ivica Boticki, Natasa Hoic-Bozic, Chee Kit Looi

PII: S0360-1315(19)30288-X

DOI: https://doi.org/10.1016/j.compedu.2019.103735

Reference: CAE 103735

To appear in: *Computers & Education*

Received Date: 22 July 2018

Revised Date: 16 October 2019

Accepted Date: 17 October 2019

Please cite this article as: Holenko Dlab M., Boticki I., Hoic-Bozic N. & Looi C.K., Exploring group interactions in synchronous mobile computer-supported learning activities, *Computers & Education* (2019), doi: https://doi.org/10.1016/j.compedu.2019.103735.

Exploring Group Interactions in Synchronous Mobile Computer Supported Learning Activities

Holenko Dlab, Martina
University of Rijeka, Department of Informatics, Radmile Matejcic 2, Rijeka, Croatia
mholenko@inf.uniri.hr

Boticki, Ivica
University of Zagreb, Faculty of electrical engineering and computing, Unska 3, Zagreb, Croatia
ivica.boticki@fer.hr

Hoic-Bozic, Natasa
University of Rijeka, Department of Informatics, Radmile Matejcic 2, Rijeka, Croatia
natasah@inf.uniri.hr

Looi, Chee Kit
National Institute of Education, Nanyang Technological University in Singapore, 1 Nanyang Walk, Singapore
cheekit.looi@nie.edu.sg

Correspondent Author:
Holenko Dlab, Martina
Address: Radmile Matejcic 2, HR-51000 Rijeka, Croatia
Telephone: +385 51584708
Mobile: +385915667669
Email: mholenko@inf.uniri.hr

Exploring group interactions in synchronous mobile computer-supported learning activities

Abstract

This paper presents the results of a study of synchronous mobile computer-supported collaborative learning (mCSCL) that emphasized levels of pre-structuring in the context of primary school participants who need more guidance to benefit from the collaborative work. The male and female participants, who were, on average, 8-year-old primary school students, used Internet-connected mobile devices to work synchronously in small groups on mathematics tasks. The study examined two mCSCL interaction modes. In the first mode, each group member is assigned a role, and should have completed one part of the task before the group members negotiated their solutions. In the second mode, all group members completed parts of the task individually, and then negotiated their solutions to progress through the activity. The two interaction modes were compared in terms of student task completion attempts and incorrect completion attempts. The study results are of medium to large effect size and indicated that for tasks of lower difficulty, task distribution using roles led to statistically significantly more incorrect task completion attempts compared to the design without roles. For tasks of greater difficulty, there were more incorrect task completion attempts in groups with no explicit distribution of work compared to the groups with roles. The design of synchronous mCSCL technology emphasizes the importance of state preservation mechanisms, synchronization mechanisms, and immediate feedback messages. Practical implications of this study are that teachers must actively consider the type of mCSCL design they choose when preparing their mobile collaborative lessons, and choose an adequate design for the planned task difficulty level.

Keywords: Mobile computer-supported collaborative learning (mCSCL), Elementary education, Group work, Interactive learning environments, Roles

1. Introduction

The area of mobile computer-supported collaborative learning (mCSCL) has been developed over the past few decades by leveraging knowledge from the well-established field of CSCL, bringing new tools, methods, and ideas used with mobile technology into the classroom environment. Among the most important ideas that mCSCL borrows from CSCL are the design and implementation of mobile collaborative activities, and the advantages of social interaction while working on a joint task, which combined with the advantages of mobility, support interaction, and enhance learning outcomes (Alvarez, Alarcon, & Nussbaum, 2011; Hall, 2014; Järvelä, Kirschner, Panadero, Malmberg, Phielix, Jaspers et al., 2014; Looi & Wong, 2018; Szewkis, Nussbaum, Rosen, Abalos, Denardin, Caballero et al., 2011). In mCSCL, mobile technology allows students to move freely around the classroom (Zurita & Nussbaum, 2007), and offers opportunities for creating friendly, creative, and pleasant learning environments, even for younger students (Papadakis, Kalogiannakis, & Zaranis, 2016).

The study presented in this paper was contextualized within a three-year mobile learning project which explores how mobile learning activities are designed and seamlessly integrated into everyday classrooms, with no standard fixed technological infrastructure apart from a computer and a projector, and no advanced skills in teaching with digital technologies on behalf of the teachers. During the project, digital learning materials for several subjects in early primary school have been co-designed in collaboration with the teachers so that the standard curriculum is supplemented with novel learning tools, rather than being merely changed to fit novel technologies. This project was based on the educational premise that students need to acquire knowledge and skills in basic concepts in mathematics as a foundation for the development of mathematic literacy, which will help students deal with problems in real-life situations (Attard, 2017; Cheung & Slavin, 2013; Haara, Bolstad, & Jenssen, 2017).

Although the advantages of integrating technology in teaching and learning of mathematics are particularly evident in the case of automation of the drill and practice method (Papadakis et al., 2016), numerous research studies have explored the use of CSCL activities (Dillenbourg, 1999) for learning with mobile devices in primary schools (Looi & Wong, 2018) and in young learners' informal learning spaces (Looi, Lim, Pang, Lay, Koh, Seow et al., 2016). These studies examined the effects of mCSCL on students' learning of mathematics concepts, such as fractions (Boticki, Looi, & Wong, 2010, 2011), practicing addition, subtraction, and multiplication (Zurita & Nussbaum, 2007), or learning geometry using the virtual tangram puzzle or similar game-based approaches (Chiu-Pin, Shao, & Lung-Hsiang, 2011; Delić, Domančić, Vujević, Drljević, & Botički, 2014).

In this study, a process-oriented approach was used that emphasized a level of pre-structuring of group interactions in mCSCL activities. By leveraging the potential of synchronous CSCL in creating a dynamic classroom environment in early primary school, this study explored how different interaction designs of mCSCL activities affect the collaboration process and its outcomes. The overarching project methodology was Design Based Research (DBR), where the system and activity designs are adapted throughout a sequence of DBR cycles (Barab & Squire, 2004). A custom mobile learning platform allowed for more flexibility in designing and deploying the design solution for mobile collaborative learning, through the cycles of DBR involving co-design and re-design processes with the teachers. The design of the mCSCL solution evolved from a structured approach using roles and a clear division of work to a less structured solution. In this design, we adopted a systematic approach to designing computer-supported group-based learning that focused on supporting the expected interaction process by varying the degree of the support provided by the technological solution (sometimes referred to as the degree of the process structure; Strijbos, Martens, and Jochems, 2004). Such an approach should contribute to better understanding of how different structures relate to the interaction processes and outcomes in mCSCL.

2. Theoretical background

Dillenbourg (1999, p. 7) defined situations “as ‘collaborative’ if peers are more or less at the same level, can perform the same actions, have a common goal and work together.” By working in groups, students leverage each other’s expertise, and engage in joint discussion and argumentation processes, thus dealing with misconceptions and advancing to the final solution (Dillenbourg, 1999; Dillenbourg, Baker, Blaye, & O’Malley, 1995). According to Vygotsky’s (1978) zone of proximal development (ZPD), collaborative work allows individuals to develop their potential and extend their knowledge and skills, by leveraging peer and group resources. Collaborating, or being engaged in collaborative learning, means that participants are engaged in a coordinated, continuing attempt to solve a problem, or in some other way, construct common knowledge (Littleton & Mercer, 2013; Szewkis et al., 2011). Collaboration is dependent on the skills, attitudes, and positioning of the participants relative to each other, and the specific structure of the task confronting them (Luckin, Baines, Cukurova, Holmes, & Mann, 2017).

As designers and educators, we try to create the task design and the conditions that will make collaboration more likely to take place. The presence of successful collaboration during a learning activity depends on whether the following conditions are met (Szewkis et al., 2011): existence of a common goal, positive interdependence among peers, coordination and communication among peers, individual accountability, awareness of other peers’ work, and joint rewards. With the advent of computer-supported collaborative learning (CSCL), computers are used as tools that contribute to such endeavors by providing more efficient and effective engagement in group work processes (Chen, Wang, Kirschner, & Tsai, 2018; Zurita & Nussbaum, 2004). Although CSCL takes various forms when implemented in classrooms, in terms of technology and pedagogy designs, two main forms can be distinguished: synchronous CSCL and asynchronous CSCL. Asynchronous CSCL utilizes tools such as online forums and message boards that can be accessed in any location and at any time. Synchronous CSCL occurs when learners engage in learning in a specific time-frame, but can, depending on the technology, be positioned at various locations (Bower, Dalgarno, Kennedy, Lee, & Kenney, 2015). Although synchronous and asynchronous CSCL designs provide great potential for use by course designers and instructors, these modalities can also be ineffective if they are used inappropriately.

In group work, fixed groups remain the same during the entire learning activity, while opportunistic groups may be changed according to learners' needs and affinities. A study exploring such a relationship revealed that in fixed groups, students score better in metacognition and reference, while opportunistic groups lead to better questions and ideas generated by students (Siqin, van Aalst, & Chu, 2015). When exploring the dynamics of synchronous fixed groups in CSCL, substantial differences in knowledge distribution between fixed groups (the groups that keep the same members throughout the course of a group activity) were found, where the students who actively participated and contributed with high-level ideas were also the students with higher-level domain knowledge (Siqin et al., 2015). A study of a microblogging-based professional development community reported uneven levels of participation when synchronous CSCL was used, but emphasized various topics and many types of interactions (Gao & Li, 2017).

Scaffolding, or the need for pedagogical support tailored to the demands of more ambitious learning tasks (Quintana et al., 2004), has been an emerging focus of design and empirical research efforts. Designing scaffolds for CSCL can be a delicate design issue as "providing learners with more than one scaffold may be overwhelming, especially when these scaffolds are presented at the same time in the learning process and when learners' individual learning prerequisites are suboptimal" (Schwaighofer, Vogel, Kollar, Ufer, Strohmaier, Terwedow et al., 2017). This study adopted the approach to CSCL research advocated by Dillenburg (1999), where computer platforms are created to scaffold productive interactions by encompassing interaction rules in the medium which are semiotic and physical, and affect the understanding of a task beyond the simple facilitation/inhibition of particular types of interactions. A characteristic of such computer platforms leveraged in this study is the ability to support synchronous CSCL facilitating peer discussion, leading to metacognitive, co-regulation, and social emotional activities occurring, to enhance learning (Lajoie, Lee, Poitras, Bassiri, Kazemitabar, Cruz-Panesso et al., 2015).

