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What do we do when we analyse the temporal aspects of computer-supported collaborative learning? A systematic literature review

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ABSTRACT

To better understand the premises for successful computer-supported collaborative learning (CSCL), several studies over the last 10 years have analysed the temporal aspects of CSCL. We broadly define the temporal aspects of CSCL as focusing on the characteristics of or interrelations between events over time. The analysis of these aspects, however, has been loosely defined, creating challenges regarding the comparability and commensurability of studies. To address these challenges, we conducted a systematic literature review to define the temporal analysis procedure for CSCL using 78 journal papers published from 2003 to 2019. After identifying the key operations to be included in the procedure, we studied how the studies implemented these operations. When analysing the temporal aspects of CSCL, six key operations were conducted: (a) proposing theoretically framed research questions (mostly descriptive) regarding the temporal aspects of CSCL; (b) setting up the context (mostly online interaction mediated by communication technologies); (c) collecting process data (mostly asynchronous online discussions); (d) conceptualising events from the process data (mostly communication units, such as messages); (e) conducting one or more temporal analysis methods (mostly social network analysis or sequential analysis); and (f) interpreting the outcomes with the temporal analysis and possible data or method triangulation (mostly sequences of two or more events that had to do with learner interaction or thoughts and ideas developed in the interaction). The temporal analysis procedure can help design both theory-driven studies and methodological experiments advancing CSCL research. Overall, our study increases scholarly understanding regarding the temporal aspects of CSCL.

1. Introduction

Since its development, research on computer-supported collaborative learning (CSCL) has included a wide range of theories, technologies, and methodologies. CSCL is a constellation of certain types of (a) *shared learning processes*, for example, knowledge

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building (Khanlari, Resendes, Zhu, & Scardamalia, 2017) and group cognition (Stahl, 2017) or (b) *shared learning activities*, for example, elaboration and co-elaboration (Lund, 2019), and argumentation (Valero Haro, Noroozi, Biemans, & Mulder, 2019), which occur in a computer-supported setting. However, a collaborative activity in computer-supported settings does not itself automatically produce learning. Instead, the quality of CSCL depends on whether a group of learners can build new knowledge or improve their shared conceptual understanding by interacting with each other in a computer-supported setting during their shared learning processes or activities (Hämäläinen & Vähäsantanen, 2011). Therefore, the core aim of CSCL research is to understand technologically mediated peer interaction processes and their outcomes (Cress, Rosé, Law, & Ludvigsen, 2019).

Current research on CSCL stems from the evaluation of learning outcomes and collaborative learning processes in computer-supported settings. More specifically, the research has focused on the effects of either using technologies in collaborative learning or implementing a specific technological tool or strategy in collaborative learning settings (Chen, Wang, Kirschner, & Tsai, 2018). Jeong, Hmelo-Silver, and Yu (2014) noted that the most typical analysis methods in CSCL contexts were inferential statistics and the coding-and-counting approach. In these methods, the assumption of the temporal homogeneity of CSCL is made in both the long and short terms. Long-term temporal homogeneity means that the effects of independent or explanatory variables (e.g., the coded units of analysis) on the dependent variable are assumed to be constant in long temporal contexts (Chiu & Khoo, 2005; Reimann, 2009). This long temporal context may include the whole CSCL session or a sequence of sessions, so that the coded units are aggregated over these sessions. By short-term temporal homogeneity, we mean that the coded units of analysis are interpreted as being isolated from a short temporal context. This short temporal context may include the previous and following units of analysis. These assumptions, however, have been proven to be partly incorrect (e.g., Kapur, Voiklis, & Kinzer, 2008), and the temporal heterogeneity of CSCL should be considered in the long and short terms. Thus, analysis methods, which only reveal the changes that have occurred or which produce cumulative frequency counts of CSCL, are not enough. Ludvigsen, Cress, Rosé, Law, and Stahl (2018) and Stahl (2017), for example, have challenged CSCL research to further develop its practices to advance the understanding of the premises for successful CSCL. To address this challenge, CSCL research needs approaches that consider CSCL as a process unfolding over time.

