Systematic review on mobile collaborative learning for engineering education

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Abstract Our daily lives have been transformed by mobile smart devices. Due to the sudden impact of the coronavirus (Covid-19) on education, the importance of mobile devices for communicating with teachers and students has risen to a new level of prominence. The Web of Science and Scopus databases were used to conduct a systematic review of the research on mobile collaborative learning in engineering education. The purpose of this review is to ascertain the degree to which research on mobile collaborative learning has been conducted in the field of engineering education between 2010 and 2020. A total of 48 articles were reviewed to ascertain the research methodologies and area of study, as well as to provide an updated review of studies on mobile collaborative applications, particularly in the field of engineering education. Among the most significant findings is that the majority of publications make use of augmented reality and mobile application development. According to the review, the majority of studies were conducted in the fields of computer sciences, electronic engineering, and artificial intelligence.

Keywords Collaborative learning · Engineering education · Mobile learning · Systematic review

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Introduction

Mobile phone markets are always evolving due to the adoption of new technologies. Mobile phones are not simply telephones; they are also minicomputers, video and still cameras, personal digital assistants, audio recorders, and GPS navigators. They also have the capability to employ smart Apps via the integrated Internet of Things. The proliferation of lightweight mobile technologies has ushered in a new era of disruptive technology in education. As a result, it enables students to participate and interact in both formal and informal learning environments, as students can access learning resources at any time from any location. Mobile learning, or m-learning, is a term that refers to this type of learning (Dyson et al., 2009). Mobile technology enables students to access a range of learning techniques regardless of their location or time constraints (Tawfik et al., 2013). Mobile learning (mLearning) is gaining popularity due to several benefits it provides to both teachers and students, including cost effectiveness, mobility, quick connectivity, and context sensitivity. Additionally, it facilitates interaction between students and professors by fostering collaborative learning, interactivity, and rapid feedback (Kukulska-Hulme et al., 2011; Neto & Williams, 2013). There are several potential benefits and limitations to the use of technologies to improve educational access. The following are some of the benefits of mobile learning technologies: (a) they remove geographical constraints in learning; (b) they help students to develop a self-centered learning pedagogy; and (c) they facilitate an efficient communication mechanism for learning as well as endorsement and review of content between teachers and learners (Chew et al., 2018; Kukulska-Hulme, 2007; Kukulska-Hulme et al., 2011; Lee, 2011).

Research in computer-supported collaborative learning (CSCL) is concerned with investigating how people can learn together with the assistance of computers as an emerging field of learning sciences (Balakrishnan, 2015; Hinze-Hoare, 2007); whereas Mobile Computer-Supported Collaborative Learning (mCSCL) research is concerned with investigating how people can learn together with the assistance of mobile devices (Amara et al., 2016; Caballé et al., 2010; Huang et al., 2010).

As described by Chatti et al. (2012) mobile learning becomes interactive when used in a collaborative environment (Lee, Clark and Nosekabel, 2011). It provides both formal and informal learning associated with interaction and exchange of information. Spikol (2008) describes how collaborative learning through mobile devices has been investigated mainly because of the availability and mobility offered by these devices. According to Jain et al. (2011), collaborative mobile learning is an activity that allows transparent collaboration by empowering the social negotiation space of group members, coordination between the activity states, encouraging members' mobility, possibility of mediation in interactivity, organization of the managed material and enabling students to collaborate in groups through wireless network supporting social face-to-face communication.

By integrating a variety of media like video clips, instant messages, photos, music, simulations, and animations, collaboration can be entertained

(Fakomogbon & Bolaji, 2017). The different media mixes in mobile learning instructional content create a meaningful engagement of the learner's intellectual capacity through active involvement in a collaborative learning setting. In addition to using the mobile device as a tool or platform for Computer-Supported Collaborative Learning (CSCL), researchers have claimed that mCSCL can increase a learner's active participation in activities by providing more opportunities for instant interaction between a learner and his or her peers via the use of mobile devices (Patten et al., 2006; Ryu & Parsons, 2012; Amara et al., 2016). Therefore, in the mobile learning environment, lecture video, lecture notes, audio, quiz and test, assignment, discussion, and grade components are generally included (Lee, Clark and Nosekabel, 2011). As a result, various tools and systems have increasingly been developed for or integrated into mobile devices for mCSCL. These activities have taken place in a variety of settings, including physical, social, and virtual environments.