The relationship between interaction and learning is seen as central in CSCL research today. As noted by Suthers, Dwyer, Medina, & Vatrapu (2010), CSCL itself has been defined as a field centrally concerned with meaning and practices of meaning-making in the context of joint activity, and with the ways in which these practices are mediated through designed artifacts (Koschmann, 2002; Suthers et al., 2010). Researchers have explored asynchronous and synchronous CSCL to identify modes of structuring interaction, and have noted that interactions in asynchronous CSCL environments add complexity to learning processes, and more guidance for students is needed to promote better conceptual understanding (Sun, Looi, & Xie, 2014). Synchronous CSCL can provide intellectually stimulating contexts in which all students learn to collaborate by interacting with one another, using well-established collaboration procedures and effective moves (Kim, 2014). Therefore, researchers in CSCL have advocated for an approach labeled "designing for interaction" (Dillenbourg & Tchounikine, 2007), in which designs include a level of heterogeneity (an intentionally designed imbalance between group members and their resources) which might stimulate group processes, including activity, the exchange of messages, deeper discussions, and more orientation toward reaching the solution as part of the group (Fidas, Komis, Tzanavaris, & Avouris, 2005).

To structure interaction, some CSCL designs use predefined roles assigned to students. For example, if students are expected to perform much better in one role than the other, then rules for assigning roles based on the individual students' characteristics are applied. If a group must solve more than one task (or task type), the roles can be rotated or alternated, to ensure that all group members engage in relevant subtasks equally (Strijbos & Weinberger, 2010), or identifying roles and supporting students can be done automatically, using an adaptive system (Marcos-García, Martínez-Monés, & Dimitriadis, 2015). Researchers indicate that distributing a task into subtasks should not lead to using too many roles, which could negatively affect the dynamics of the synchronous learning activity (Kooloos, Klaassen, Vereijken, Van Kuppeveld, Bolhuis, & Vorstenbosch, 2011).

3. Research design

The study described in this paper sought to explore the effects of social scripts on domain-specific knowledge identified in previous research (Pozzi, Hofmann, Persico, Stegmann, & Fischer, 2011), and tries to fill the gap identified by Strijbos et al. (2004), by exploring the effect to which mCSCL designs determine changes in expected interaction in advance. Strijbos et al. (2004) noted that "the impact of interaction processes on learning is [often] explained in retrospect, i.e. it is determined whether outcomes were affected by the interaction observed. Retrospective examination of interaction can provide indicative evidence regarding a relationship between outcome and interaction, but there is little certainty that it can be reproduced since it was not planned" (p. 406). A study on promoting learner autonomy in the context of collaborative mobile learning, which built on the work by Strijbos et al. (2004), reported that in the context of mCSCL, structuring of a learning continuum was "a necessary and pivotal measure to facilitate the execution of the unstructured learning space and to provide learners with the cognitive autonomy support" (Tan & So, 2013). The study described in this paper explored this identified gap further, with the use and comparison of two mCSCL designs, to identify the context in which two collaborative interaction modes can be used for structuring group work in early primary school mathematics education: Role-to-Collaborative (R-to-C) and Individual-to-Collaborative (I-to-C) designs (referred to as interaction modes in this paper). These two designs were selected to vary the level of structuring of the mCSCL environment, and to shed more light on how varied structuring affects learning mathematics by primary school students.

The two interaction modes for structuring group work were used in a primary school classroom for mathematics learning. Students were assigned to groups in both approaches and needed to follow specific scaffolds which shaped their interaction and collaboration. By engaging in interaction and collaboration students completed the mathematics tasks and helped each other when impasses occurred. Students' answers, both incorrect and correct, and the number of task completion attempts were recorded for each of the interaction modes.

The research question explored in the study is the following: How does the number of incorrect attempts for mathematics tasks differ between the two interaction modes (R-to-C and I-to-C)?

3.1. Research model

The project utilized a DBR approach, in which the design is refined and implemented with incremental improvements that are always informed by the results of the previous cycle, and integrated into new redesigns. Such an approach allows for agile absorption of emergent design ideas in a novel technology-enhanced project, where the project and research requirements are not fixed from the project start, but they evolve and change as research and development proceed (Amiel & Reeves, 2008; Bakker & van Eerde, 2015; Wang & Hannafin, 2005). Two DBR cycles were conducted during this study. Each cycle included mCSCL activities with different modes to structure the interaction (the R-to-C interaction mode in the first cycle and the I-to-C interaction mode in the second cycle).

A possible alternative to the DBR approach would have been an experimental research approach with a randomized control trial (RCT) in which participants are randomly assigned to one of two groups: the experimental group receiving the treatment that is being tested or the control group receiving an alternative treatment. In such a research setting, researchers typically use hypotheses that are formulated beforehand to test if there is a significant difference between the two conditions (Bakker & van Eerde, 2015). Experimental research often targets implementation of theories and designs in a controlled environment, but the DBR approach tends to inform theory and the educational context (The Design-Based Research Collective, 2003). Therefore, educational interventions in a real classroom context using the DBR approach were deemed more appropriate compared to research in controlled conditions in which procedures are fixed, and only particular variables are isolated and manipulated. According to the DBR approach, a successful innovation is seen as a joint product of the designed intervention and the real context that has dynamics, complexity, and limitations. To stay objective, experimental researchers often are not present during interventions, while DBR researchers manage research processes in collaboration with the participants, to intervene and improve the initial designs without waiting until the end of the experiment (Wang & Hannafin, 2005). The possibility for collaboration between researchers and practitioners (school teachers) was one of the main advantages, because it allowed the researchers to identify necessary adjustments of the learning activity design (the interaction modes) and the technology design (the mCSCL system) in a real educational environment.

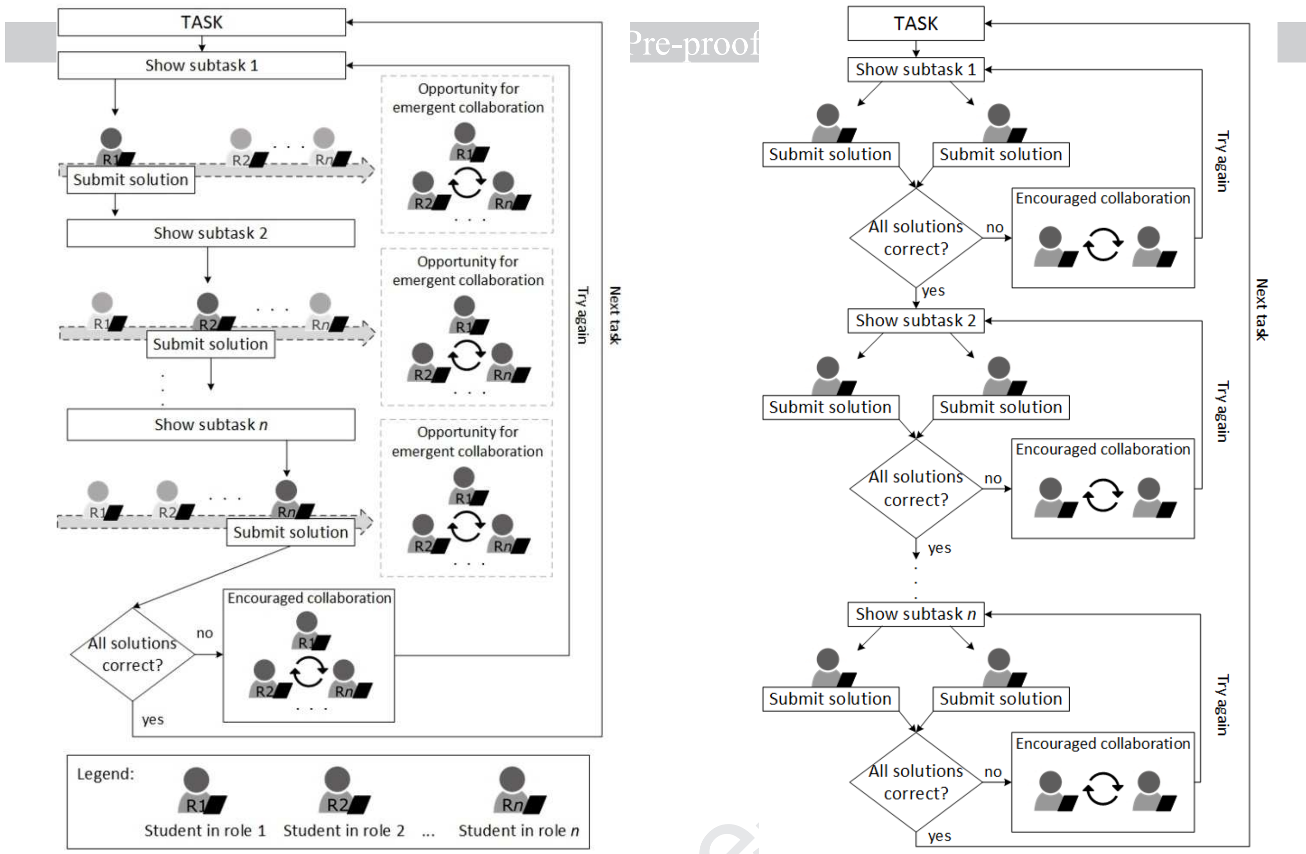
The within-subjects study design was chosen for the implementation of the mCSCL system (Davidian & Giltinan, 2003; Lawal, 2014). In the within-subjects design, the outcome variables are measured for all subjects across time, exposing all participants to all research treatments. This study design does not require a large number of participants, and because all participants are exposed to all research treatments, individual differences do not distort the results. The main disadvantage of this approach is the potential residual effect (Lawal, 2014), which occurs when the effects of one experimental condition persist long enough to affect the results of the following experimental conditions (Greenwald, 1976). To counterbalance the carry-over effect, there should be a certain time period between the condition measurements (Barlow & Hayes, 1979).

To answer the research question, descriptive statistics of the variables showing the number of (incorrect) attempts made by individual students during their collaborative work were used. In addition to quantitative analysis, qualitative analysis of data regarding the interactions among the students during collaborative activities was conducted. Data collection and analysis, as well as the results obtained, are discussed according to the guidelines proposed by López, Valenzuela, Nussbaum, and Tsai (2015).

3.2. Role-to-Collaborative and Individual-to-Collaborative interaction modes

The two interaction modes explored during the study are shown in Fig. 1. In the Role-to-Collaborative mode for structuring group interactions, each group member is assigned a predefined role, and must work in the assigned role to complete the assigned subtask (Fig. 1a). While the students are solving their subtasks, there is an opportunity for *emergent collaboration*, because other students may decide on their own to help their peers. Emergent collaboration is not explicitly encouraged by the system, but evolves among participants during the learning process, and depends on the level of student involvement and the students' commitment to the process of solving the task (Nachmias, Mioduser, Oren, & Ram, 2000). For example, emergent collaboration might occur when more knowledgeable peers help those who cannot come up with a solution for their own subtask.

