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Mobile computer-supported collaborative learning for mathematics: A scoping review

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Abstract
This study conducted a scoping review of publications in mobile Computer-Supported Collaborative Learning for mathematics. Papers published between 2007 and 2021 inclusive were retrieved from research databases to achieve this goal. Twenty-eight papers met the inclusion–exclusion criteria of the study. It was shown that two papers were published on average over the last 15 years. The majority of the papers were published in peer-reviewed journals. Intending to improve mathematics pedagogy, the two most popular math mCSCL contents were general elementary mathematics and geometry. The review also revealed that math mCSCL benefited elementary students the most. The majority of math mCSCL software was custom-built and designed for synchronous sharing. The research designs were consistent with the existing reviews. The effects on social and attitude skills, as well as mathematics competency, were the most frequently mentioned benefits of math mCSCL. Usability issues, device unfamiliarity, inability to track students' activities, synchronization, and coordination concerns were among the problems highlighted during the implementation of math mCSCL. The implications for future research are discussed.

Keywords Collaboration · Geometry · Mobile learning · Review · Software

1 Introduction

Computer-supported collaborative learning (CSCL) is defined as "the activity of peers interacting with one another for the purpose of learning, with the assistance of information and communication technologies (ICT)" (Suthers & Seel, 2012, p.

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719). ICTs include the World Wide Web, mobile phones, desktop computers, laptop computers, and other handheld devices (Suthers & Seel, 2012). In general, CSCL is beneficial for individual learning because of its adaptive features (Sung et al., 2017). It is also known to have a desirable impact on students' motivation, self-efficacy, and attitudes (Jeong et al., 2019). Different studies consistently found the positive effects of CSCL on students' mathematics (e.g., Lin et al., 2011; Mullins et al., 2011), STEM (science, technology, engineering, and mathematics education) (Jeong et al., 2019), and general academic achievements (Sung et al., 2017). These studies further disclosed that it has a positive impact on the process (e.g., individual task, collaborative process), cognitive (e.g., understanding of concepts and principles, generating a design solution, critical thinking skills, course grades, unspecified achievement tests), and affective (e.g., attitudes, perceptions, motivation, interests, confidence, and satisfaction) aspects of learning.

However, CSCL has limitations in terms of mobility, flexibility, and face-to-face information sharing (Kukulska-Hulme, 2009; Wong & Looi, 2011; Zurita & Nussbaum, 2004). It also restricts elaborate communication, discussions, and explanations (Arnseth & Ludvigsen, 2006; Stanton & Neale, 2002). These limitations were addressed with the introduction of mobile devices (e.g., cell phones, smartphones, tablets, and PDAs). Mobile CSCL (mCSCL) is a subfield of CSCL in which mobile devices are used as a platform for CSCL. It can help students with collaborative learning whenever and wherever they want (Looi et al., 2010). Mobile CSCL can increase instant and simultaneous interactions among group members (Lestari et al., 2019; Parsons et al., 2012; Ryu & Parsons, 2012) without the barrier of location, time, and space (Looi et al., 2010; Song, 2014). The seamless interactions among and between team members can lead to more efficient information exchanges and an increase in problem-solving abilities (Botički et al., 2020; Santosa et al., 2020). The meta-analysis of 48 peer-reviewed journal articles and doctoral dissertations published between 2000 and 2015 confirmed that mCSCL addressed these CSCL limitations (Sung et al., 2017).

Prior reviews were conducted to determine the impact of mCSCL. These reviews, however, included all applications of mCSCL in various domain subjects (e.g., Fu & Hwang, 2018; Sung et al., 2017), which led to general insights across all domain subjects. Moreover, they focused on various fields and ignored the fact that different academic fields have different learning contexts (Fu & Hwang, 2018). There is a growing body of literature on systematic or meta-analytic reviews of mobile learning (e.g., Fu & Hwang, 2018), but very little is known about mCSCL in mathematics (subsequently referred to as math mCSCL). Conducting a scoping review to understand the current trends, nature, and coverage of mCSCL research evidence in mathematics will highlight the current state of the field and areas that may warrant further research (Munn et al., 2018).

Furthermore, it is important to understand the relevance of mCSCL in the context of mathematics learning. Mathematics is a primary driver of logical and higher-order thinking skills (Hagan et al., 2020). In a broader perspective, it serves as a tool that supports the daily activities of society (Niss, 1994). Unfortunately, mathematics has been regarded as a difficult subject (Acharya, 2017; Vitasari et al., 2010). Students develop anxiety, misleading beliefs, negative attitudes, and avoidance behavior toward mathematics because of the challenges in learning it (Chinn, 2012). Other researchers pointed out that some of these constructs (e.g., negative attitudes and math anxiety) have a negative impact on students' mathematics performance (Hagan et al., 2020; Núñez-Peña et al., 2013).

Students collaborating with their peers to solve mathematics problems may address some of these learning challenges (Mullins et al., 2011; Phelps & Damon, 1989; Summers, 2006). Educators can leverage the capabilities of mCSCL to support collaborative learning activities in mathematics and, consequently, help students learn mathematics. Students may become more motivated, develop positive beliefs and attitudes toward mathematics, learn socialization, and improve communication skills while learning in this learning environment (De Corte et al., 2002; Hurme & Järvelä, 2005). In math mCSCL, students can put together their ideas, skills, and efforts in this learning environment as they aim to complete mathematical tasks (e.g., Botički et al., 2010). Likewise, math mCSCL learning setup may create a friendly, fun, and creative learning environments for students (Dlab et al., 2020; Papadakis et al., 2016), which can minimize students' mathematics anxiety. Thus, understanding the current state of math mCSCL is important since it could inform educators, researchers, and software developers about which areas of this field are still unexplored.

This current study was conducted to fill these research gaps. To achieve this goal, a scoping review of math mCSCL was conducted to identify knowledge gaps in existing studies, potentially leading to key concepts in the advancement of mobile collaborative software in mathematics and addressing existing pedagogical issues in the use of math mCSCL. The study specifically sought to answer the following questions:

1. What are the features of the included studies in terms of publication information, instructional context, and types of mobile learning?
2. What are the methodological features of the included studies in terms of research design, sample size, age, gender, educational level, group size, group composition, duration, software packages utilized, and area of research?
3. What are the benefits of math mCSCL?
4. What are the limitations and challenges of the existing math mCSCL research?