In light of the widespread use of mobile devices in education, research on mobile learning is rapidly expanding (Bhati & Song, 2019; Cabada, Barrón Estrada, and Reyes García 2011; Dyson et al., 2009; Lu et al., 2015), and as a result, it has been reviewed in many publications (Connolly et al., 2012; Hwang & Tsai, 2011; Hwang and Wu 2014; Sum Cheung and Foon Hew 2009; Wu et al., 2012; Xia & Zhong, 2018; Zydney & Warner, 2016). Specific aspects of mobile learning were examined in some reviews, such as mobile learning games (Avouris & Yiannoutsou, 2012; Malegiannaki & Daradoumis, 2017), mobile computer-supported collaborative learning (Pimmer et al., 2016; Swid, Hsu, and Wang 2018), or mobile apps (Atawneh et al., 2020; Avouris & Yiannoutsou, 2012; Xia & Zhong, 2018; Zydney & Warner, 2016).

Fu and Hwang (2018) undertook a study of the literature on collaborative learning facilitated by mobile technologies. They discovered that collaborative learning through mobile devices is a fast emerging study topic that has the potential to boost learners' cognitive and metacognitive growth. As shown on Table 1, several valuable systematic literature surveys were done on mobile learning. However, certain areas require further investigation. For instance, there is considerable potential for mobile learning to be used in the field of engineering education, owing to several factors that make it unique and well-suited to the affordances of mobile technology. The majority of engineering activities occur outside of the classroom.

However, no systematic review on mobile collaborative learning for engineering education has been published in the last decade. There were five review articles, each focusing on a different aspect or dimension of the advancement of mobile collaborative learning. Thus, the purpose of this study was to determine how mobile collaborative learning research is conducted in the field of engineering education. The purpose of this research review is to provide an updated overview of studies on mobile applications, specifically in the field of engineering education. We proposed the following research questions.

- (1) During 2010 to 2020, what are the research methodologies adopted for studying mobile collaborative learning in engineering education?

Table 1 Systematic review articles on mobile learning

Author	Article	Study period	No. of articles	Main research outcome
(Sum Cheung and Foon Hew, 2009)	Research methodologies used in studies on mobile handheld devices in K-12 and higher education settings	2008	44	<ul style="list-style-type: none"> • Students and teachers mostly used mobile handheld devices as communication and multimedia access tools • Descriptive research is the most often used research method • Common data collection method used is the questionnaire • Students' learning is enhanced through the use of mobile handheld devices
(Avouris & Yiannoutsou, 2012)	Mobile Location-based Games for Learning across Physical and Virtual Spaces	2004–2010	26	<ul style="list-style-type: none"> • Games studied were either of ludic or pedagogic nature and shared some common characteristics • Discovered main issues related to location-based games and further research areas
(Wu et al., 2012)	Review of trends from mobile learning studies: A meta-analysis	2003–2010	164	<ul style="list-style-type: none"> • The majority of studies on mobile learning focus on effectiveness, followed by system design • Primary research methodologies included surveys and experiment • Most frequently focus on use in supporting professional subjects and applied sciences, followed by the humanities and formal sciences also widely used in courses related to environmental studies, forestry and health sciences
(Hsu and Ching 2013)	Mobile computer-supported collaborative learning: A review of experimental research	2004–2011	9	<ul style="list-style-type: none"> • Found that following research areas lacking in MCSCL • Web 2.0 applications and social media to promote interaction • Examining affordances of currently dominant devices and OSs for CL

Table 1 (continued)

Author	Article	Study period	No. of articles	Main research outcome
(Baran, 2014)	A Review of Research on Mobile Learning in Teacher Education	2000–2014	37	<ul style="list-style-type: none"> • There is a growing tendency toward integrating mobile learning into contexts of teacher education • Several pedagogical affordances facilitate the integration of mobile learning into teacher education • Except for five research on science, the rest of the studies span many curriculum areas. They include mathematics, literacy, physical education, information technology, STEM teacher education, English teaching, and home economics teacher education
(Zheng, 2015)	A literature review of features and trends of technology-supported collaborative learning in informal learning settings	2007–2018	70	<ul style="list-style-type: none"> • Undergraduate and postgraduate students mainly participated in technology-supported collaborative learning • Dominant area was Nature science and Social science followed by Engineering and Technology
(Zydney & Warner, 2016)	Mobile apps for science learning: Review of research	2007–2014	37	<ul style="list-style-type: none"> • Mostly about elementary school students in general education and only a few studies that are focused on students who received either special education or gifted services • Mobile apps for science learning offered a number of similar design features
(Pimmer et al., 2016)	Mobile and ubiquitous learning in higher education settings. A systematic review of empirical studies	2008–2012	36	<ul style="list-style-type: none"> • The three dominant subjects were language learning studies, health sciences and computer sciences • Helped to connect learning in formal and more informal and personalized learning environments