The mCSCL system evaluates the correctness of the proposed solutions, and if one or more subtasks were not solved correctly, encourages the group to collaborate before individual students try again. In the process of re-working, the students must complete their subtasks again. As the system does not reveal whose solution is incorrect, the students are supposed to negotiate their own solutions with peers during the *encouraged collaboration* process to find the correct solution. Only after all group members in their own roles contribute correctly with their subtask solutions is the overall task considered completed correctly, and the group can proceed to the next task (if any).



(a) (b)

Fig. 1. The two modes of structuring group interaction in collaborative small-group activities: (a) R-to-C interaction mode, (b) I-to-C interaction mode.

In the Individual-to-Collaborative mode, individual group members should complete the entire task consisting of a complete set of subtasks (Fig. 1b). After the individual subtask, in which students are supposed to work on their own, is solved, the mCSCL system evaluates the students' solution. Collaboration is explicitly encouraged by the mCSCL system in the case of incorrect solutions. The system does not reveal who made the error. The students are expected to figure it out during the *encouraged collaboration* process, and to assist their fellow group members in finding the correct solution to a subtask in the next attempt. The group cannot proceed to another subtask or task until the current subtask or task has been solved. Conversely, in the R-to-C interaction mode, each group member is assigned a specific role that is bound to a particular subtask. Once a student has completed his or her assigned subtask, the student in another role takes over, and completes the following subtask.

4. Material and methods

This study employs mixed-methods research methodology where both quantitative and qualitative methods were used throughout the DBR cycles. In order to get a more complete and comprehensive understanding of the research results, concurrent nested/embedded design was used. In this mixed methods study design, quantitative and qualitative data are being collected at the same time but one of the methods dominates whilst the other one is nested or embedded (Almeida, 2018). In the study described in this paper, quantitative method was predominant while qualitative method was used in parallel to give additional insights into students' behavior.

The DBR cycles in this study include mCSCL activities with different modes to structure interaction: The first cycle was the mCSCL activities with the R-to-C interaction mode. The second cycle was the mCSCL activities with the I-to-C interaction mode.

4.1. Study design and procedure

In <authors' country – omitted for peer review>, a common curriculum is in place, so all students are taught the same subjects, and the corresponding curricular content. The implementation relies heavily on teachers who have the flexibility to choose their own methods for teaching the curricular topics. Following the DBR framework proposed by Amiel and Reeves (2008), after analyzing practical problems that occurred in the practitioners' use of collaboration, the technology-enhanced solution was developed as part of the study. Standard lessons in mathematics taught by primary school teachers were digitalized to replace solving tasks on a paper (in books or notebooks) with the use of tablet computers (one device per student). The solution was then tested in practice and refined, and general design principles were identified before the next lesson implementation cycle during which all the steps were repeated.

The researchers conducted interventions with the digital lessons during a 6-month period (from January 2017 to June 2017). The digital lessons, which included word problems that involved addition, subtraction, multiplication, and division, were stored in the central project server repository. Such mathematics tasks can be immediately evaluated by the system, and immediate feedback information can be given to the students.

Fig. 2 shows the sequence of mCSCL activities (treatments) included in the study. In line with the chosen within-subjects design, students in both classes were exposed to the same treatment in both DBR cycles, first to the mCSCL activities with the R-to-C interaction mode and then to the mCSCL activities with the I-to-C interaction mode.

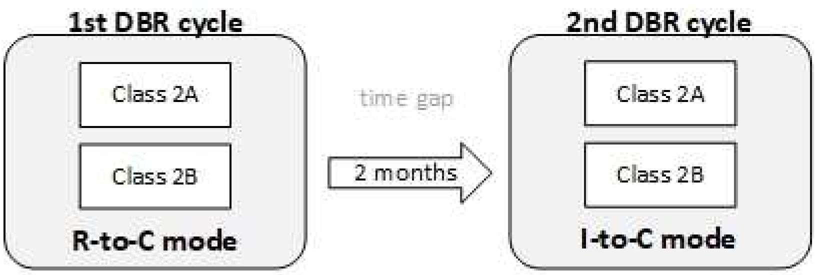


Fig. 2. mCSCL activities implemented in the study.

mCSCL activities were conducted three times in each class during a period of several weeks. Activities in classes 2A and 2B were conducted on the same day, but at a different time (i.e., first in one class followed by another class), and lasted for about 1 school hour (45 minutes). To counterbalance the possible carry-over effect during the within-subject design, the time period between the treatments was set to 2 months (Fig. 2). Students in both classes were exposed to one treatment first (mCSCL activities with the

R-to-C interaction mode), and after a time gap of 2 months, to the second treatment (mCSCL activities with the I-to-C interaction). Two months between the treatments should be enough, according to the teachers, to minimize the carryover effects. After this pause, different curricular contents were taught and used in the digital lessons, which also helped reduce the carry-over effects.

Throughout the whole duration of each activity, the students used the mCSCL system with digital lessons. Each digital lesson included a set of tasks consisting of word problems with addition, subtraction, multiplication, and division, and students solved the problems in dyads and triads. The total number of tasks assigned to students during the treatments is shown in Table 1. Because the experiments were conducted as part of regular classes, the number of tasks assigned to each class varied, due to the inevitable differences in the classroom environments. Before and in-between treatments (mCSCL activities), students practiced mathematics with their teachers without the technology.

Table 1

The total number of mathematics tasks assigned in the study.

Contents	Interaction mode	Class	Total number of tasks
Math word problems covering addition, subtraction, multiplication and division	R-to-C	2A	26
	R-to-C	2B	25
	I-to-C	2A	40
	I-to-C	2B	30

Data regarding students' attempts were automatically logged by the mCSCL system. At least two researchers were present in the classroom during lessons and took field notes, and the activities were recorded with two video cameras.

Quantitative analysis, as a predominant method in this study was used to compare students' achievement following the completion of collaborative mathematics tasks in the R-to-C and I-to-C interaction modes. The relevant variables were extracted from the system's log files and statistically analyzed to explore how the number of attempts differs between the two interaction modes.

Although not predominant, qualitative analysis made it possible to gain in-depth perspective of the students' performance. Qualitative data that included researchers' field notes and the video recordings taken during the lessons were analyzed separately. Qualitative analysis resulted in alignment of transcripts of interactions, which enabled identification of more, and less engaged students (in respect to different task difficulties) and their behavior in situations when incorrect solutions were offered. In addition to that, positions of group members during collaboration and technical system performance were recorded and analyzed.

In the iterative DBR process, the results from the first cycle were used to make adjustments in the technology design interaction mode for use in the second DBR cycle.

4.2. Participants

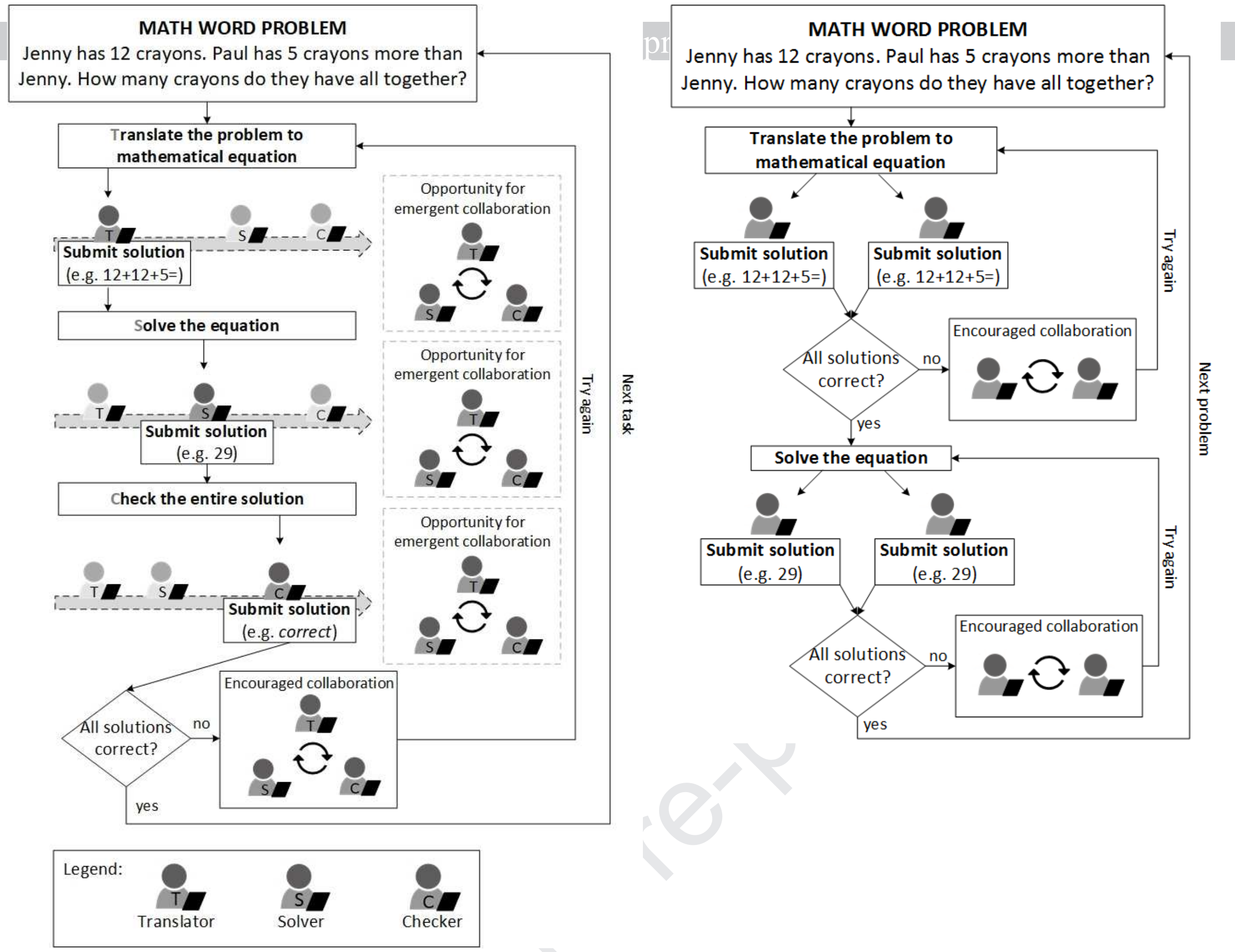
The participants were students from two primary school grades in one academic year: 2A and 2B. The students (N = 33) were from the same school, and they were assigned to classes randomly, upon enrolling in school. Both classes were composed of students from low, medium, and high academic performance groups. In <authors' country – omitted for peer review>, the usual setup of primary school classes includes mixed genders and mixed-ability students. In class 2A, there were 18 students ($n_{2A} = 18$, $n_{Am} = 8$ boys, $n_{Af} = 10$ girls), and in class 2B, there were 15 students ($n_{2B} = 15$, $n_{Bm} = 6$ boys and $n_{Bf} = 9$ girls). The average student age was 8 years.