2 Literature review

2.1 Computer-supported collaborative learning

CSCL is an interdisciplinary research field that investigates how collaborative learning, aided by technology, can improve peer interaction and group work, as well as how collaboration and technology facilitate the sharing and distribution of knowledge and expertise among community members (Jeong et al., 2019; Lipponen et al., 2004). Learners are encouraged to collaborate with their peers through CSCL, and their contributions to group success are more easily identified (Abrami & Bures, 1996). It facilitates and supports the individual and shared construction of knowledge, skills, and products (e.g., notes, conversations) (Gress et al., 2010).

It also provides immediate feedback and assessments of the individual and group members (Gress et al., 2010). Collaborations like these result in a deeper understanding of the learning materials (Jeong et al., 2019).

CSCL is based on collaborative learning, which can take many forms, including problem-based learning, inquiry learning, collaborative problem-solving strategies, design artifacts, and small group discussions (Jeong et al., 2019). Various studies have demonstrated the effectiveness of CSCL in conjunction with these learning approaches. For example, Chen et al. (2018) conducted a meta-analysis of 425 studies published between 2000 and 2016. Collaboration in CSCL has been shown to have significant positive effects on knowledge gain, skill acquisition, and student perceptions. CSCL collaboration had the greatest impact on skill acquisition (effect size = 0.64). In another study, Jeong et al. (2019) discovered that STEM CSCL had a moderate but significant effect size (0.51) on educational research. The greatest impact was on process outcomes, followed by knowledge outcomes, and finally affective outcomes. In a more recent study, Talan (2021) examined the effectiveness of CSCL on academic achievement reported in 40 studies from 2010 to 2020 and revealed that CSCL had a positive and moderate effect on academic achievement. This finding is consistent with that of Chen et al. (2018) and Jeong et al. (2019).

2.2 Mobile learning for mathematics

Two studies focused on reviewing mobile learning for mathematics. Fabian et al. (2016) examined 60 papers published between 2003 and 2012 on the use of mobile technologies in mathematics. The majority of students' attitudes toward mobile technologies for mathematics were positive. The use of these technologies increased students' engagement with one another and with learning activities. Mobile phones (25 studies) were the most commonly used mobile devices. Tablets (10 studies) also gained popularity due to their low cost. The primary focus of the reviewed literature was on elementary students, and none mentioned the involvement of college students. The intervention typically included fewer than 50 participants (29 studies) and lasted less than four weeks (24 studies). The majority of the papers looked into attitudes (32 studies), math achievements (31 studies), and engagement (32 studies).

Crompton and Burke (2017) conducted a similar study, synthesizing 36 studies published between 2000 and 2017. They found eight themes that were partially similar to the findings of Fabian et al. (2016). These themes include (a) the focus of the studies was on evaluating mobile learning, (b) the most employed research designs (i.e., case studies and experimental designs), (c) the positive effects of mLearning for mathematics on students' learning outcomes, (d) the mobile phones as the most utilized platform, (e) the most preferred research setting (i.e., elementary schools), (f) the research finding indicating that most studies did not report the specific mathematical concepts investigated, and (g) the geographical locations of researchers conducting mLearning in mathematics.

2.3 Mobile CSCL

Four systematic literature studies were conducted to determine the extent of publications in mCSCL. Song (2014) examined the methods used in mCSCL publications between 2000 and 2014. The author further determined whether these methods were effective when they were used, and what methodological issues were raised in mCSCL studies. The author also found that the studies mostly involved 10–50 participants (60%), mostly elementary students (37%), with interventions that lasted for 1 to 4 weeks (48%) and that mathematics had a low representation in the literature (17%). Besides that, mCSCL was found to be more likely to be implemented in smartphones (36%), PDAs (34%), mobile phones (14%), and tablets (8%) while experimental and quasi-experimental designs (44%) were the most employed research designs. Finally, the studies revealed that learning performance, collaborative behaviors/patterns, prior knowledge skills, student satisfaction, attitude, perception towards the system, metacognitive strategies, the process of collaborative interactions, perception of learning skills, participation, self-efficacy, and affordances and limitations of collaborative learning system/tool were the constructs measured in the investigations.

Amara et al. (2016) investigated group formation strategies in 12 studies published between 2005 and 2013. The most commonly used personal characteristics of learners were age, gender, interests, preferences, and learning background and experience (e.g., learning scores). In mCSCL, more than 20 learning behaviors were used to group students. Students were also divided into groups based on context information.

Sung et al. (2017) performed a meta-analysis of 48 peer-reviewed journal articles and doctoral dissertations published between 2000 and 2015. With an overall mean effect size of 0.516, mCSCL had an above-average effect on students' academic performance. Furthermore, the most commonly measured learning outcomes were learning achievement (66%), learning attitude (22%), and interaction (12%). College (35%) and elementary (33%) students participated in the mCSCL studies. Very few studies were conducted in mathematics (5 studies). The most common group sizes were mixed (29%) and triad (21%) whereas the intervention typically lasted for 1 to 4 weeks (33%) in a classroom setting (73%). It is also worth noting that the majority of the papers (56%) did not report the group composition. Despite being in a collaborative learning setup, students were rewarded individually (81%).

Finally, Peramunugamage, Ratnayake, and Karunanayaka (2022) recently conducted a systematic review of 48 published papers on mobile collaborative learning for engineering education. The most widely published topics in collaborative learning for engineering education were mobile and agent-based application development. The most commonly used research designs were mixed methods, case studies, and experimental. The authors also reported the study sample sizes, which ranged from 26 to 1,121 participants.