Table 1 (continued)

Author	Article	Study period	No. of articles	Main research outcome
(Heil et al., 2016)	A review of mobile language learning applications: trends, challenges and opportunities	As at 2015 (Apple and Google Play store)	50 apps	<ul style="list-style-type: none"> • There is a strong emphasis on teaching language as isolated vocabulary words rather than contextualized usage in the commercial app industry
(Chee et al., 2017)	Review of Mobile Learning Trends 2010–2015: A Meta-Analysis	2010–2015	144	<ul style="list-style-type: none"> • The majority of M-Learning research focuses on effectiveness, followed by a review of M-Learning • M-Learning is most typically used to enhance language and art education, followed by science education • At present, the smartphone is the most often utilized device for M-Learning • Informal learning is the preferred method of instruction when combined with M-Learning • The majority of M-Learning research has used a quantitative approach as the primary research strategy
(Kumar & Mohite, 2018)	Usability of mobile learning applications	2005–2016	23	<ul style="list-style-type: none"> • There are 15 different attributes used with each author using its own set of attributes • Research is still expanding in the area
(Kumar & Chand, 2018)	Mobile learning adoption: A systematic review	2009–2017	27	Increasing research activity, lack of adoption models and insight into individual factors that are influential in mobile learning adoption

Table 1 (continued)

Author	Article	Study period	No. of articles	Main research outcome
(Fu & Hwang, 2018)	Trends in mobile technology-supported collaborative learning: A systematic review of journal publications from 2007 to 2016-	2007 to 2016	90	<ul style="list-style-type: none">•Most of the research was focused on improving learners' performance in science, especially social science, and in natural scenarios outside of the classroom, but less emphasis was put on developing learners' skills and higher order skills•Little research focusing on different selection methods of group members and the teaching effects of grouping design

- (2) During 2010 to 2020, what are learning environments used in mobile collaborative learning for engineering education?
- (3) During 2010 to 2020, what are the theoretical foundations widely applied for mobile collaborative learning in engineering education?

This paper first describes how the literature review was carried out. Second, the results of the review are presented followed by discussions of methodological issues and potential directions for future mobile collaborative learning in engineering education research. Finally, conclusions are drawn.

Method of article selection

The data collection and analysis process was guided by previous studies such as Hsu and Ching (2013) and Hwang and Tsai (2011), which requires conducting a review based on quality publications. For literature reviews conducted concerning higher education, the Web of Science (all databases) and SCOPUS databases were used to search for mobile collaborative learning in engineering education which has been recommended by several previous studies. Therefore, in this study, the Boolean expressions (“collaborative learning” OR “cooperative learning”) AND (“m-learning” OR “mobile learning” OR “ubiquitous learning”) were used to search for publications from the Web of Science database and SCOPUS databases. These databases were chosen because they are known for encompassing high-impact, high-quality journals indexed in the Science Citation Index and the Social Citation Index. Both databases were searched with the same Boolean expression. Related terms were used to create a more comprehensive search. For example, alternative keywords for mobile included ubiquitous and m-learning; the alternative keyword for collaborative was cooperative; and the alternative keywords for engineering were Computer Science Interdisciplinary Applications or Education Scientific Disciplines or Engineering Electrical Electronics or Computer Science Information Systems or Telecommunications or Computer Science Artificial Intelligence or Computer Science Software Engineering or Engineering Multidisciplinary or Computer Science Cybernetics or Computer Science Hardware Architecture or Computer Science Theory Methods or Automation Control Systems or Robotics.

The authors developed this criteria list based on previously published criteria (Moher et al. 2009), but narrowed it further during the article review to conduct a more focused, in-depth review of the studies. To locate high-quality literature, the SCI and SSCI databases were chosen as target databases for literature searches. Additionally, the period was set from 2010 to 2020, and the literature types were designated as “articles” under the recommendations of several previous review studies (Hwang & Tsai, 2011; Wu et al., 2012; Zydney & Warner, 2016). After removing duplicates, 182 articles remained for further selection. We reviewed titles and abstracts to identify papers that met the following criteria: (1) peer-reviewed journal articles (2) full-text access and (3) undergraduate education (4) engineering education-related (5) mobile collaborative learning; and (6) investigation of mobile collaborative learning platforms, including their development and evaluation. After the

review of abstracts, 76 studies were deleted because they did not meet the inclusion criteria.