4.3. Implementation of digital lessons with math word problems

In the R-to-C interaction mode (Fig. 3a), group members worked in triads (which were generated randomly by the system), and were assigned one of the three available roles, translator, solver, or checker. The roles were rotated for each task so that all group members got to participate in all roles equally <reference to authors' publication – omitted for peer review>. The translator was asked to translate the problem into a formula (mathematical equation), the solver was asked to calculate it, and the checker was asked to mark the entire solution as correct (OK) or incorrect (C). Collaboration was encouraged by the system at the end, once all group members had provided their solution according to their role. In Fig. 4, the mCSCL system interface shows the translating subtask assigned to the translator, the solving subtask assigned to the solver, and the checking subtask assigned to the checker.

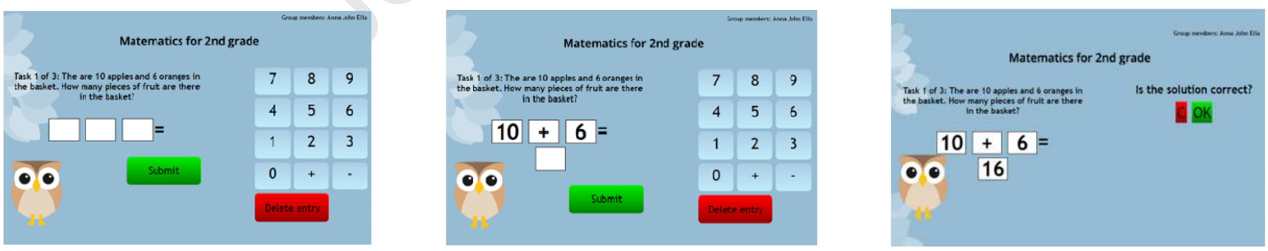
In the I-to-C interaction mode (Fig. 3b), students worked in dyads generated randomly by the system, and were assigned the same task to complete on their own. First, they had to examine the given text, and then translate the given problem into a formula. In the event both students in a dyad were not able to translate the problem into the correct formula, the mCSCL system would encourage them to collaborate before making another attempt. Once both students submitted the correct formula, they could move on to the next subtask, where they were asked to provide the solution to the formula individually. Similarly to providing a formula, getting to the correct solution through collaboration was encouraged by the mCSCL system.

In the R-to-C and I-to-C interaction modes, the mCSCL system automatically checked the solution for a subtask before allowing the students to start with the next subtask. In the case of an incorrect solution, the mCSCL system encouraged collaboration between the students, never revealing whose solution was incorrect. Students were expected to discuss their offered solutions, and collaborate to reach the correct one.



(a) (b)

Fig. 3. The instantiation of the two modes for structuring group interaction in collaborative small-group activities: (a) R-to-C interaction mode, (b) I-to-C interaction mode.



(a) (b) (c)

Fig. 4. A tool that supports synchronous mCSCL using roles: (a) Translator role – ready for a translating attempt (number - operation - number), (b) Solver role – translation entered, ready for a solving attempt (number), (c) Checker role – translation entered and solved, ready for a checking decision.

All the tasks were presented in textual form, and the task contents were carefully aligned with the curriculum area of the students' native language. The difference in task difficulty was modeled by using difficulty coefficients (DCs) ranging from 1 to 3 (1 is less difficult than 2, which is less difficult than 3) referring to the difficulty of translating a word problem into a formula and solving it (performing a calculation). During the task generation process, the teachers assigned difficulty coefficients to tasks based on the rules the teachers had previously agreed upon with the researchers. The rules for assigning difficulty coefficients and examples of tasks are given in Table 2. For example, tasks that required adding numbers without carrying over (e.g., 43 + 11) were considered less complex than tasks that required carrying over (e.g., 46 + 17), because the latter came later in the curriculum, and students had fewer opportunities to practice these tasks. Similarly, the tasks that required multiplication with 5 were considered less complex than the tasks that required multiplication with 9. Regarding the grammatical structures and extra information in the word problems, the task "*Jenny has 12 crayons, and Paul has 5 crayons. How many crayons do they have all together?*" was considered less complex than the task "*Jenny has 12 crayons. Paul has 5 crayons more than Jenny. How many crayons does Paul have?*"

Table 2
The rules for assigning difficulty coefficients to tasks with examples.

DC	Rule for assigning the difficulty coefficient	Task examples
1	Word problems with simple sentences in which values in the text are represented with digits. To solve the problem, two values should be used in the calculation. The students previously practiced the calculation, to perform it well.	Mom wants to bake 36 cookies. Yesterday she baked 14 cookies. How many more cookies does she need to bake?
2	Word problems with simple sentences in which values in the text are represented with digits. The students previously practiced the calculation, to perform it moderately.	The teacher has 60 crayons. She will fairly divide the crayons to 10 students. How many crayons will each student receive?
	OR	
	Word problems with semi-complex grammatical structures and extra information. The students previously practiced the calculation to be performed (with two values) well.	Diana brought 54 sweets and 42 cookies to school on her birthday. How many sweets has she left is she gave 38 sweets and all cookies to her classmates?
3	Word problems with semi-complex grammatical structures and extra information. The type of calculation that must be performed includes two or three values, and was previously only moderately practiced.	There are 7 trees in the park and 7 birds in each tree. Each bird has 2 legs. How many birds are sitting on the trees?
	OR	
	Word problems with complex grammatical structures which require wider vocabulary, as well as abstraction and reasoning skills, with only some of the values represented with digits. The students previously practiced the calculation to perform it (with two or three values) well.	A brother and sister are collecting money for a field trip. How many coins have they collected together if the brother collected 13 coins, and the sister collected five coins more than he did?

DC – Difficulty coefficient

To determine the difference between the interaction modes in terms of the performance exhibited by the participating students, the following research question was explored: How does the number of incorrect attempts for the mathematics tasks differ between the two interaction modes (R-to-C and I-to-C)?

The difference between the interaction modes was further explored in the context of this study using two additional research questions:

(1) How does the number of incorrect *translating* attempts per task (the first subtask) differ between the two interaction modes (R-to-C and I-to-C)?

(2) How does the number of incorrect *solving* attempts per task (the second subtask) differ between the two interaction modes (R-to-C and I-to-C)?

4.4. Data collection and analysis

The research questions were answered by collecting and analyzing the data on the interactions among students obtained via log files, lesson video recordings, and observation of classroom activities. The main instrument relied on computer-supported data logging mechanisms provided by the technology used as part of the study. All user actions (i.e., every touch of the tablet screen) were precisely recorded by the mCSCL system with the use of data logs. This approach directly contributed to the robustness of the study, as this approach can accurately measure the number of correct and incorrect task attempts.

The logs containing relevant data for quantitative analysis were filtered and processed after the experiment. Table 3 shows the structure of the collected logs that were analyzed in the study and the list of all extracted variables. The variables were the number of correct and incorrect attempts made by a student to solve one of the two subtasks (translating the problem into a formula and solving the formula), as well as the overall number of attempts per task. In the collaboration activities, students needed to complete a task successfully to move on to another task. This implies that all tasks were eventually completed successfully, and that some students attempted to solve a task multiple times, making the incorrect attempts an important performance measure. Variables were analyzed for only two subtasks, because the checker role used in the R-to-C interaction mode was removed in the second DBR cycle redesign (there were only two group members in the I-to-C interaction mode). Such an approach allowed for the analysis of attempts made by individual students during their collaborative work, including the descriptive statistics (mean values and standard deviations), the comparison of differences between students, using the paired-samples t-test, and the effect sizes. A paired-samples t-test was used to compare the continuous variables across conditions after testing them for outliers and normality, because both groups of students were exposed to the first treatment, and after the time gap, to the second treatment.

Table 3

Example of a software log and the extracted variables analyzed in the study.

Software log example	List of all the extracted variables (per Student)
Data format: Lesson;DifficultyCoefficient;Group; TranslatorElapsedTime;SolverElapsedTime;CheckerElapsedTime;TranslatorAnswer;SolverAnswer,CheckerAnswer;ProblemNumber;ProblemFormula *Sample data:* SubstractionWordProblems_2;2;Anna Smith,Joe Doe,Adam Filips;38752;13044;4045;98-47;51;Ok;1;98-47=51	Number of Tasks Number of Incorrect Task Attempts Number of Task Attempts Number of Translation Attempts Number of Incorrect Translation Attempts Number of Solving Attempts Number of Incorrect Solving Attempts

At least two researchers were present during the observations of the collaborative classroom activities that were conducted three times in each class. The researchers took field notes regarding the most significant moments in the lessons: communication among students (e.g., lively discussions or negotiations), communication with teachers or researchers (e.g., when students asked for help), and physical activity (e.g., when students were searching for another place to work in the classroom). Qualitative analysis of the field notes was performed to get additional insights into the students' performance after they found the correct solutions for tasks of differing difficulty. The researchers focused on the students' level of involvement in the collaboration process, and reactions, in the case of incorrect solutions (whether the students were interested in the actions of other group members, were ready to offer or receive help, and similar actions). To complement the field notes, each lesson was recorded with two cameras from two different angles. This resulted in 14 video entries (the duration of each video was around 50 minutes), which included interviews with the students and the teachers conducted after each lesson.

By analyzing the field notes and video clips, transcripts of interactions were reconstructed, and more and less engaged students were identified. More engaged students were those who were ready to start a discussion to solve a misconception, encouraged others to revise their solutions, and were willing to learn from other group members. Less engaged students were those who lacked focus on the task, were not interested in initiating or participating in discussions, and did not have the patience to listen to the explanations given by others (regardless of the number of incorrect answers). In addition to which incorrect solutions were offered, the researchers analyzed whether the students explained to each other the correct ways of solving a task. Positions of group members during collaboration (whether they were sitting around the table, sitting or standing somewhere in the classroom, or lying on the classroom floor) and technical system performance (the number of cases in which a complete restart lesson was needed due to interruptions in the network infrastructure or problems with synchronization mechanisms) were also analyzed.