2.4 Mathematics mCSCL

Collaborative learning (CL) has been shown to improve students' mathematics learning (Mullins et al., 2011). Mobile devices can help support CL activities in mathematics, resulting in a learning environment that engages and motivates students to learn the course materials. Math mCSCL could help students learn real-world applications through situational learning (e.g., Sollervall & Milrad, 2012; Spikol & Eliasson, 2010). Students are able to socialize and learn to negotiate when solving mathematics problems using mobile devices (e.g., Boticki et al., 2012). Handheld devices, unlike personal computers, can support face-to-face communications, allowing students to work collaboratively and understand the situations of group members (e.g., Järvenoja et al., 2020; Laru et al., 2015; Roschelle et al., 2010). Despite the efforts of math mCSCL researchers to contribute to the literature, its current state is inadequate to enable investigators to arrive at anything conclusive about it.

3 Methodology

This study followed the PRISMA methodological guidance in conducting scoping reviews (Tricco et al., 2018). The eligibility criteria and study collection methods are established and discussed in the following sections (Hernandez et al., 2021).

3.1 Eligibility criteria

All original conference papers, journal articles, and dissertation papers on mobile collaborative mathematics learning were taken into account. Only articles written in English were considered. The use of collaborative mobile mathematics learning software at all levels of education (elementary, secondary, college, and graduate school) was considered. Only empirical studies involving student collaboration were included in the study. The study did not include work in progress, editorials, book chapters, or position papers.

3.2 Information sources and search strategy

A comprehensive search of the published studies was conducted from January 4, 2022, to June 4, 2022. EBSCO Discovery Service, Google Scholar, Scopus, and search article functions of journal publishers served as the platforms to search for published studies. EBSCO Discovery Service is "the only discovery service that properly leverages native MeSH (Medical Subject Headings), CINAHL, APA, and other thesauri and controlled vocabularies to connect these different terminologies" (EBSCO Information Services, 2022). EBSCO Discovery Service is a keyword-enabled search interface to access peer-reviewed (e.g., journal articles, conference papers, dissertations, thesis) and non-peer-reviewed (e.g., books, e-books, magazines, etc.) articles. It retrieves articles from EBSCOhost. The latter is a database of high-quality articles licensed from reputable publishers (EBSCOhost, 2022). Meanwhile, Scopus is "the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings" (Elsevier, 2022).

The literature search was conducted using an advanced search with an “AND” condition and covered the years 2007 to 2021 inclusive. “Mobile collaborative learning” and “mathematics” were used as the keywords in EBSCOhost. The year 2007 was selected as the starting point because it was the year that the first Wi-Fi-enabled smartphone was released (Fon, 2022). Google Scholar and Scopus were also utilized to ensure wider coverage of the literature. The keywords “mobile collaborative learning for mathematics” and “mathematics m-learning” were used to search for the articles in Google Scholar and Scopus. Only the first ten pages of Google Scholar search results were selected since articles on the eleventh and subsequent pages were deemed irrelevant. The citing articles of the search results were also examined on Google Scholar to identify potentially relevant articles. Date and topic filters were applied in Google Scholar to meet this goal. Lastly, the search article functions of the top five journal publishers (i.e., Elsevier, Springer, Wiley, Taylor & Francis, and Sage) were also utilized to search for the articles (Kim & Park, 2020). Searched results from these journal publishers confirm the results of the articles found in EBSCO Discovery Service, Scopus, and Google Scholar.

3.3 Study selection

The PRISMA diagram for this study is shown in Fig. 1. It shows the detailed process of the scoping review carried out in this study. All articles in collaborative mobile learning for mathematics at all education levels were selected from the databases. Abstracts were reviewed to see if the contents of the papers met the inclusion criteria. Two of the researchers in this study independently screened the abstracts. In the event of a disagreement, the researchers deliberate until they reach an agreement.

3.4 Data analysis

The data was analyzed using mean, standard deviation, frequency count, percentage, and range. The math mCSCL types were based on Lai and Hwang’s (2015) ten mobile learning classifications. Two of the authors of this study independently coded the types of the math mCSCL. In the event of a disagreement, the researchers deliberate until they reach an agreement. Meanwhile, the benefits of math mCSCL were classified based on the learning outcomes reported in the studies.

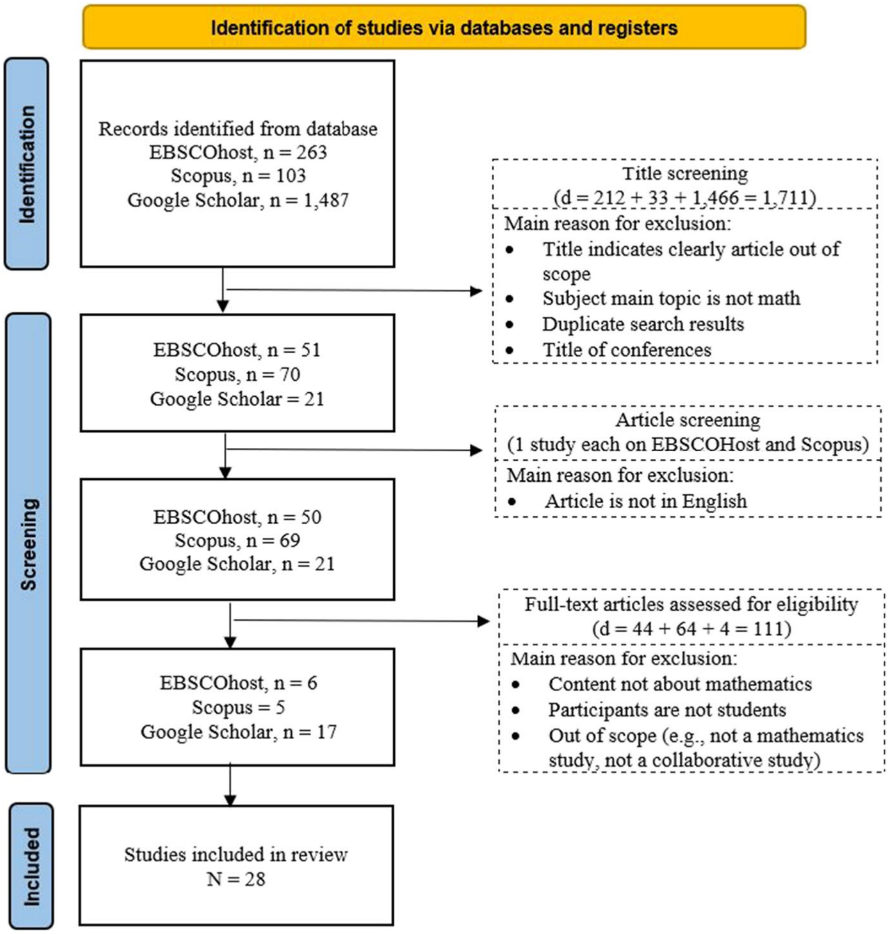


Fig. 1 Studies Included in the Review are based on the PRISMA protocol

4 Results

4.1 RQ1. Features of the studies included

4.1.1 Publication information

Table 1 shows that the publication is dispersed across all of the publication titles. There are a total of 28 distinct publication titles. WMUTE, one of the first conferences devoted to mobile learning, had the most published articles (n=4). Its first publication was in 2002 (Hoppe et al., 2002). The majority of the publications (17 out of 28 articles; 61% of the total) were journal articles.