Several exclusion criteria were also applied: (1) used for professional learning (e.g., teacher education, engineering, the management or engineering professionals), (2) emphasized app design and development as opposed to student outcomes, (3) aimed exclusively at outcome measures unrelated to engineering learning (e.g., usability, engagement, interest), (4) directed at laptop use, robots, or wearable systems as opposed to tablets or phones, (5) focused on student-created apps (e.g., experiments, prototypes, not available in the market) and (6) did not include an in-person component. Based on the established inclusion criteria, the abstracts of the 182 articles were read and analyzed, and irrelevant articles were excluded. Finally, 110 articles were chosen for inclusion in the analysis. Figure 1 shows the process and methods of data searching and collection. Sixty-one full-text articles were reviewed and sixty-two articles were eliminated from the analysis due to the unavailability of the full-text, being focused on language learning or other management activities or case studies or samples but not for undergraduate education. A total of 48 articles met the criteria to be included in the final review and were considered for the qualitative

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Fig. 1 PRISMA flow: data extraction procedure

Table 2 Distribution of eligible articles in all referred journals

Journal	Number of papers
Artificial Life and Robotics, Electronics, IEEE transactions on Industrial Electronics, IEEE Transactions on Services Computing, Innovations in Education and Teaching International, Interactive Learning Environments, International Journal of Computer Applications in Technology, International Journal of Advanced Computer Science and Applications Eurasia Journal of Mathematics Science and Technology Education,	1
British Journal of Educational Technology, Computer Applications in Engineering Education, International Journal of Emerging Technologies in Learning, International Journal of Mobile and Blended Learning, Telematics and Informatics	2
Expert systems with applications	3
Computers & Education, Educational Technology & Society	4
IEEE Transactions On Learning Technologies	5

synthesis/meta-analysis. According to the distribution of eligible journal articles in Table 2, IEEE Transactions on Learning Technologies contributed to the publication of five articles on mobile collaborative learning in the field of engineering education. During the last decade, four (4) articles from each of the journals Computers & Education and Educational Technology met the research criteria.

Data distribution

After content-coding and analysis, we classified the 48 articles by publication year and conducted a preliminary examination of the data sources to determine whether the definition of mobile collaborative learning in engineering education was consistent with the research findings. The data distribution is depicted in Fig. 2. As can

Fig. 2 Distribution of mobile collaborative learning literature in engineering education during 2010–2020

be seen, the amount of literature on mobile collaborative learning in engineering education has gradually increased over the last decade, which corresponds to the regularity with which new items are developed. Hsu and Ching (2013) summarized research on mobile computing-enabled collaborative learning that was published in peer-reviewed journals between 2000 and 2011, encompassing a total of nine studies. Before 2013, there was little research on mobile collaborative learning, which is consistent with the findings of this study (Hsu and Ching 2013). The data were established to be correct, and thus the study could progress to the next stage of the coding scheme.

The word cloud is a widely used technique for visualizing the key terms contained in the title, abstract, and keywords of selected papers in review studies (Asadi et al., 2017; Tricco et al., 2016). The larger the word in the graphical representation, the more frequently it appears in the keywords of the chosen papers. Figure 3 depicts a word cloud created from the keywords extracted from selected papers in this study. This illustration can assist in visualizing the purpose and structure of the selected publications. As illustrated in Fig. 3, the term “collaborative” is the most frequently used in the selected studies (28 times), followed by “mobile” (26 times), “collaborative learning” (25 times), and “mobile learning” (13 times).

Coding scheme and process

In order to systematically examine the development status and trends of mobile collaborative learning in engineering education research from 2010 to 2020 from

Fig. 3 Word cloud for keywords

different dimensions, the coding scheme was established from diverse dimensions, learning environment, research participants and subjects, research methodology, and type of interactions for collaborative learning.

(1) Codes for the learning environment.

The coding scheme of the mobile learning environment includes classroom or laboratory, school campus, LMS, and non-specified.

(2) Codes for research participants and subjects.

The codes for participants and subjects were proposed by Hwang and Tsai (2011). The codes for participants include engineering undergraduates, others, and non-specified, while the codes for learning subjects include engineering or computers, science (e.g., physics, chemistry, other and non-specified).

(3) Codes for collaborative learning strategies.