5. Results

As part of the study, first DBR cycle included mCSCL activities with the R-to-C interaction mode to structure interaction. Based on the results from the first cycle, this mode evolved into the I-to-C interaction mode to structure interaction in the second DBR cycle. Table 4 shows the evolution of the redesign process by illustrating the changes that occurred in the two main design elements for synchronous mCSCL: the learning activity design and the technology design. Design principles of I-to-C mode, extracted after the first cycle of the DBR process, are the following:

- *Learning activity design*
  - group members are not assigned to roles bound to a particular subtask (as in the R-to-C mode)
  - individual group members are supposed to complete the entire task consisting of a set of subtasks (and not only one subtask as in the R-to-C mode)

- the mCSCL system evaluates students' solution after each individual subtask (and not only at the end, after solutions of all subtasks have been submitted by group members, as in the R-to-C mode)
- the mCSCL system explicitly encourages collaboration on several occasions - after checking the submitted solution for each subtask (and not only at the end, as in the R-to-C mode)

- *Technology design*
  - mCSLC system synchronization mechanisms were improved resulting in faster information flow towards students' devices
  - lesson restart and resume mechanisms were introduced so that the students could resume their lessons after accidental interruptions or planned pauses
  - activity logs were improved and reorganized for easier subsequent data analysis

Table 4

Two cycles of the DBR approach in the study.

DBR cycle	Cycle description	Cycle result
1	*Learning activity design*	
	R-to-C interaction mode	A relatively high number of incorrect subtask attempts were observed (0.17 incorrect formula attempts per task, 0.19 incorrect calculation attempts per task, and 0.15 incorrect checking attempts per task). Based on this result and the literature review, a change in the interaction mode was warranted. The I-to-C interaction mode was proposed for the second DBR cycle.
	Technology design	
	Synchronization and sequencing mechanisms, state preservation	In the case of network infrastructure interruptions, a complete restart of a lesson was necessary. Modification of the lesson execution was proposed for the second DBR cycle, by introducing synchronization, sequencing, and state preservation support.
2	*Learning activity design*	
	I-to-C interaction mode	Students were expected to complete the subtask individually, and then discuss and negotiate their solutions with peers (0.24 incorrect formula attempts per task and 0.08 incorrect calculation attempts per task).
	Technology design	
	Lesson restart and resume mechanisms, improved activity logs	The mCSCL system required the change of a smaller number of synchronization mechanisms, leading to improved system performance.

5.1. Descriptive statistics

During the study, students solved tasks with word problems in the R-to-C and I-to-C interaction modes. One student participated in, on average, 20 R-to-C tasks and 29 I-to-C tasks over the course of this study. Because the students were solving the tasks at their own pace, some were not able to complete all the tasks, possibly having multiple submissions of a subtask (translation and/or solving) as part of solving one task. The average number of R-to-C task attempts was 29, and the average number of I-to-C attempts was 71 (the figures are averages per student). Students participated in, on average, 14 translating attempts in the R-to-C interaction mode and 40 in the I-to-C interaction mode. The average number of solving attempts per student for the R-to-C interaction mode was 8, and for the I-to-C interaction mode was 31.

Tables 5a and 5b show descriptive statistics of the selected variables listed in the right column of Table 3 for the R-to-C and I-to-C interaction modes. The descriptive statistics give the overall trends, but the statistics do not show how many translating or solving attempts students had per task, and whether the attempts were correct or incorrect. To deal with this issue, all the variables were grouped per task, and the average values were calculated.

Table 5a

Descriptive statistics for the main variables in the R-to-C and I-to-C interaction modes (*N* = 33 students), aggregated.

	R-to-C		I-to-C	
Variable	*M*	*SD*	*M*	*SD*
Number of Tasks	20.36	4.25	28.79	4.36
Number of Translation Attempts	13.73	6.15	40.48	7.61
Number of Solving Attempts	8.09	6.42	30.91	5.90
Number of Task Attempts	28.67	7.33	71.39	12.33

Table 5b

Descriptive statistics for the main variables in the R-to-C and I-to-C interaction modes (*N* = 33 students), per difficulty coefficient.

		R-to-C		I-to-C	
DC	Variable	*M*	*SD*	*M*	*SD*
1	Number of Tasks	12.82	2.72	12.03	1.61
	Number of Translation Attempts	9.03	4.30	14.82	2.65
	Number of Solving Attempts	5.09	4.10	13.18	2.66
	Number of Task Attempts	18.09	3.70	28.00	4.54
2	Number of Tasks	4.42	2.10	11.48	2.06
	Number of Translation Attempts	2.21	2.74	16.67	5.73
	Number of Solving Attempts	1.97	2.56	12.64	3.79
	Number of Task Attempts	6.27	3.36	29.30	8.73
3	Number of Tasks	3.12	0.83	5.27	1.46
	Number of Translation Attempts	2.48	1.89	9.00	2.65
	Number of Solving Attempts	1.03	1.80	5.09	2.81
	Number of Task Attempts	4.30	2.31	14.09	4.63

DC – Difficulty coefficient

Tables 6a and 6b show per-task averages of the main translating and solving attempt variables in the R-to-C and I-to-C interaction modes. When the values are examined by the task difficulty coefficient, the I-to-C interaction mode had lower averages compared to the R-to-C interaction mode for the lowest task difficulty coefficient (DC = 1) and higher averages for medium and high task difficulty coefficients (DC = 2 or 3), indicating the I-to-C interaction mode might be more appropriate when solving tasks of lower difficulty, while the R-to-C interaction mode might be more appropriate when solving tasks of greater difficulty.

Table 6a

Descriptive statistics for the main translating and solving attempt variables in the R-to-C and I-to-C mCSCL interaction modes (*N* = 33 students), aggregated.

	R-to-C		I-to-C	
Variable	*M*	*SD*	*M*	*SD*
Number of Incorrect Translation Attempts (Per task)	0.17	0.19	0.24	0.08
Number of Incorrect Solving Attempts (Per task)	0.18	0.25	0.08	0.04
Number of Attempts (Per task)	0.15	0.11	0.22	0.07

Table 6b

Descriptive statistics for the main translation and solving attempt variables in the R-to-C and I-to-C interaction modes (*N* = 33 students), detailed per difficulty coefficient.

		R-to-C		I-to-C	
DC	Variable	*M*	*SD*	*M*	*SD*
1	Number of Incorrect Translation Attempts (Per task)	0.24	0.27	0.16	0.09
	Number of Incorrect Solving Attempts (Per task)	0.23	0.29	0.06	0.06
	Number of Attempts (Per task)	0.16	0.11	0.14	0.71
2	Number of Incorrect Translation Attempts (Per task)	0.11	0.13	0.24	0.14
	Number of Incorrect Solving Attempts (Per task)	0.06	0.09	0.09	0.06
	Number of Attempts (Per task)	0.10	0.12	0.23	0.11
3	Number of Incorrect Translation Attempts (Per task)	0.00	0.00	0.42	0.22
	Number of Incorrect Solving Attempts (Per task)	0.12	0.18	0.11	0.11
	Number of Attempts (Per task)	0.06	0.10	0.40	0.22

DC – Difficulty coefficient

To answer the research questions, the variables in Tables 6a and 6b showing student attempts in both mCSCL interaction modes (R-to-C and I-to-C) were further compared, using a paired-samples t-test to detect between-mode differences. Results in Table 7 show mean differences between the number of attempts (per task), the number of incorrect translating attempts (per task), and the number of incorrect solving attempts (per task) in the R-to-C and I-to-C interaction modes, with the corresponding Cohen effect size. In addition to the overall results, the table shows the comparison results according to the difficulty coefficients. The results indicate that students had statistically significantly more attempts per task in the I-to-C interaction mode compared to the R-to-C interaction mode ($t(32) = 3.527$, $p < 0.001$), and statistically significantly fewer incorrect solving attempts in the I-to-C interaction mode compared to the R-to-C interaction mode ($t(32) = –2,432$, $p < 0.05$). A possible explanation for the inverse statistically significant difference with respect to the total number of attempts and incorrect solving attempts is that working in the R-to-C interaction mode results in more errors, although students do not attempt to complete as many tasks as in the I-to-C interaction mode.

Table 7

Mean differences and Cohen effect size between the R-to-C and I-to-C interaction modes (N = 33 students).

DC	Variable	Mean difference between R-to-C and I-to-C interaction modes
1	Number of Attempts (Per task)	0.022 (*d*=0.22)
	Number of Incorrect Translation Attempts (Per task)	0.068 (*d* =0.35)
	Number of Incorrect Solving Attempts (Per task)	0.175** (*d* =0.81)
2	Number of Attempts (Per task)	-0.118** (*d* =0.95)
	Number of Incorrect Translation Attempts (Per task)	-0.094 (*d* =0.67)
	Number of Incorrect Solving Attempts (Per task)	-0.021 (*d* =0.23)
3	Number of Attempts (Per task)	-0.338** (*d* =2.0)
	Number of Incorrect Translation Attempts (Per task)	-0.395**
	Number of Incorrect Solving Attempts (Per task)	-0.002 (*d* =0.01)
all	Number of Attempts (Per task)	-0.071** (*d*=1.30)
	Number of Incorrect Translation Attempts (Per task)	-0.066 (*d*=0.39)
	Number of Incorrect Solving Attempts (Per task)	0.106* (*d*=0.45)

DC – Difficulty coefficient

The detailed analysis according to task difficulty coefficients revealed that there was a statistically significant difference of a mean of 0.175 between the R-to-C and I-to-C interaction modes only for the incorrect solving attempts variable in the easiest tasks (DC = 1, N = 31 tasks) ($t(30) = 3.205$, $p < 0.001$). There were no statistically significant differences between tasks with medium difficulty coefficients in the incorrect solving attempts or in incorrect translating attempts (DC = 2). There was a statistically significant difference of M = –0.395 between the R-to-C and I-to-C interaction modes for the incorrect translating attempt variable (DC = 3, N = 14 tasks) ($t(13) = –7.555$, $p < 0.001$).

During the study, the student groups in the R-to-C interaction mode were composed of three members; the groups in the I-to-C interaction mode had two members. Due to the DBR methodology of the project design and implementation, the checker role used in the R-to-C interaction mode was found to be superfluous, so the role was removed in the subsequent DBR iteration, and was not used in the I-to-C interaction mode. Therefore, the analysis presented in this section was conducted at the individual student level, and examined attempts made by individual students, and not by the groups of students, and does not consider attempts made by the students in the checker role in the R-to-C interaction mode.

5.2. Analysis of interaction

In addition to the quantitative data analysis, qualitative data analysis can be used to show how tasks with different difficulties affect students' performance in providing correct solutions in the R-to-C and I-to-

C interaction modes. In this study, researchers observed interactions between students while the latter were solving tasks and discussing their proposed translations (formulas) and calculations.