Today, capturing various process data (e.g., video, audio, or log data) is easier than ever, making it possible to analyse CSCL as a process that unfolds over longer periods of time (Mercer, 2008). Using such process data raises the question of how to approach this kind of data methodologically (e.g., Bridges, Hmelo-Silver, Chan, Green, & Saleh, 2020; Kapur, 2011). One solution is to consider events of interest that the process data reveals (Reimann, 2009, 2021). In the current article, we use the term "temporal aspects of CSCL" when analysing these events to understand CSCL as a process unfolding over time. Thus, we broadly define the temporal aspects of CSCL as focusing on the characteristics of events or the interrelations between these events over time. Because we recognise both that making sense of the characteristics of events and the interrelations between these events over time may be challenging and that researchers must balance accuracy, generality, and simplicity when developing theories based on the temporal aspects of CSCL (Langley, 1999), our aim is to determine what actually occurs when the temporal aspects of CSCL are analysed. Interpreting CSCL as a process unfolding over time can occur after researchers perform a set of actions. To assist researchers in conducting actions consciously and deliberately, a temporal analysis procedure is required for CSCL. We define the temporal analysis procedure for CSCL to include a set of dependent key operations. The key operations are theoretically and methodologically motivated actions, which researchers decide and which outline the research procedure. The key operations, thus, help to establish the practices for conducting the temporal analysis of CSCL. Moreover, identifying the temporal analysis procedure, its key operations, and their implementations may also reveal the implicit conceptualisations of the temporal aspects of CSCL, whose analysis has been seen as one of the most promising trends in learning research (Ludvigsen et al., 2018).

2. Aims

A body of literature addressing the temporal aspects of CSCL is emerging, but the research on these aspects is scattered across different theoretical approaches, research aims, and methodologies. Particularly, the lack of temporal analysis procedure for CSCL reduces the comparability and commensurability of studies. Thus, a synthesis of the emerging literature is indispensable. We conducted a systematic literature review that provides a "roadmap" for future studies focusing on the temporal aspects of CSCL. The roadmap is based on (i) guiding the analysis of the temporal aspects of CSCL and (ii) identifying possible research gaps. To address these aims, we answer the following research questions:

1. What are the key operations for the analysis of the temporal aspects of CSCL?
2. How are the key operations carried out when analysing the temporal aspects of CSCL?

3. Method

We followed preferred reporting items for systematic review and meta-analyses protocols (PRISMA-P; Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009; Shamseer et al., 2015) when searching and selecting the included studies. The searching and selecting process was composed of four main steps: (1) identification, (2) screening, (3) eligibility, and (4) inclusion. In the following section, we elaborate on these steps individually.

3.1. Literature search

We used three databases (ERIC, Scopus, and Web of Science) to identify peer-reviewed journal articles published in English. All searches were conducted in February 2019. Identification was executed in two phases. In the first phase, we used the search terms referring to (a) temporality, (b) collaborative learning, and (c) computer-supported learning (see Table A1). We used the AND operator to identify the articles. Depending on the options provided by the database, the search terms also had to appear somewhere other than in the main text (i.e., in the title, abstract, or keywords). We identified 236 articles, of which 79 were duplicates. We screened the titles and abstracts of these 157 articles. In this phase, we excluded 117 articles. We excluded the article if (a) the focus was not on CSCL in formal learning environments (e.g., working life contexts) from kindergarteners to higher education institutes; (b) the focus was on the role of teachers, not the interaction between learners; (c) the analysis methods did not focus on the temporal aspects of CSCL (e.g., analysing only learners' performance or conducting a content analysis with a mere coding-and-counting technique).