On average, there were about 1.9 papers in a year published from 2007 to 2021 (Table 2). No papers were published in 2009, 2013, and 2017. The studies

Table 1 Publication Information

Publication Title	Publication Type	Number of Articles
IEEE International Conference on Wireless, Mobile, and Ubiquitous Technology in Education	Conference	4
Computers & Education	Journal	2
International Journal of Mobile Learning and Organisation	Journal	2
TechTrends	Journal	1
British Journal of Educational Technology	Journal	1
Education Sciences	Journal	1
International Congress on Advanced Applied Informatics	Conference	1
Personal and Ubiquitous Computing	Journal	1
Journal of Computers in Education	Journal	1
Learning and Instruction	Journal	1
Computers in Human Behavior	Journal	1
Educational Technology Research and Development	Journal	1
International Conference on Advanced Learning Technologies	Conference	1
Educational Technology & Society	Journal	1
International Conference on Computers in Education	Conference	1
Global Chinese Conference on Computers in Education	Conference	1
IADIS International Conference on Cognition and Exploratory Learning in Digital Age	Conference	1
TOJET: The Turkish Online Journal of Educational Technology	Journal	1
International Symposium on Emerging Technologies for Education	Conference	1
CSCL 2015 Proceedings	Conference	1
Educational Media International	Journal	1
Contemporary Educational Psychology	Journal	1
International Conference on Mobile and Contextual Learning	Conference	1
TOTAL		28

of Botzer and Yerushalmy (2007), Liu et al. (2007), and Zurita and Nussbaum (2007) were the first-three papers published in mathematics in mCSCL. Zurita and Nussbaum's (2007) paper was published in the British Journal of Educational Technology. Botzer and Yerushalmy's (2007) and Liu et al.'s (2007) papers were published in the IADIS International Conference on Cognition and Exploratory Learning in the Digital Age and the International Conference on Advanced Learning Technologies, respectively. Hsu et al. (2021) had a recent publication, which appeared in TechTrends. All of these journals and conferences are still in operation today. When compared to other mobile learning publications, only a few studies have been published in math mCSCL (Song, 2014; Sung et al., 2017). The relative scarcity of math mCSCL publications may be attributed to implementation challenges (e.g., Halloluwa et al., 2018; Jagušt & Botički, 2019). The implementation challenges are discussed further in the following section. This finding allows mCSCL researchers to focus their research efforts in this area.

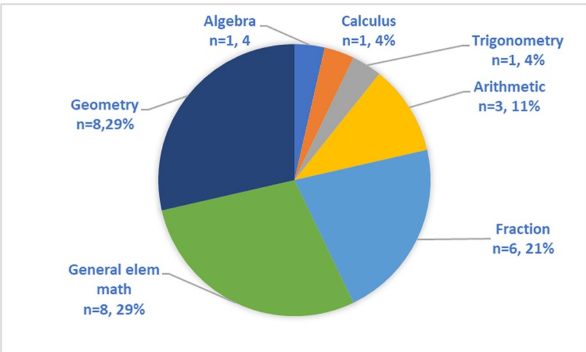
Table 2 Number of Published Papers from 2007 to 2021

Year	Number of Papers
2007	3
2008	3
2009	0
2010	4
2011	2
2012	3
2013	0
2014	1
2015	1
2016	1
2017	0
2018	2
2019	3
2020	4
2021	1
Total	28
Average	1.9

4.1.2 Instructional context

The majority of mCSCL publications focused on general elementary mathematics and geometry (Fig. 2). There are eight publications in each subject domain. The scope of mathematics was not specifically stated by researchers of general elementary mathematics (e.g., primary or fifth-grade mathematics). This finding is similar to that of Crompton and Burke's study (2017) (Fig. 3). Meanwhile, the remaining publications covered specific subject domains such as arithmetic (n = 3, 11%), fractions (n = 6, 21%), algebra (n = 1, 4%), trigonometry (n = 1, 4%), and calculus (n = 1, 4%). Furthermore, as shown in Fig. 4, the primary participants in the studies (n = 20) were elementary students. This result is consistent with those of Fabian et al. (2016), Crompton and Burke (2017), and Song (2014).

Fig. 2 Publication Distribution in terms of Subject Domain



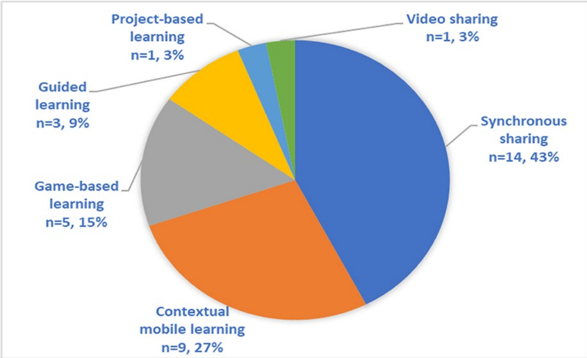


Fig. 3 Types of Mobile Learning

4.1.3 Types of mobile learning

From 2007 to 2021, the most popular type of mobile learning was synchronous sharing (n = 14, 43%) (Fig. 3). In this type of mobile learning, students can use the learning platform to discuss, show, and check their answers in learning activities with other members of the team in real time (Lai & Hwang, 2015). For instance, Järvenoja et al. (2020), and Laru et al. (2015), allowed their participants to collaborate in real-time in developing their mathematics midterm lesson plan for a primary school (Table 3). Participants can make suggestions and refine their lesson plans until they reach an agreement. This result is in line with the goal of collaborative learning.