In the I-to-C interaction mode, collaboration is encouraged with a feedback message from the system indicating that someone has made a mistake. As indicated in the transcript in Table 8, students may need several attempts to reach the correct solution for a certain subtask, because the collaboration encouraged by the system does not necessarily lead to the correct solution. During the first attempt, student 1, certain that his translation “12 + 5” was correct, persuaded the other student to enter “12 + 5” as a solution. Without considering that this solution could be incorrect, and without argumentation for how he came up with this solution, student 1 did not contribute to solving the subtask. Student 2 was passive, and without further discussion, replaced his correct solution with the incorrect one. During the second attempt, the group members were more engaged, thus indicating that the encouraged collaboration led to a successful solution.

Table 8

Transcript of interaction in the I-to-C interaction mode.

Task: Jenny has 12 crayons. Paul has 5 crayons more than Jenny. How many crayons do they have all together?				
Activity		Student submissions		Feedback from the system
Translating	Attempt 1	Student 1: 12+5	Student 2: 12+12+5	Incorrect! Discuss your solutions and try again.
	Encouraged collaboration	When student 1 saw that someone's solution is incorrect, he convinced student 2 to enter 12+5.		
	Attempt 2	Student 1: 12+5	Student 2: 12+5	Incorrect! Discuss your solutions and try again.
	Encouraged collaboration	When student 1 saw that his solution was incorrect, he suggested that they read the task more carefully. Student 2 pointed out that Paul (the name in the task) did not have just 5 crayons, because the word problem says: “Paul has 5 crayons more than Jenny.” He explained that this meant the number of Paul’s crayons should be calculated as the sum of Jenny’s crayons and the number 5 (12 + 5). After a short contemplation, student 1 concluded that the equation should have three numbers: one denoting Jenny’s crayons, and the other two denoting the number of Paul’s crayons, exactly as student 2 indicated in his first task completion attempt.		
	Attempt 3	Student 1: 12+12+5	Student 2: 12+12+5	Correct!
Solving	Attempt 1	Student 1: 19	Student 2: 29	Incorrect! Discuss your solutions and try again.
	Encouraged collaboration	When student 2 saw that someone’s solution was incorrect, he advised student 1 to pay more attention while summing the tens of the given numbers.		
	Attempt 2	Student 1: 29	Student 2: 29	Correct!

In the R-to-C interaction mode, the system encourages collaboration only at the very end, after all group members have submitted the solutions of their assigned subtasks, and in case at least one of the solutions is incorrect. However, students can spontaneously decide to help their group members in solving their subtasks (they have the opportunity for emergent collaboration). Such a case is shown in the transcript in Table 9, where the students in the group provided help to their peer in the translator role who was struggling with translating the given problem into a mathematical equation during the first attempt. The feedback the struggling student received after the first attempt also helped the student in the checker role to become aware of the mistake made by the student in the translator role. During the second attempt, the group members were more engaged, and emergent collaboration was observed on two occasions.

Table 9

Transcript of the interaction in the R-to-C interaction mode.

Task: Jenny has 12 crayons. Paul has 5 crayons more than Jenny. How many crayons do they have all together?”			
Attempt number	Activity	Student submission	Feedback from the system
1	Emergent collaboration	none	
	Translation	Translator: 12+5	
	Emergent collaboration	none	
	Solving	Solver: 17	
	Emergent collaboration	none	
	Checking	Checker: Correct (OK)	Incorrect! Discuss your solutions and try again.
	Encouraged collaboration	The translator and the solver were first convinced that they had solved their subtasks correctly, but the solver, after thinking about the task more thoroughly, advised the translator to read the problem more carefully.	
2	Emergent collaboration	The solver noticed that the translator was struggling with representing the given problem with a mathematical equation, so he tried hard to explain the problem by reading the task out loud and using his fingers. The solver pointed out that the text of the task did not just say “Paul has 5 crayons” but “5 crayons more than Jenny”. Therefore, to calculate how many crayons Paul has, it is necessary to increase the number of Jenny’s crayons by 5. He needed to repeat this claim several times before the translator realized that the total number of crayons could be calculated by adding number of Paul’s crayons (12 + 5) to the number of Jenny’s crayons (12).	
	Translation	Translator: 12+5+12	
	Emergent collaboration	Translator noticed that solver is having problems with adding three numbers, so he gave him a hint to first break numbers into tens and ones.	
	Solving	Solver: 29	
	Emergent collaboration	none	
	Checking	Checker: Correct (OK)	Correct!

6. Discussion

6.1. Comparing the two mCSCL interaction modes

As part of the learning activity design, the study presented two interaction modes: the R-to-C interaction mode and the I-to-C interaction mode. The students made considerably more attempts to solve the tasks in the I-to-C interaction mode (without roles) compared to the R-to-C interaction mode (with roles). This is the result of the interaction mode design, in which students in the I-to-C interaction mode spent more time working individually, and engaged in group interaction when errors occurred, and when explicitly prompted by the mCSCL system. Students in the I-to-C interaction mode made fewer errors than the students in the R-to-C interaction mode in the process of completing the mCSCL tasks, despite making more task attempts. This result indicated the I-to-C interaction mode with no roles was able to leverage group support in completing the tasks better.

More detailed analysis of the tasks in terms of the translations and calculations submitted by the students during group work showed that the students working in the I-to-C interaction mode made statistically significantly fewer incorrect attempts for the easiest tasks than the students working in the R-to-C interaction mode. There was no difference for medium-level task difficulty, while the students in the R-to-C interaction mode with roles had fewer incorrect attempts when they worked on the most difficult tasks. Such results indicated that the use of roles in mCSCL might be suitable for tasks of greater difficulty. As the study results indicated a statistical difference in the incorrect solving attempts between the examined interaction modes, role-based group work might be less suitable for use with mathematical problems that require calculations.

The treatment conditions in the second DBR cycle of this study were different from the conditions in the first DBR cycle in terms of the number of group members, technology design, and task content. Although the analysis of the number of (incorrect) task attempts was conducted at the individual level, and not at the group level, the difference in the number of group members in the explored interaction modes certainly represent a limitation of this study.

Several changes were made in the technology design, including introducing synchronization, sequencing, and state preservation support, in the second DBR cycle, leading to more engagement in the mCSCL activities, and more seamless completion of tasks in the I-to-C interaction mode. To account for that, the analysis as part of this study was conducted per task, possibly moderating the higher number of tasks completed by the students.

In addition to the changes in technology, the content taught changed between conditions due to the repeated-measures study design. The first subtask of translating word problems (translating the text into a formula) did not differ between the two cycles. Because there were differences in the second subtask, where the students were supposed to perform different kinds of mathematical operations, tasks were labeled with difficulty coefficients ranging from 1 to 3 with the help of the teachers. The rules took into account the complexity of the sentences that described the problem and the difficulty of the calculation that must be performed to solve the problem. The difficulty of the calculation was estimated based on the extent to which the students practiced certain types of calculations with their teachers during previous in-class lessons that occurred before the intervention.

6.2. Experiences gained in the mCSCL technology design

For the purpose of this study, a custom mCSCL system was developed which allowed for flexibility in designing and deploying the solution for collaborative mathematics learning. This system relied on several technology design sub-elements that must be aligned to be able to work with minimal delays, and with a good performance. The group formation sub-element randomly generates groups, or utilizes students' background information to create groups of students according to the input parameters. Timely transfer of the data, which ensures that the users do not notice any delays, from the group formation and role assignment sub-element to the task and content distribution sub-element plays a crucial role in the initial task distribution process, in which the right students get the right task content in an adequate (small) amount of time. Fig. 5 shows students participating in the study activities by working at their desks (top picture), and leveraging the mobile system design in creating their personal space to complete the tasks (bottom pictures).

Fig. 5. Students completing tasks at their desks (top) and students leveraging mobility in completing the tasks (bottom).

In synchronous mCSCL learning environments, immediate knowledge exchange between learners should be encouraged (Vuopala, Hyvönen, & Järvelä, 2016). Therefore, open-ended designs with inadequate levels of structure are not always suitable, which was reported by Tan and So (2013). Content used in mCSCL activities should contribute to structuring the synchronous interaction process (which in the case of mCSCL matches an interaction pattern supported by the system), along with ensuring that the task is visually adapted for representation on a mobile device.

6.3. Strengths and limitations

This study further contributes to the research gap identified by Strijbos et al. (2004), who indicated that although collaboration essentially entails interaction, the impact of the interaction process on learning is usually explained in retrospect, by examining whether learning outcomes were affected by the observed interaction. Thus, the contribution of this study pertains to a process-oriented approach that emphasizes the level of pre-structuring in the context of younger participants, who need more guidance at the micro-level to optimally benefit from working on the task (Carmien, Kollar, Fischer, & Fischer, 2007). The study presented two learning contexts and conditions in which two interaction designs were compared, to ascertain how they affected the collaboration process and outcomes: (1) the R-to-C design with role-based scaffolding and task distribution and (2) the I-to-C design with no task distribution, and where students complete parts of the task individually and then negotiate their solutions, to progress through the activity. The collaborative script for the I-to-C interaction mode was similar to Nussbaum, Alvarez, McFarlane, Gomez, Claro, and Radovic's (2009) collaborative scaffolding script. In addition, in both approaches, the success of group work during the synchronous mCSCL activity depended on the engagement level of the group members. The process of reaching consensus in the I-to-C interaction mode is less structured compared to collaborative scaffolding, because discussions among group members are neither guided by the mCSCL system nor by the teacher, who, according to Nussbaum et al. (2009), also plays an important role in ensuring fruitful collaboration. Conversely, the process of task solving in the I-to-C interaction mode serves as a mediation mechanism. Instead of the open tasks used in collaborative scaffolding, students are supposed to solve a structured sequence of subtasks (which can be automatically evaluated by the mCSCL system), so consensus should be reached only for a small part of the original problem. In this work, we proposed an alternative script for the R-to-C interaction mode, where group members worked on different aspects of the task. Our contribution was to explore more designs of structuring group interaction in small-group tasks. In particular, we iterated the design of the two scripts of the I-to-C and R-to-C interaction modes, using a design-based research approach, and compared the outcomes of these two scripts in relation to collaboration tasks with different complexity.

The study was implemented using the design-based research approach, and took place in real classroom settings. One of the main advantages of this approach was the collaboration between the researchers and the practitioners that guided the development of the mCSCL system. This approach enabled the identification of necessary adjustments of the learning activity design and the technology design to the real educational environment that happened during the DBR cycles. Due to utilization of such a research model, this study had the following limitations: small sample size, the application of mechanisms of random group formation, differing numbers of group members across conditions, possible residual effects, difference in the lesson content, and the use of teachers' subjective criteria for assigning difficulty coefficients to tasks.