When screening the articles, we noticed that the authors did not necessarily refer explicitly to the term "temporality", even when they focused on the temporal aspects of CSCL (e.g., statistical discourse analysis in Molenaar, Inge, & Chiu, 2017). Thus, in 40 articles that passed the screening, we searched for analysis methods that had been employed to study the temporal aspects of CSCL. We found eight different analysis methods, which we then added to the search terms (Table A1). With these supplemented search terms, we repeated the search in the second phase of the identification and discovered 405 articles. After combining the articles from the first and second phases (445 articles in total), we removed 166 duplicates. We again screened the titles and abstracts of 279 articles. We excluded 151 articles based on the three criteria that were previously mentioned. One of the authors screened the titles and abstracts of all the articles, while a research assistant screened a randomly selected one-third of articles. Cohen's kappa indicated that there was moderate agreement between the screeners ($\kappa = 0.64$). Disagreements were solved afterwards.

We assessed the eligibility of 128 articles, basing decisions on the full texts. Here, we excluded 50 articles because (a) the outcomes did not include information about the temporal aspects of CSCL ($n = 12$); (b) the focus was not on empirical findings but on presenting new applications, systems, or frameworks with which to analyse the temporal aspects of CSCL ($n = 11$); (c) no full text was available ($n = 10$); (d) the interaction among learners was not supported with technologies ($n = 9$); (e) the focus was not on CSCL between learners ($n = 5$); and (f) the focus was not on CSCL in formal learning environments ($n = 3$). Thus, we included 78 articles for further analysis. Fig. 1 summarises our literature search procedure.

3.2. Analysis of the included literature

Two authors read all the included 78 articles: The first author read all articles, and each co-author read portions of the articles. We analysed the characteristics of each article, filling out a template with 21 items related to the different article sections (see Table A2). To answer RQ1 (What are the key operations for the analysis of the temporal aspects of CSCL?), we sequenced the research procedures presented in the included studies according to the items in Table A2. We identified the common operations implemented in the included papers and combined items under certain operations in an iterative way (e.g., forming the context of the studies involved, among other things, decisions about learner interaction and technologies used to support collaborative learning in Table A2). This bottom-up approach led to the determination of the key operations used for analysing the temporal aspects of CSCL.

To answer RQ2 (How are the key operations carried out when analysing the temporal aspects of CSCL?), we focused on the key operations identified in the previous phase of the analysis (RQ1). We formed the final codes from the bottom-up by merging our original input to eight items: (1) research aims, (2) learner interaction, (3) form of participation, (4) group size, (5) technologies used to support collaborative learning [for (5), we used the codes in Jeong, Hmelo-Silver, & Jo, 2019], (6) process data, (7) units of analysis,