Contextual mobile learning is the second most popular type. Real-world objects are used to reinforce learning in this type of mobile learning. Fabian et al. (2018) conducted their research using a mobile collaborative application in which students photographed objects. A pair of students can use the same application to annotate the area and perimeter of the captured image of the object.

The enjoyable aspect of the game was also incorporated into mCSCL (n = 5, 15%). Botički, Wong et al. (2011) used this type in their research where they utilized a custom-built software for learning fractions called FAO. Every player in the game would receive a portion of a fraction. The participant's goal is to combine all of their assigned fractions to form a whole. To check their assigned fractions, participants

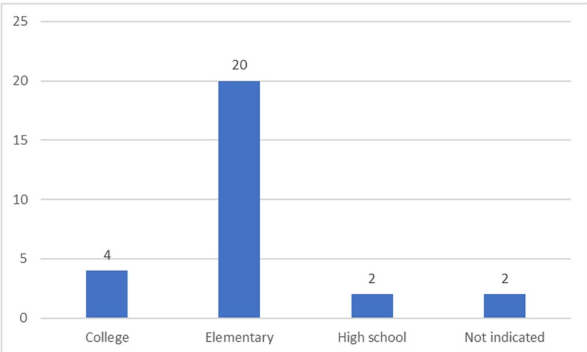


Fig. 4 Publication Distribution in terms of Educational Level

Table 3 Name, Types, and Utilization of Software Packages

Name of Software	Type	Software Utilization
Math-MCSCL (Zurita & Nussbaum, 2007)	Off-the-shelf	The student must complete the number of objects. Students with excess objects must seek out students with a scarcity of objects to complete the remaining objects. Students must communicate to determine which objects must be exchanged in order to achieve the desired number of objects
Math4Mobile (Botzer & Yerushalmy, 2007)	Off-the-shelf	Students run the mathematical applets to construct graphs on their cellular phones. They used the SMS and MMS capabilities of cellular phones to exchange messages and video clips
MePlot-free (Araujo et al., 2014)	Off-the-shelf	Students used tablets to run MePlot-free to understand the behavior of the graphs, and each member of the team explained their observations
SnapShot Bingo (Fabian et al., 2018)	Off-the-shelf	Students sought, captured, and organized the images of specific symmetrical objects provided by SnapShot Bingo
Kahoot! (Ting et al., 2019)	Off-the-shelf	Two classes received a game-based active learning method via Kahoot!
Skitch (Fabian & Topping, 2019)	Off-the-shelf	Students used tablets to take pictures and annotate the images using Skitch
Blackboard (Hsu et al., 2021)	Off-the-shelf	Students used the Blackboard learning management system (LMS) to communicate and collaborate in building mobile applications
Math Widget (Jagušt & Botički, 2019)	Custom-built	Students were assigned to one of the versions of the Math Widget. The two versions are non-collaborative. The third version allowed members of the team to solve an arithmetic problem. Each member of the team played a specific role: an author (who translated the problem to an equation), the editor (who provided the solution to the problem), and the checker (who verified the solution of the editor)
S-Reg (Järvenoja et al., 2020; Laru et al., 2015)	Custom-built	While constructing a midterm lesson plan for a primary school, S-Reg provided a visual representation of the group's cognitive, motivational, and emotional state. A prompt was given to regulate the situational needs of the team members
GeM Project (Spikol & Eliasson, 2010)	Custom-built	The goal of the students was to design a new campus building. Their task was to explore and collect data collaboratively (e.g., height, diameter, and area) on the possible locations within the campus. The GeM Project runs on cellular phones. After these collaborations, they returned to the class to design buildings in 3D

Table 3 (Continued)

Name of Software	Type	Software Utilization
Graphical Partitioning Model (Kong, 2008a, 2008b)	Custom-built	A pair of students had to decide whether two fractions were equivalent. The first student acted as the question-setter and the second as the respondent
Collboard (Alvarez et al., 2010)	Custom-built	Collboard is composed of a digital pen and an interactive whiteboard. Students solved the mathematics problem individually and submitted the solution in paper and digital format (i.e., using the Collboard). The teacher reviewed the solutions (either in paper or digital format) and started a discussion regarding the solutions. Students were asked to explain their solutions one by one
Eduinnova and TechPALS (Roschelle et al., 2010)	Custom-built	The software provided students with four collaborative tasks, namely, solving, identifying equivalents, arranging, and estimating fractions. Students could not proceed to the next task if one of the team members had an incorrect answer
Tangram Puzzle (Lin et al., 2011)	Custom-built	Students made a funnel and a sailing boat using geometric shapes. Throughout these tasks, students worked collaboratively, and peer assessment took place afterward
HiTeach (Tung et al., 2020)	Custom-built	Group members shared their problem-solving solutions using the HiTeach interactive learning platform
Math Widgets (Botički et al., 2020)	Custom-built	See Jagušt and Botički (2019)
FAO (Botički et al., 2010; Botički et al., 2011; Botički et al., 2012)	Custom-built	Students collaborated and formed groups by adding (merging) fractions until they came up with full circles (wholes)
Gamified educational mobile application (no name) (Halloluwa et al., 2018)	Custom-built	In the game, a group of students acted as shoppers. They had to purchase goods in the game, which re-enforced their currency awareness and arithmetic skills
Math mCSCL (no name) (Liu et al., 2007)	Custom-built	The software presented a mathematics word problem to each student in the form of a comic story. The team discussed the issue before tackling it individually. The procedure was repeated until the group found the correct answer
POE supported by mobile devices (no name) (Gau & Yang, 2019)	Custom-built	The study employed a predict-observe-explain (POE) learning model for mathematics learning with the aid of mobile devices. In this approach, students collaboratively wrote and discussed their ideas on mobile devices
Training app (no name) (Reychav & Wu, 2016)	Custom-built	The training app had interactive features that could support three levels of cognitive tasks (e.g., computing perimeter, identifying shapes as parallelograms or not, and identifying the same perimeter). In a collaborative setting, students worked collaboratively to achieve group-level agreements on various cognitive training tasks

Table 3 (Continued)

Name of Software	Type	Software Utilization
Geometry mobile application (no name) (Sollervall & Milrad, 2012)	Custom-built	A pair of students executed three tasks in the mobile application. For the first two tasks, students used a mobile application that allowed them to measure distances between fixed and moving targets. In the last task, students worked collaboratively to compute the center of mass
Geometry mobile application (Sollervall et al., 2012)	Custom-built	Students determined the height of a building on their campus. They collaborated and discussed the height of the building. They used mobile devices to choose the height of the building. They also took pictures of the buildings and recorded why they came to such conclusions. Then, they presented their findings in class
Tao et al. (2008)	Custom-built	See Liu et al. (2007)

must look at the devices of the other participants. To achieve the goal of the game, participants must all work together on the software.