The small sample size possibly reduced the potential for generalization of the study results, while the random grouping mechanisms might have resulted in uneven group structures. Although the task attempts were analyzed at the individual student level, and not at the group level, differences in the number of group members participating in mCSCL activities in the two modes (three members in the R-to-C interaction mode versus two members in the I-to-C interaction mode) could have affected the results in many ways. According to Melero, Hernández-Leo, and Manatunga (2015), in the context of group mCSCL activities with four and five students, group size does not affect individuals' performance, but students in groups with fewer members express higher levels of engagement. Thus, members of dyads might have been more engaged in helping their peers than members of triads, which could have resulted in fewer incorrect task attempts in the I-to-C interaction mode. This is in line with the work of Schneider, Valdes, Temple, Shen, and Shaer (2013), who reported that by having students work in triads instead of dyads, groups are more likely to have one student who does not contribute to the group work (the so-called "free rider"). However, the group interactions could be related to the number of possible relationships by pairs (Akcaoglu & Lee, 2016), so the triads might have had more opportunities for successful collaboration (resulting in fewer incorrect task attempts in the R-to-C interaction mode), because each student, in the case of misconceptions, could get help from the two other group members. When the complexity of interactions is observed in this way, the number of possible interactions increases with the number of group members, so the difference between dyads and triads is considerably smaller than between dyads and larger groups (e.g., groups of four or five members). Nevertheless, according to Strijbos et al. (2004), the impact of group size on interaction is relative, and should be discussed with respect to the designed interaction mode and tools that support the collaboration process. The mCSCL system used in this study stimulated collaboration in dyads and triads, by prompting students when someone made a mistake, and encouraging group discussion of individual solutions. Triads in the R-to-C interaction mode were encouraged to collaborate after all group members had submitted solutions to the assigned subtasks, while dyads were encouraged to collaborate during the activity after each subtask in the I-to-C interaction mode. Groups in the context of this study were created randomly, which means that some students could have been more engaged in helping their peers than others, regardless of the number of group members, and the encouragement provided by the mCSCL system. Students in the R-to-C interaction mode had the opportunity for emergent collaboration, which, compared to the encouraged collaboration, requires higher levels of engagement from the group work participants, possibly resulting in more individual differences in the engagement levels of triads. Emergent collaboration occurs when students spontaneously decide to help their group members in solving their parts of the task. More knowledgeable peers can often provide help to others (Vygotsky, 1978; Webb & Mastergeorge, 2003), but they might be passive, and only wait for their turn to solve the assigned subtask, which results in no collaboration at all.

Possible residual effects, known to appear in the within-subjects study design, were reduced by scheduling time intervals between the digital lessons included in the study. The tasks used in the digital lessons differed: The tasks required the students have the ability to perform different mathematical operations. Attempts were made to reduce the effect of using different tasks in the digital lessons on the results by assigning difficulty coefficients to the tasks, and by comparing task attempts according to the difficulty coefficients. However, as the teachers had an important role in assigning difficulty coefficients to the tasks, the findings regarding the choice of interaction mode in relation to the difficulty of the task highly depend on the teachers' subjective criteria.

This study presents an addition to the range of technology-based solutions available today, such as educational computer games and learning applications, in terms of example designs and evidence for how they affect children's learning in the classroom. The present research indicated designs and contexts in which collaborative and role-based designs can be used for structuring group work in the early primary school mathematics classroom. The practitioner community can leverage the technology and learning activity designs presented as part of this study to create their own innovative solutions for technology-supported collaborative learning.

6.4. Conclusions

The study presented in this paper explored two modes of interaction in synchronous mCSCL activities: Role-to-Collaborative and Individual-to-Collaborative. The results showed that in the context of solving tasks in mathematics problems during mCSCL activities in lower primary school, the choice of a role-based interaction is related to the difficulty of the assigned task, in which role assignment is more suitable for tasks that are more difficult. For less demanding tasks, roles may not be needed, and less structured interaction modes in which students work individually, and discuss their solutions only in case of disagreement or misconception, could be used. This conclusion, however, depends on subjective criteria posed by the teachers who participated in determining the rules for assigning difficulty coefficients to the tasks. There can be multiple designs of even one such interaction mode. Thus, we call for more research in this space using perspectives from the learning sciences, and seeking additional explanatory mechanisms of what works for a particular context, and why.

The technology design and evolution throughout the study were dichotomous: More coordination and synchronization mechanisms were introduced to better orchestrate and scaffold the activity flow, and the synchronization mechanisms were simplified, to reduce the number of steps, and mutual approvals and confirmations. We need flexible scripts to harness the technology design, as over-scripting of the interactions will be inadequate in terms of ensuring stable and robust activity flow (i.e., some students tend to give up, leaving others deadlocked in the activity), and in terms of technology elasticity, in the case of different types of interruptions.

Practical implications arising from this study are related to the design of mCSCL learning environments that is typically done by teachers. Such designs include ensuring that the right technology is chosen to ensure specific lesson learning goals are met. Teachers may decide to convert pen-and-paper lessons into their digital counterparts, and add collaborative learning elements, if they were not present in the original lessons. While choosing designs, teachers consider the task difficulty that must be completed by the students, and choose an adequate level of pre-structuring for the lesson. Roles with more pre-structuring will be chosen for more complex mathematics tasks, where students need more guidance and scaffolds in completing their assignments, and individual work with joint discussions will be chosen for easier, shorter, and more dynamic learning scenarios, which might easily replace standard drill-and-practice lessons, and bring more value as collaboration in classrooms emerges.

Future work will be continued in new DBR cycles, with the aim of improving mathematics learning. It will include the introduction of alternate modes of group formation, such as homogeneous and heterogeneous group formation. Future studies will explore how group formation affects group work processes and interactions in mCSCL activities exhibited by students. Other themes to be explored are the use of learning analytics algorithms to ascertain students' group work profiles and types, to be subsequently used as input in adaptivity algorithms when creating and supporting groups, and choosing an adequate level of pre-structuring for a specific learning activity.

References

Akcaoglu, M., & Lee, E. (2016). Increasing Social Presence in Online Learning through Small Group Discussions. *The International Review of Research in Open and Distributed Learning*, *17*(3). https://doi.org/10.19173/irrodl.v17i3.2293

Almeida, F. (2018). Strategies to Perform a Mixed Methods Study. *European Journal of Education Studies*, *5*(1), 137–151. https://doi.org/10.5281/ZENODO.1406214

Alvarez, C., Alarcon, R., & Nussbaum, M. (2011). Implementing collaborative learning activities in the classroom supported by one-to-one mobile computing: A design-based process. *Journal of Systems and Software*, *84*(11), 1961–1976. Retrieved from http://www.sciencedirect.com/science/article/pii/S0164121211001865

Amiel, T., & Reeves, T. (2008). Design-based research and educational technology: Rethinking technology and the research agenda. *Journal of Educational Technology & Society*, *11*(4), 29. Retrieved from http://www.jstor.org/stable/jeductechsoci.11.4.29

Attard, C. (2017). Introducing iPads into primary mathematics classrooms: Teachers' experiences and pedagogies. In *Educational Leadership and Administration: Concepts, Methodologies, Tools, and Applications* (pp. 660–680). IGI Global.

Bakker, A., & van Eerde, D. (2015). An Introduction to Design-Based Research with an Example From Statistics Education. In C. Bikner-Ahsbahs, A. Knipping & N. Presmeg (Eds.), *Approaches to Qualitative Research in Mathematics Education* (pp. 429–466). Springer, Dordrecht. https://doi.org/10.1007/978-94-017-9181-6_16

Barab, S., & Squire, K. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences*. https://doi.org/10.1207/s15327809jls1301_1

Barlow, D. H., & Hayes, S. C. (1979). Alternating treatments design: one strategy for comparing the effects of two treatments in a single subject. *Journal of Applied Behavior Analysis*, *12*(2), 199–210. https://doi.org/10.1901/jaba.1979.12-199

Boticki, I, Looi, C. K., & Wong, L. (2011). Supporting mobile collaborative activities through scaffolded flexible grouping. *Journal of Educational Technology & Society*, *14*(3), 190–202. Retrieved from http://www.jstor.org/stable/jeductechsoci.14.3.190

Boticki, Ivica, Looi, C., & Wong, L. (2010). Doing collaboration and learning fractions with mobile devices. In *Proceedings of 14th global chinese conference on computers in education* (pp. 9–15).

Bower, M., Dalgarno, B., Kennedy, G. E., Lee, M. J. W., & Kenney, J. (2015). Design and implementation factors in blended synchronous learning environments: Outcomes from a cross-case analysis. *Computers and Education*, *86*, 1–17. https://doi.org/10.1016/j.compedu.2015.03.006

Carmien, S., Kollar, I., Fischer, G., & Fischer, F. (2007). The interplay of internal and external scripts. *Scripting Computersupported Communication of Knowledgecognitive Computational and Educational Perspectives*, (17), 303–324. https://doi.org/10.1007/978-0-387-36949-5_17

Chen, J., Wang, M., Kirschner, P. A., & Tsai, C.-C. (2018). The Role of Collaboration, Computer Use, Learning Environments, and Supporting Strategies in CSCL: A Meta-Analysis. *Review of Educational Research*, 003465431879158. https://doi.org/10.3102/0034654318791584

Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K-12 classrooms: A meta-analysis. *Educational Research Review*, *9*, 88–113. https://doi.org/10.1016/j.edurev.2013.01.001

Chiu-Pin, L., Shao, Y., & Lung-Hsiang, W. (2011). The impact of using synchronous collaborative virtual tangram in children's geometric. *TOJET: The Turkish Online Journal of Educational Technology*, *10*(2), 250–258.

Davidian, M., & Giltinan, D. M. (2003). Nonlinear models for repeated measurement data: An overview and update. *Journal of Agricultural, Biological, and Environmental Statistics*, *8*(4), 387–419. https://doi.org/10.1198/1085711032697

Delić, A., Domančić, M., Vujević, P., Drljević, N., & Botički, I. (2014). AuGeo: A geolocation-based augmented reality application for vocational geodesy education. In *Proceedings Elmar - International Symposium Electronics in Marine* (pp. 289–292). https://doi.org/10.1109/ELMAR.2014.6923372

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative Learning Cognitive and Computational Approaches* (pp. 1–19). Oxford: Elsevier. https://doi.org/10.1.1.167.4896

Dillenbourg, P., Baker, M. J., Blaye, A., & O'Malley, C. (1995). The evolution of research on collaborative learning. In E. Spada & P. Reiman (Eds.), *Learning in Humans and Machine: Towards an interdisciplinary learning science* (pp. 189–211).