Johnson et al. (1998) pointed out eight commonly used collaborative learning strategies. Accordingly, the coding scheme for collaborative learning strategies included learning together, team games tournaments, group investigation, academic controversy, jigsaw II, student team achievement divisions, team-assisted individualization, cooperative integrated reading and composition, other, and non-specified (Johnson, Johnson, and Smith 1998)

(4) Codes for research methods.

Pimmer et al. (2016) divided research methods into quantitative, qualitative, mixed-method, case studies, and others were added in the coding scheme (Pimmer et al., 2016).

(5) Codes for interactions.

As Moore et al. (1989) introduced there are four types of interactions. Accordingly, the coding scheme for interactions is learner-content, learner-instructor, learner-learner, and learner-interface (Jayaweera, 2019; Moore, 1989).

Overview of reviewed studies

Of the 48 studies reviewed from 2010 to 2020, the majority of studies (40 articles) were published after 2013. The number of student participants in the studies ranged from 10 to 1121 with a median of about 23 as shown in Table 3. The research contribution of 48 articles can be categorized into six main thematic areas as shown in Table 4, such as Collaborative Learning Contribution, Mobile App development as a supporting tool for collaborative learning, use of Web 2.0 technologies to enhance collaborative learning, the introduction of models for mobile collaborative learning, and algorithm generation for group formation and integration.

In engineering education, the development of mobile agents or multi-agent-based architectures was extremely popular. There is only one article in the literature that discusses the use of augmented reality technologies in engineering education over the last decade. Additionally, mobile instant messaging, SMS, chat applications, and a forum were evaluated as mechanisms for collaborative learning.

Engineering education also has a demand for mobile application development. Eight journal articles described artificial intelligence-enhanced mobile game-based

Table 3 The number of student participants in the studies

Author/s	Number of students/ Sample Size
Alnabhan et al. (2018)	135
Atawneh et al. (2020)	26
Huang et al. (2014)	63
Temdee (2014)	50
Ryu et al. (2012)	45
Lim et al. (2019)	14 and 21
Temdee (2016)	50
Chung et al. (2017)	58 and 61
Lee et al. (2016)	25
Sun et al. (2016)	100
Manathunga and Hernandez-Leo (2018)	100
Reychav et al. (2015)	251/112
Alioon and Delialioglu (2019)	30 and 33
Ma et al. (2020)	165
MacCallum et al. (2017)	30
Domínguez et al. (2017)	25
Albers et al. (2017)	118
Ramírez-Donoso et al. (2017)	68 and 34
Brett (2011)	1121
Chew et al. (2018)	7 teachers
Dyson et al. (2018)	316
Zhu et al. (2019)	144
Chen et al. (2015)	80 60 77
Snoussi et al. (2020)	284
Muhisn et al. (2019)	109
Araújo et al. (2017)	121
Lopez Garcia et al. (2016)	21
Lin et al. (2016)	simulated 50 real 117
Son et al. (2016)	258
Chuang (2015)	200
Laru et al. (2015)	10 22 21
Balakrishnan B	30
Zhou et al. (2014)	57
Huang et al. (2010), Choi and Kang (2012), Scott and Benlamri (2010), Bhati and Song (2019), Calvo et al. (2017), Sun et al. (2018), Osman et al. (2018), Acedo et al. (2017), Cabada et al. (2011), Troussas et al. (2020), Yafie et al. (2020), Garshasbi et al. (2019), Yannibelli and Amandi (2012), Al-Abri et al. (2017)	Not mentioned
Rodriguez-Andina et al. (2010)	No student involves