Only a few studies used guided learning (e.g., Fabian & Topping, 2019; Reychav & Wu, 2016). Instructors utilize the math mCSCL to teach students the content of the syllabus or textbooks in this system. Together with the mCSCL activities, teachers provided a list of topics to students. Meanwhile, one study was reported using project-based learning (Hsu et al., 2021) and video sharing (Botzer & Yerushalmy, 2007). It is worth noting that in one study, Jagušt and Botički (2019) used three mobile learning strategies (contextual mobile learning, synchronous sharing, and game-based learning). The implementation of project-based learning was also discussed in the study of Peramunugamage et al. (2022).

4.2 RQ 2. Methodological features

Table 4 shows the sample size, age distribution, sex distribution, and duration of the experiment for the methodological features of the papers selected in this study. There could be as few as three participants or as many as 365 participants ($M=67.1$, SD = 98.6). One study reported the number of sections that participated but not the number of students. The team size, however, ranges from 2 to 35 students. One study involving 35 participants per group was conducted in a developing country where access to mobile devices is known to be limited (Halloluwa et al., 2018). More than half of the studies (15 out of 28) included 2 to 4 students in a group. This finding agrees with the finding of Sung et al. (2017).

In terms of sex distribution, the proportions of male participants range from 18 to 71%. The percentages for female participants range from 29 to 82%. One study had four participants, all of whom were female students. On average, 47% of participants were men and 53% were women. However, the sex of the participants was not reported in 54% of the studies (n = 14).

The majority of the studies (n = 20; 71%) involved elementary students. Fabian et al. (2016), Crompton and Burke (2017), and Song (2014) had similar findings. There were only a few studies that included high school students (n = 2; 7%) and college students (n = 4; 14%). This contradicts the finding of Sung et al. (2017), who found that the majority of mCSCL users were college students. The shortest collaborative activity lasted 12 days, while the longest lasted 15 weeks. However, 65% of the studies (n = 17) did not report how groups were formed, which is consistent with the finding of Sung et al. (2017). Nonetheless, the remaining studies reported on their group formation

Table 4 Methodological Features of the Papers

Feature	Minimum	Maximum
Sample size	3 students	365 students
Group size	2 students	35 students
Age	6 years old	25 years old
Sex	Male: 18%	Male: 71%
	Female: 29%	Female: 82%
Duration	12 days	15 weeks

Table 5 Research Design of the Selected Studies

Research Design	*n*	%
Not specified	13	45
Case study	5	17
Quasi-experimental	5	17
Experimental	3	10
Observation	2	7
Randomized trial control design	1	4
Total	29	100%

strategies that include student selection through the student registry (i.e., arranged alphabetically), purposeful selection (e.g., at-risk students), and random assignment.

Three studies attempted to form heterogeneous groups by combining at-risk/low-performing, average-performing, and high-performing students in a team (Botzer & Yerushalmy, 2007; Kong, 2008a; Tung et al., 2020). In one study, group composition is inapplicable because the activity (i.e., making the fraction whole) is dependent on the random assignment of the fractions rather than on the students' abilities (Botički et al., 2012). Araujo et al. (2014) used a less strict rule for group formation since they allowed students to form their own groupings. Meanwhile, Fabian et al. (2018) asked teachers to divide the students in their studies into groups.

Almost half of the studies (n = 13, 45%) did not report their research designs (Table 5). Nonetheless, case studies (Botzer & Yerushalmy, 2007; Halloluwa et al., 2018; Hsu et al., 2021; Jagušt & Botički, 2019; Kong, 2008a) and quasi-experimental (Fabian et al., 2018; Gau & Yang, 2019; Kong, 2008b; Lin et al., 2011; Ting et al., 2019) were the most widely used research designs. Crompton and Burke (2017), Song (2014), and Sung et al. (2017) reported the same research findings. In each research design, there were five studies (17%). The experimental design was used in three studies. Two papers also used observational design studies. Only one study used a randomized trial control design. In addition, one paper used both an experimental and an observational study design. This explains why the number of research designs exceeded the number of selected studies.

In terms of the contributions to research areas, 50% of the literature focused on improving mathematics pedagogy (Fig. 5). This finding is consistent with the

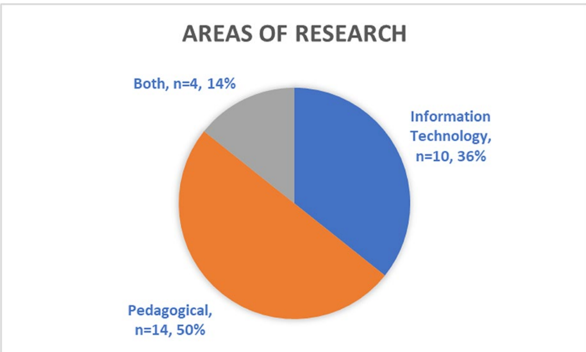


Fig. 5 Areas of Research

Table 6 Benefits of Math mCSCL

Benefits of Math mCSCL	Number of Studies
Social Skills and Attitudes-related Benefits	
• Group Interactions	15
• Motivation	5
• Interest	3
• Satisfaction	2
• Group Cohesiveness	1
• Group Decision-making	1
• Perception towards mathematics	1
Mathematics Competency-related Benefits	
• Mathematics Performance	8
• Mathematical Knowledge	6
• Real-world Applications	2

results shown in Table 6. More than one-third of the research, on the other hand, was directed toward the field of Information Technology, specifically the development of mCSCL software. For instance, Botički et al. (2010) developed software that allowed students to collaborate and form groups by adding (merging) fractions until they reached full circles (wholes) (Table 3). A small number of studies contributed to both software development and pedagogy. These studies first created the software and then tested it to see if it served its educational purpose (e.g., Halloluwa et al., 2018; Sollervall et al., 2012).