Dillenbourg, P., & Tchounikine, P. (2007). Flexibility in macro-scripts for computer-supported collaborative learning. *Journal of Computer Assisted Learning*, *23*(1), 1–13. https://doi.org/10.1111/j.1365-2729.2007.00191.x

Fidas, C., Komis, V., Tzanavaris, S., & Avouris, N. (2005). Heterogeneity of learning material in synchronous computer-supported collaborative modelling. *Computers and Education*, *44*(2), 135–154. https://doi.org/10.1016/j.compedu.2004.02.001

Gao, F., & Li, L. (2017). Examining a one-hour synchronous chat in a microblogging-based professional development community. *British Journal of Educational Technology*, *48*(2), 332–347. https://doi.org/10.1111/bjet.12384

Greenwald, A. G. (1976). Within-subjects designs: To use or not to use? *Psychological Bulletin*, *83*(2), 314–320. https://doi.org/10.1037/0033-2909.83.2.314

Haara, F. O., Bolstad, O. H., & Jenssen, E. S. (2017). Research on Mathematical Literacy in Schools--Aim, Approach and Attention. *European Journal of Science and Mathematics Education*, *5*(3), 285–313.

Hall, B. M. (2014). Designing Collaborative Activities to Promote Understanding and Problem-Solving. *International Journal of E-Collaboration (IJeC)*, *10*(2), 55–77.

Järvelä, S., Kirschner, P. A., Panadero, E., Malmberg, J., Phielix, C., Jaspers, J., Koivuniemi, M., & Järvenoja, H. (2014). Enhancing socially shared regulation in collaborative learning groups: designing for CSCL regulation tools. *Educational Technology Research and Development*, *63*(1), 125–142. https://doi.org/10.1007/s11423-014-9358-1

Kim, I.-H. (2014). Development of reasoning skills through participation in collaborative synchronous online discussions. *Interactive Learning Environments*, *22*(4), 467–484. https://doi.org/10.1080/10494820.2012.680970

Kooloos, J. G. M., Klaassen, T., Vereijken, M., Van Kuppeveld, S., Bolhuis, S., & Vorstenbosch, M. (2011). Collaborative group work: Effects of group size and assignment structure on learning gain, student satisfaction and perceived participation. *Medical Teacher*, *33*(12), 983–988. https://doi.org/10.3109/0142159X.2011.588733

Koschmann, T. (2002). Dewey ' s Contribution to the Foundations of CSCL Research. *Proceedings of CSCL 2002*, (1999), 17–22. https://doi.org/10.3115/1658616.1658618

Lajoie, S. P., Lee, L., Poitras, E., Bassiri, M., Kazemitabar, M., Cruz-Panesso, I., Hmelo-Silver, C., Wiseman, J., Chan, L. K., & Lu, J. (2015). The role of regulation in medical student learning in small groups: Regulating oneself and others' learning and emotions. *Computers in Human Behavior*, *52*, 601–616. https://doi.org/10.1016/j.chb.2014.11.073

Lawal, B. (2014). Repeated Measures Design. In *Applied Statistical Methods in Agriculture, Health and Life Sciences* (pp. 697–718). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-05555-8_18

Littleton, K., & Mercer, N. (2013). *Interthinking: Putting Talk to Work*. London: Routledge.

Looi, C. K., & Wong, L.-H. (2018). Mobile Computer-Supported Collaborative Learning. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *The International Handbook of the Learning Sciences*.

Looi, C. K., Lim, K. F., Pang, J., Lay, A., Koh, H., Seow, P., Sun, D., Boticki, I., Norris, C. & Soloway, E. (2016). Bridging formal and informal learning with the use of mobile technology. In C. S. Chai, C. P. Lim, & C. M. Tan (Eds.), *Future learning in primary schools* (pp. 79–96). Singapore: Springer. https://doi.org/10.1007/978-981-287-579-2

López, X., Valenzuela, J., Nussbaum, M., & Tsai, C.-C. (2015). Some recommendations for the reporting of quantitative studies. *Computers & Education*, *91*, 106–110. https://doi.org/10.1016/J.COMPEDU.2015.09.010

Luckin, R., Baines, E., Cukurova, M., Holmes, W., & Mann, M. (2017). *Solved! Making the case for collaborative problem-solving*. London, UK. Retrieved from http://oro.open.ac.uk/50105/1/solved-making-case-collaborative-problem-solving.pdf

Marcos-García, J.-A., Martínez-Monés, A., & Dimitriadis, Y. (2015). DESPRO: A method based on roles to provide collaboration analysis support adapted to the participants in CSCL situations. *Computers & Education*, *82*, 335–353. https://doi.org/10.1016/J.COMPEDU.2014.10.027

Melero, J., Hernández-Leo, D., & Manatunga, K. (2015). Group-based mobile learning: Do group size and sharing mobile devices matter? *Computers in Human Behavior*, *44*, 377–385. https://doi.org/10.1016/J.CHB.2014.11.078

Nachmias, R., Mioduser, D., Oren, A., & Ram, J. (2000). Web-supported emergent-collaboration in higher education courses. *Ournal of Educational Technology & Society*, *3*(3), 94–104. Retrieved from https://www.jstor.org/stable/pdf/jeductechsoci.3.3.94.pdf

Nussbaum, M., Alvarez, C., McFarlane, A., Gomez, F., Claro, S., & Radovic, D. (2009). Technology as small group face-to-face Collaborative Scaffolding. *Computers & Education*, *52*(1), 147–153. https://doi.org/10.1016/J.COMPEDU.2008.07.005

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016). Comparing Tablets and PCs in teaching Mathematics: An attempt to improve Mathematics Competence in Early Childhood Education Learning History through Location-Based Games View project Support Distance Learning Program in Mathematics View project. *Preschool and Primary Education*, *4*. https://doi.org/10.12681/ppej.8779

Pozzi, F., Hofmann, L., Persico, D., Stegmann, K., & Fischer, F. (2011). Structuring CSCL Through Collaborative Techniques and Scripts. *International Journal of Online Pedagogy and Course Design*, *1*(4), 39–49. https://doi.org/10.4018/ijopcd.2011100103

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. In *Journal of the Learning Sciences* (Vol. 13, pp. 337–386). https://doi.org/10.1207/s15327809jls1303_4

Schneider, B., Valdes, C., Temple, K., Shen, C., & Shaer, O. (2013). Comparing "In the Wild" Studies with Laboratory Experiments: A Case of Educational Interactive Tabletops. In *The Computer Supported Collaborative Learning (CSCL) Conference 2013, Volume 2* (pp. 351–352).

Schwaighofer, M., Vogel, F., Kollar, I., Ufer, S., Strohmaier, A., Terwedow, I., Ottinger, S., Reiss, K., & Fischer, F. (2017). How to combine collaboration scripts and heuristic worked examples to foster mathematical argumentation – when working memory matters. *International Journal of Computer-Supported Collaborative Learning*, *12*(3), 281–305. https://doi.org/10.1007/s11412-017-9260-z

Siqin, T., van Aalst, J., & Chu, S. K. W. (2015). Fixed group and opportunistic collaboration in a CSCL environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(2), 161–181. https://doi.org/10.1007/s11412-014-9206-7

Strijbos, J.-W., & Weinberger, A. (2010). Emerging and scripted roles in computer-supported collaborative learning. *Computers in Human Behavior*, *26*(4), 491–494. https://doi.org/10.1016/J.CHB.2009.08.006

Strijbos, J. W., Martens, R. L., & Jochems, W. M. G. (2004). Designing for interaction: Six steps to designing computer-supported group-based learning. *Computers and Education*, *42*(4), 403–424. https://doi.org/10.1016/j.compedu.2003.10.004

Sun, D., Looi, C.-K., & Xie, W. (2014). Collaborative Inquiry with a Web-Based Science Learning Environment: When Teachers Enact It Differently. *EDUCATIONAL TECHNOLOGY & SOCIETY*, *17*(4), 390–403.

Suthers, D. D., Dwyer, N., Medina, R., & Vatrapu, R. (2010). A framework for conceptualizing, representing, and analyzing distributed interaction. *International Journal of Computer-Supported Collaborative Learning*, *5*(1), 5–42. https://doi.org/10.1007/s11412-009-9081-9

Szewkis, E., Nussbaum, M., Rosen, T., Abalos, J., Denardin, F., Caballero, D., Tagle, A. & Alcoholado, C. (2011). Collaboration within large groups in the classroom. *International Journal of Computer-Supported Collaborative Learning*, *6*(4), 561–575. https://doi.org/10.1007/s11412-011-9123-y

Tan, E., & So, H.-J. (2013). Students' capacity for autonomous learning in an unstructured learning space on a mobile learning trail. In *Computer-Supported Collaborative Learning Conference, CSCL* (Vol. 2).

The Design-Based Research Collective. (2003). Design-Based Research: An Emerging Paradigm for Educational Inquiry. *Educational Researcher*, *32*(1), 5–8. https://doi.org/10.3102/0013189X032001005

Vuopala, E., Hyvönen, P., & Järvelä, S. (2016). Interaction forms in successful collaborative learning in virtual learning environments. *Active Learning in Higher Education*, *17*(1), 25–38. https://doi.org/10.1177/1469787415616730

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. *Cambridge, MA: Harvard University Press.*

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23. https://doi.org/10.1007/BF02504682

Webb, N. M., & Mastergeorge, A. (2003). Promoting effective helping behavior in peer-directed groups. *International Journal of Educational Research*, *39*, 73–97. https://doi.org/10.1016/S0883-0355(03)00074-0

Zurita, G., & Nussbaum, M. (2004). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education*, *42*(3), 289–314. https://doi.org/10.1016/j.compedu.2003.08.005

Zurita, G., & Nussbaum, M. (2007). A conceptual framework based on Activity Theory for mobile CSCL. *British Journal of Educational Technology*, *38*(2), 211–235. https://doi.org/10.1111/j.1467-8535.2006.00580.x

Acknowledgements

This work has been fully supported by the Croatian Science Foundation under the project UIP-2013-11-7908. The authors would like to thank the staff of Primary School Trnjanska for their enthusiastic partnership in the realization of the study. We would also like to thank Mia Carapina for the participation in the project activities occurring prior to the presented study.

Research highlights:

Study on Role-to-Collaborative and Individual-to-Collaborative interaction

R-to-C interaction includes task and subtask distribution

In I-to-C interaction, students work individually and negotiate their solutions

R-to-C interaction is recommended for more and I-to-C for less difficult tasks

mCSCL design should consider state preservation, synchronization and feedback