Table 4 Six thematic areas of research articles during 2010 to 2020

Author	Collaborative learning contribution [10] 21%
(Atawneh et al., 2020; Ryu & Parsons, 2012; Temdee, 2014, 2016)	A mobile agent, multi-agent-based architecture
(Fonseca Escudero et al., 2017)	Using digital image processing techniques, and (b) creating 3D virtual environments in different formats, including AR
(Bhati & Song, 2019; Brett, 2011; Lim et al., 2019)	Mobile instant messaging, SMS
(Calvo et al., 2017)	Chat applications
(Reychav et al., 2015)	Forum -MOOC
<i>Mobile App development [8] 17%</i>	
(Chung et al., 2017)	Push–pull technology-based mobile learning system
(Lee et al., 2016)	Mobile learning game designed
(Alioon & Delialioğlu, 2019)	Mobile game-based learning application which incorporates artificial intelligence techniques
Alnabhan et al. (2018)	m-learning context prototype
(Troussas, Krouska, and Sgouropoulou 2020)	Mobile game-based learning application which incorporates artificial intelligence techniques
(Chew et al., 2018)	Game-based learning, mobile learning, flipped classroom, and seamless learning
(Son et al., 2016)	MyResponse mobile app
(Snoussi et al., 2020)	Collaborative mobile seamless learning (CMSL) based on android apps
<i>Web 2.0 technologies [10] 21%</i>	
(Huang et al., 2010)	Web 2.0 learner-oriented mobile learning knowledge networks forming of collaborative groups dynamically
(Choi & Kang, 2012)	Helps in obtaining learning-related information on the Internet through social network services
(Sun & Shen, 2016)	The cloud-based Jigsaw Classroom
(Cabada et al., 2011)	Software tool (EDUCA) to create adaptive learning material in a Web 2.0 collaborative learning environment
(Manathunga & Hernández-Leo, 2018)	It includes an authoring tool training workshops, valued positively PyramidApp features
(Balakrishnan, 2015)	Google Docs and adoption of CSCL using Google Docs
(Huang et al., 2013)	Jigsaw-based cooperative learning strategy with Google +
(MacCallum et al., 2017)	Web 2.0, Google Drive, Google +, social media and mobile tools
(Albers et al., 2017)	WhatsApp, Instagram, Twitter, KIK
(Laru et al., 2015)	Write blog entries cloud-based Wikispaces wiki service Flickr, WordPress, and Wikispaces
(Muhisn et al., 2019)	Integrating social media tools
<i>Model Creation [9] 19%</i>	
(Scott & Benlamri, 2010)	Near Field Communication (NFC) technology

Table 4 (continued)

Author	Collaborative learning contribution [10] 21%
(Osuna Acedo, Gil Quintana, and Cantillo Valero 2017)	Evaluation of the authoring tool
(Ma et al., 2020)	Collaborative learning, connectivism, and experiential learning
(Osman et al., 2018)	The model was utilized to design a questionnaire for a survey about user acceptance
(Dyson & Frawley, 2018)	Self-reported learning
(Zhu et al., 2019)	Transition-rate analysis, entropy-analysis, and sequential pattern mining to analyze the chat message
(Chen and;Dong, Jang;Anthony 2015)	Digital content can be provided as personalized assistance
(Yafie et al., 2020)	Everyday Informal Learning through what is being offered via self-direction
<i>Group Formation [3] 6%</i>	
(Garshasbi et al., 2019)	Developed intelligent algorithm in the optimal group formation process
(Yannibelli & Amandi, 2012)	Deterministic crowding evolutionary algorithm to assist teachers when forming well-balanced collaborative learning teams
(Lin, Chang, and Chu 2016)	Genetic Algorithm (GA)—facilitating the tradeoff multi-objective grouping optimization
<i>Learning Environment [8] 16%</i>	
(Al-Abri et al., 2017)	Integrated into the Classroom experience, a multimedia capture platform for educational environments
(Araújo et al., 2017)	Classroom eXperience (CX) platform
(Lopez Garcia et al., 2016)	Remote Labs, Debates, Work in groups
(Chuang, 2015)	Smartphone-Supported Collaborative Learning System (SSCLS)
(Sun et al., 2018)	A smart microlearning environment (MOOC)
(Ramírez-Donoso et al., 2017)	LMS-MOOC
(Zhou et al., 2014)	Moodle-based learning system
(Rodriguez-Andina et al., 2010)	About the novel approaches

learning applications. It met the research's search criteria, and the majority of them have attempted to increase interactions through the development of mobile game-based learning applications. As part of collaborative learning activities, Web 2.0 technologies such as cloud-based Jigsaw Classroom, Google Docs, WhatsApp, Instagram, Twitter, KIK, write blog entries, cloud-based Wikispaces, wiki service, Flickr, WordPress, and Wikispaces were used.

The development of algorithms for optimal group formation and team composition, as well as the introduction of new models for collaborative learning, have made a significant contribution to engineering education. MOOCs, virtual labs, and

learning management systems have all been used as collaborative learning environments in engineering education over the last decade.

When subject areas of review articles are analyzed, the majority of research is conducted in computer science, electronic, or electrical engineering. According to the review, 32 articles failed to specify the subject area for which the research was evaluated or tested. The most frequently repeated subjects in the selected studies are “artificial intelligence” (3 times), “information and communication technologies” (2 times), and “learning technologies” (2 times).