Meanwhile, a significant number of the software utilized was custom-built (n = 19, 68%; Table 3). Custom-built collaborative software packages were developed and utilized because they served specific pedagogical or educational purposes (Table 3). Blackboard, Math-MCSCL, Kahoot!, SnapShot Bingo, Math4Mobile, Skitch, and MePlot-free were the off-the-shelf software packages utilized in seven different studies. Another seven studies did not specify the name of the software they utilized. Botički and colleagues (2010, 2011, and 2012) used the same software, named FAO, in all three of their studies.

Personal digital assistants were the most commonly used devices for collaborative learning in 2007 and 2008. In four studies, PDA was used as the primary platform for math mCSCL. This is because, during those years, this was the most convenient handheld device to use (Viken, 2009). Math mCSCL is then integrated into new mobile devices such as smartphones (n = 7; 25%) and tablets (n = 8; 29%). More than 50% of the math mCSCL was implemented on smartphones and tablets. Song (2014) reported the same findings. Interestingly, more than 30% of the studies either did not report the device or only provided a general term (i.e., mobile device).

4.3 RQ3. Benefits of math mCSCL

The majority of the papers (n = 15) cited group interactions as the primary advantage of math mCSCL. Students participate in group interactions by discussing, sharing, communicating, and negotiating ideas. They also present arguments for the group to reach a decision. Furthermore, they were able to demonstrate group cohesiveness – the commitment of team members to achieving the group's goal.

Math mCSCL influences students' attitudes towards mathematics learning. Using math mCSCL (n = 5), students were more motivated to learn. Students' interest in mathematics can be piqued using software packages (n = 3). Two studies found that students were satisfied with the software packages they used. Another study found that software packages aided students' positive learning experiences. These findings agree with those of Fabian et al. (2016) and Song (2014).

Mathematics competency-related benefits are the second most frequently mentioned benefits of math mCSCL. Eight papers reported that mCSCL improved students' mathematics performance. Six papers documented the increased mathematical knowledge of students. Students value math mCSCL because the software packages provide real-world mathematics applications (n = 2).

4.4 RQ4: Limitations and challenges of math mCSCL

The implementation strategies face a variety of challenges, both in pedagogical and technical aspects. In terms of pedagogical limitations, some studies revealed insignificant or negative effects of math mCSCL. Botički et al. (2012) disclosed that students used the software on a trial-and-error basis, resulting in an impasse. In another study, students with low levels of self-regulation thought math mCSCL was just a tool that did not affect their math performance (Laru et al., 2015). Other studies found that math mCSCL did not improve students' learning outcomes (Fabian & Topping, 2019; Kong, 2008b; Reychav & Wu, 2016).

Usability is one technical issue reported in the literature. In a geometry class, for example, elementary students struggle to manipulate objects on mobile devices (Halloluwa et al., 2018). Experimenting with math mCSCL may also take longer because both teachers and students must become acquainted with the software and devices (Halloluwa et al., 2018). Sollervall et al. (2012) disclosed that their software was unable to track and follow up on the students' activities.

Another study reported issues of synchronization and coordination between and among students (Jagušt & Botički, 2019). Connection problems (Halloluwa et al., 2018), decreased interest, peer pressure (Jagušt & Botički, 2019), confusion, weather conditions (Sollervall and Milrad, 2012), random invitation, impasse (Botički et al., 2011), extreme students' behaviors, and unmotivated participants (Roschelle et al., 2010) contribute to these constraints.

5 Discussion

This study conducted a scoping review of math mCSCL publications published from 2007 to 2021 inclusive. A systematic literature search was conducted in various research databases to achieve this goal. Twenty-eight papers were eligible for review. Math mCSCL researchers are more likely to publish their findings in peer-reviewed journals. From 2007 to 2021, approximately two papers were published per year on average. This publication, however, is relatively low in comparison to the other publications in mCSCL (Song, 2014; Sung et al., 2017).

General elementary mathematics and geometry are the most popular mCSCL topics. However, it is unclear what specific topics are covered in general elementary mathematics because no further elaboration is found in the papers. This could be attributed to a lack of space (Botički et al., 2010). Geometry benefited the most from mCSCL because mobile devices could support real-time and interactive geometric object visualization (Leitão et al., 2018). Mobile devices may also provide more geometric objects because they use fewer tangible resources such as paper and scissors (Fabian et al., 2018).

The study of fractions has captured the interest of mCSCL researchers. The researchers developed mCSCL software packages as teaching and learning tools to explain the abstract and simplify the complex concept of fractions (Kong, 2008b; Pitkethly & Hunting, 1996). These tools have been shown to improve group interactions, support group cohesiveness, and increase mathematical knowledge (Botički et al., 2011, 2012; Kong, 2008a, 2008b). There are very few studies in the fields of algebra, calculus, arithmetic, and trigonometry. Furthermore, the other ten branches of mathematics (e.g., combinatorics, statistics, set theory, and so on; Encyclopaedia Britannica, 2021; Funk Wagnalls New World Encyclopedia, 2018) have not yet been studied in the context of mCSCL. These gaps in the literature offer numerous research opportunities in the field of mCSCL.

Synchronous sharing is the most utilized type of mobile learning in math mCSCL. Students exchange ideas and information in a face-to-face mCSCL setup. This finding is not surprising given that the goal of collaborative learning is synchronous sharing. It should be noted, however, that the majority of the studies (23 out of 28) were conducted before the COVID-19 pandemic declaration on March 11, 2020 (World Health Organization, 2020). In general, collaborative learning in an online setting is difficult (Mustakim et al, 2021). The current COVID-19 pandemic complicates the logistics of implementing face-to-face math mCSCL (Bringula, 2020).