As shown in Table 5, Nine articles were used mixed-method, case study, and experimental designs to analyze the aforementioned learning environments and the effectiveness of developed models and algorithms. Since it would be easy for researcher to practice with different sample sizes and participants with the changes of demographic factors. To create mobile applications, learning environments, and agent-based systems, methodologies of action research, prototyping, and experimentation were used enormously (14 articles), because those research methods

Table 5 Distribution of research methodologies used in review articles

Authors	Research methodology
(Albers et al., 2017; Atawneh et al., 2020; Brett, 2011; Calvo et al., 2017; Dyson & Frawley, 2018; Osuna Acedo et al., 2017; Troussas et al., 2020; Zhou et al., 2014)	Mixed method, Case studies
(Cabada et al., 2011; Chung et al., 2017; Fonseca Escudero et al., 2017; Lee et al., 2016; Lin et al. 2016; Ma et al., 2020; Manathunga & Hernández-Leo, 2018; Son et al., 2016)	Experimental design
(Laru et al., 2015; Lopez Garcia et al., 2016; Mac-Callum et al., 2017; Ryu & Parsons, 2012; Scott & Benlamri, 2010)	Case studies
(Choi & Kang, 2012; Garshasbi et al., 2019; Scott & Benlamri, 2010)	Action research qualitative research approach
(Balakrishnan, 2015; Huang et al., 2010; Muhisn et al., 2019; Osman et al., 2018; Reychav et al., 2015; Snoussi et al., 2020; Temdee, 2016)	questionnaire surveys and Empirical Study
(Alioon & Delialioğlu, 2019; Bhati & Song, 2019; Ramírez-Donoso et al., 2017)	design-based research approach, mixed methods
(Al-Abri et al., 2017; Garshasbi et al., 2019; Yannibelli & Amandi, 2012)	Algorithm generation and Experiments
(Sun et al., 2018)	Prototype
(Chew et al., 2018; Rodriguez-Andina et al., 2010)	Qualitative methods
(Zhu et al., 2019)	Control group
(Lu et al., 2015; Temdee, 2014)	pre-test as well as a post-test
(Yafie et al., 2020)	Ghirardini model is a modification of ADDIE and Expert Judgment
(Araújo et al., 2017)	As a proof of concept
(Chuang, 2015)	Delphi method

supported to researcher to carry out the design or artifact iterative incremental manner and researchers emphasized the empirical experience in both experimental environments and real scenarios. Additionally, qualitative and quantitative analyses were discovered to carry out the research, although the amount of qualitative research was relatively small.

Discussion

With the integration of new technology, distinct classrooms and learning environments (e.g., game-based learning, flipped classroom, seamless learning) are being displaced by new pedagogies, applications, and concepts in the field of educational technology. It has grown rapidly and vitally. The integration of mobile smart devices has had a significant impact on modern education. Harasim et al. (1995) defined online collaborative learning as “a process in which two or more individuals work collaboratively to create meaning, explore a topic, or improve skills.” Mobile collaborative learning contributed significantly to increasing mobility and collaboration without regard for time, pace, or location constraints (Makewa et al., 2014).

From 2010 to 2020, a review of the research literature reveals a range of approaches and methodologies, including experimental, action, case study, Delphi, qualitative, quantitative, and design research as shown in Table 5. The methods vary according to the theoretical framework used by the researcher, and the studies also vary in their goal of collaborative learning, which may include app development, enhancing interactions, improving content sharing capabilities, developing mechanisms or algorithms for effective group formation, supporting asynchronous and synchronous communication, and utilizing various applications, such as platforms. For example, Acedo et al. (2017) developed a bidirectional communication model that engages students by making them feel like co-participants in a unique experience. Additionally, Arajo et al. (2017) developed an educational support tool for recording classes in instrumented settings, storing captured multimedia content, and making it accessible to students for revision. It is a significant effort and a contribution to the mobile learning environment.

The review of the literature revealed a dearth of research on the effects of group size on mobile collaborative learning. However, the learning group should be small enough to allow students to participate fully and to foster group cohesion (Barker, 2007; Tuckman, 1965). A larger group size may detract from the learner's experience. Groups can be formed in a variety of ways. A group's membership can be determined by the teacher, selected by students, or randomly assigned, and the groups can be heterogeneous or homogeneous. In this study, random group formation and student-selected groups were discovered in review articles (Lopez Garcia et al., 2016; Sun & Shen, 2014; Zhu et al., 2019). In the field of engineering education, it is critical to have a diverse group of members; these groups expose the learner to a variety of perspectives on issues and tasks, based on the diverse backgrounds and experiences of the group members, as revealed in the literature. Lin et al. (2016) created a web-based group support system to assist educators in grouping homogeneous intergroup and heterogeneous intragroup members appropriately. However, and Garshasbi et al. (2019) developed an

intelligent algorithm for the optimal group formation process that efficiently divides learners into inter-homogeneous and intra-heterogeneous learning groups. Additionally, Yannibelli and Amandi (2012) created an algorithm to aid teachers in forming balanced collaborative learning teams.

When it comes to collaborative learning, many different methodologies can be used. Some of the most common are think-pair-share; informal collaborative learning groups; and formal collaborative learning groups. Other collaborative learning methodologies include problem-based and collaborative-based groups; and jigsaw collaborative learning. In accordance with the review articles, the majority of the articles were devoted to formal collaborative learning as well as jigsaw collaborative learning (Huang et al., 2010, 2013; Sun & Shen, 2016). Yafie and colleagues (2020) considered informal collaborative mobile learning based on Android apps as part of their research (Yafie et al., 2020).

As defined by the definition of collaborative learning, student interaction is critical. In technology-enhanced learning environments, various types of interaction occur. As an example, there are learner-content (LC), learner-teacher (LT), learner-learner (LL), and learner-interface (LI). Nonetheless, there are five studies (Atawneh et al., 2020; Calvo et al., 2017; Chuang, 2015; Lim et al., 2019; Temdee, 2016) that focused primarily on interaction monitoring in this study. When researchers were developing agent-based applications, they took into account the aforementioned interaction types. For instance, Atawneh et al. (2020) defined four distinct types of agents: learner agents, teacher agents, device agents, and social agents. Lim et al. (2019) used mobile instant messaging to attempt to increase LT and LL interactions. Temdee, P. (2014) developed an agent-based model for collaborative interaction. Additionally, Calvo et al. (2017) enhanced interactions through the use of the Edmodo chat application.

Conclusions

Based on a 10-year review study conducted in recent years, this paper presents an investigation into the use of mobile collaborative learning for engineering education during the last decade (2010–2020). Using specific search terms keyed into two large scientific electronic databases, we were able to identify forty-eight (48) papers that discussed the use of mobile collaborative learning in engineering education. It appears from the review articles that mobile-based collaborative learning is becoming increasingly popular, particularly in engineering education where the majority of activities were experimental and student-oriented. Mobile learning is a vast field, and it has been discovered that there are numerous opportunities for research in this area that have not yet been explored in the context of engineering education.

Identified gaps and future research

This systematic review identified research gaps and research opportunities in the area of mobile collaborative learning in engineering education, and it made recommendations for future research. First and foremost, the majority of the articles

chosen were concerned with mobile app development and agent-based applications. There has only been a small amount of research conducted on various types of web 2.0 applications for collaborative learning in engineering. In addition, collaborative learning allows for more interactions to take place. But only a few studies have been done on the topic of interaction monitoring in mobile collaborative learning in engineering education, according to the authors of the paper.

For the second time, the findings of this systematic review revealed that the pedagogy involved in engineering education has not been adequately addressed when designing engineering courses for mobile collaborative learning environments. It is possible to incorporate virtual laboratories into engineering curricula, which is a novel screening technique that can shape engineering education. Third, according to the findings of this systematic literature review, when implementing mobile collaborative learning in engineering education, two articles used a design-based research approach to do so. Finally, engineering education encompasses a wide range of disciplines such as civil engineering, chemical engineering, material engineering, and many others. However, the studies included in this review were restricted to computer engineering, electrical engineering, and electronic engineering. In order to investigate mobile collaborative learning for other engineering disciplines, there are numerous opportunities to do so.

Limitations

The scope of this review was limited to articles indexed in two databases: Web of Science and SCOPUS, with publication dates ranging from 2010 to 2020. While it is believed that the publications in these databases will have a significant impact on the field, it is possible that they will not include the most recent research because articles published in top-ranked journals take several years to publish. However, because this study's findings and recommendations are based on peer-reviewed research, the findings may be limited to studies that established statistically significant findings. Despite the small number of papers included in this review, the selection procedure was methodical to avoid bias in the results. Future evaluations may seek to increase the number of articles reviewed by utilizing additional databases and including conference proceedings and open-access journals in order to obtain more current research trends.

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