Sample and group sizes in the selected studies greatly vary. This variation is attributed to the context and research design of the study. For example, three hearing-impaired students participated in an observational study by Liu et al. (2007). This sample size is acceptable for qualitative research (Moser & Korstjens, 2018). Meanwhile, due to the limited number of devices, other researchers were prompted to form groups of as many as 35 participants per group (Halloluwa et al., 2018). The selection of group size also depends on the intended benefits the participants will achieve in the collaborative activities (Sung et al., 2017).

An examination of the 28 studies revealed the breadth of the literature on the types of study designs used in these studies. The finding shows that there are a large number of papers that could be subjected to further systematic or meta-analysis. In terms of sex, there are nearly equal numbers of male and female participants. This finding suggests that the math mCSCL researchers made an effort to represent both sexes in this field of study. Another interesting finding of this study is the duration of the intervention, which is similar to the existing literature (Sung et al., 2017). Hence, the intervention durations for math mCSCL are coherent with the current practices of mCSCL studies.

The math mCSCL software was most beneficial to elementary students. It is critical to assist students in their mathematics courses at a young age to increase their motivation and develop positive attitudes toward mathematics courses. These attitude-related factors are significant because they have the potential to influence students' math performance in subsequent mathematics learning (Aunola et al., 2006). College and elementary students were the primary participants of mLearning because of convenience (Chee et al., 2017). However, research is scarce at the higher educational levels in this study. Thus, there might be other reasons why higher mathematics is underrepresented in mCSCL studies. These findings offer mCSCL researchers the opportunity to better understand these research gaps.

The methodological features discovered in this study shed light on the benefits of math mCSCL over CSCL. Math mCSCL incorporates the adaptive features of CSCL. Both math mCSCL and CSCL software can provide learning content and feedback mechanisms. In addition to these features, math mCSCL enables students to learn real-world problems and share their data collected during outdoor class activities (e.g., Sollervall et al., 2012). Even in an indoor learning environment, students can move around the classroom and communicate with their classmates to solve a math problem or complete a math task (e.g., Botički et al., 2010, 2011, 2020). In other words, these studies address the limitations of CSCL in terms of portability, mobility, flexibility, and face-to-face sharing.

Software utilization provides an overview of the various types of software used and how they are applied in different studies. The use of software has a positive impact on students' mathematics competency. This finding implies that the software packages used in the studies are capable of achieving their pedagogical objectives. The literature supports these findings (Fabian et al., 2016; Song, 2014). Other CSCL research studies also established the same results (e.g., Crompton & Burke, 2017; Fabian et al., 2016; Jeong et al., 2019). Hence, both mCSCL and CSCL can achieve the desired pedagogical outcomes of the mathematics course.

In addition to improving mathematics competency, students' social and attitude aspects benefited in math mCSCL. Even though there were reported cases of behavioral issues during the intervention periods, there were more positive outcomes reported than negative ones. With math mCSCL, students' motivation, attitudes, and interaction improve. These results are similar to CSCL (Jeong et al., 2019). However, it should be noted that this study showed a significant number of reviewed studies that found that math mCSCL had the most impact on social skills and attitude outcomes.

This current study demonstrates that the majority of the reviewed studies were focused on improving mathematics pedagogy through mCSCL. The number of studies devoted to software development informs future researchers about the need to develop other mCSCL in other fields of mathematics. The developed mCSCL software can then be tested for educational and usability effectiveness. This may help to close the identified gap in math mCSCL.

On the one hand, there are issues or challenges with implementation. The participants' socioeconomic situations, environmental conditions, systems usability, and students' attitudes and behaviors toward technology all contribute to these issues and challenges. Students may not have access to mobile devices because of their economic status (Halloluwa et al., 2018). This situation prompted the authors to organize groups composed of 35 students each. This problem may not be solved by the authors themselves. To overcome this challenge, institutional and government support is needed.

Researchers can address the pedagogical and technical challenges of math mCSCL. Detectors of students exhibiting trial-and-error, low self-regulation, decreased interest, and unmotivated behaviors, for example, can be included in the software. The interface interactions of the students can be logged and analyzed to detect their behaviors. This will necessitate the use of artificial intelligence (Bringula, 2020). Other technical issues, such as connection problems and weather conditions, are beyond the researchers' control. Nonetheless, meticulous planning is required to at least mitigate these challenges. Overall, it can be concluded that the benefits of math mCSCL outweigh the disadvantages.

6 Conclusions, recommendations, limitations, and future research

This study conducted a scoping review to determine the extent of publications in math mCSCL. Twenty-eight papers satisfied the inclusion–exclusion criteria outlined in this study. It was found that there are a considerable number of papers published in this subject domain. The majority of the studies used synchronous sharing and were published as journal articles. During the 15 years, an average of two papers were published. However, when compared to other subject domains, these publications are scarce. Nonetheless, future researchers are advised that the 28 studies may be subjected to further systematic review or meta-analysis.

Math mCSCL can improve students' cognitive abilities, social skills, and attitudes towards the course. Elementary students benefited the most from math mCSCL. Elementary mathematics is the most preferred subject, probably because of its simplicity and the abundance of digital materials about the subject. Thus, the scoping review presented initial evidence on the scope of math mCSCL. However, other branches of mathematics are underrepresented in mCSCL research. Future studies may identify the reasons and address research gaps.

The study also confirms that the methodological features of the 16 studies are consistent with the other existing CSCL studies. Hence, the 16 reviewed studies adhered to the same level of scientific rigor as the other CSCL studies. Custom-built software packages running on smartphones and tablets are the current trends in math mCSCL. This is primarily due to the technological advancements of handheld devices. Math mCSCL researchers are leveraging the computing capabilities of these devices.

Despite the findings of this study, it acknowledges its three limitations. First, we may have omitted relevant publications because other papers did not reflect the search terms we used in this study. The second limitation is the usage of other databases such as the ACM Digital Library, IEEE Xplore, and Web of Science. Finally, other publishers' article search functions were not taken into account in this study. These issues may be addressed in future research.

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Data Availability The authors declare that all data supporting the findings of this study are available within the article.

Declarations

Competing interest The author reports there are no competing interests to declare.

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