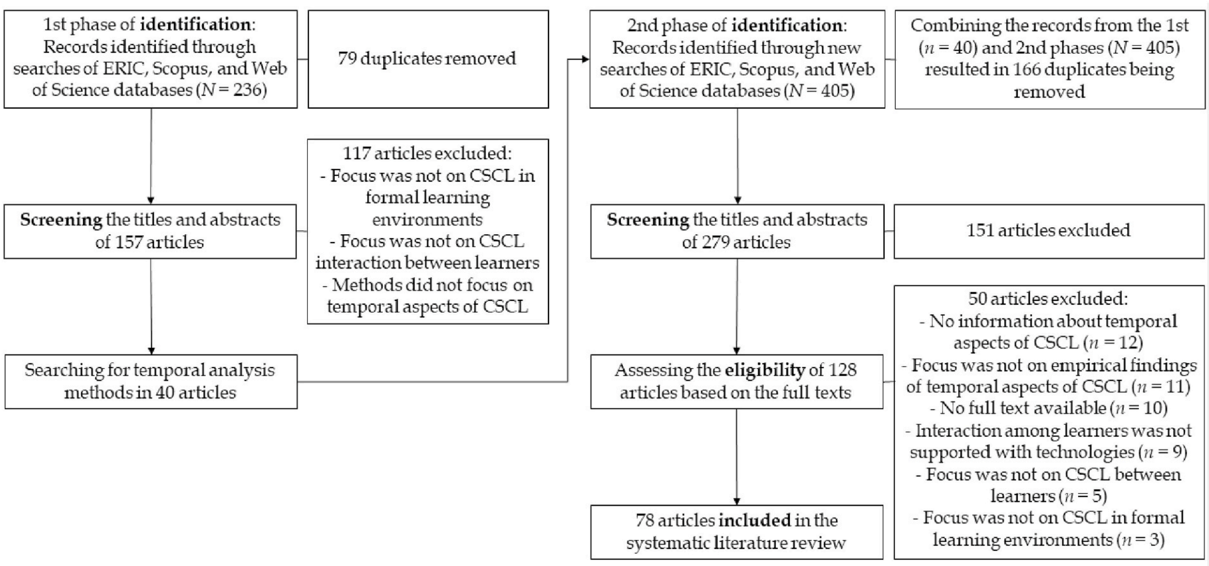

Fig. 1. Flowchart of the literature search procedure based on the PRISMA protocol.

(8) temporal analysis methods, and (9) data and method triangulation (for (9), we used the codes in Dado and Bodemer [2017]). Since a few codes would not have captured the essential features and differences between the findings and implications of the studies, we did not merge our original input to these items (see section 4.2). The codes were not exclusionary, but we could assign several codes to articles: for example, an article might have different types of aims [e.g., Wise & Chiu (2011) had both descriptive and relational aims], or the collaborative learning could be supported with various technologies [e.g., Lin, Mai, and Lai (2015) used communication technologies and sharing and co-construction technologies]. We present these nine items, their codes, and the code definitions with examples in Table A3.

We assessed the inter-rater reliability according to the codes of items (1)–(9) listed previously. We calculated Cohen's kappa (Cohen, 1960, p. 40) separately for each code as the codes were independent, that is, the presence of one code was not affected by that of another. These calculations also guaranteed that a high agreement in one code did not hide a low agreement in another code (Shaffer, 2017). Next, we set 0.7 as a threshold value of Cohen's kappa to indicate good reliability (Cicchetti, 1994). We then applied an empirical rejective method and calculated Shaffer's rho (Eagan et al, 2017, 2020; Shaffer, 2017) separately for each code by using an R-package called rhoR (Eagan, Rogers, Pozen, Marquart, & Shaffer, 2016; see Table A3). Shaffer's rho also controls for Type I error in our coding. Altogether, when Cohen's kappa >0.7 and Shaffer's rho <0.05, we considered the coding as reliable, but all the disagreements were jointly resolved among the authors. When one or both of these conditions were not met, we revised the coding manual (Table A3), and the first author and a researcher outside the current study rechecked and recoded the articles with disagreements. For example, the code of face-to-face interaction indicated lower agreement than other codes within the item "Interaction." We revised the definition of the code so that it only considered the learners' interaction upon which the analysis of the temporal aspects of CSCL is based but not face-to-face interactions amongst learners and teacher if that was not examined through temporal analysis. After this rechecking and recoding, the authors and the researcher outside the current study resolved all disagreements in common meetings.

4. Results

Overall, we found that an increasing number of studies focusing on the temporal aspects of CSCL have been published, with many of them published in various high-impact journals (e.g., *Computers & Education*, $n = 11$; *Computers in Human Behavior*, $n = 5$; *International Journal of Computer*-Supported *Collaborative Learning*, $n = 11$; *Journal of Computer Assisted Learning*, $n = 4$) over the last 10 years (see Fig. 2 and Table A4). On average, the sample size was 81 participants (SD = 163, min. 2 learners, max. 1214 learners), whereas the median was 40 (the lower quartile, 23 learners; upper quartile, 73 learners). Most of the studies ($n = 53$) were conducted in higher education contexts, whereas studies in primary and secondary schools (Grades 1–12) were rarer ($n = 17$).[1]

We divided the rest of the section into two subsections. In section 4.1, we present the key operations for the analysis of the temporal aspects of CSCL based on the included papers (Tables A2 and A3; RQ1). In Section 4.2, we describe how the included papers implemented these key operations when analysing these aspects (RQ2).

4.1. *Key operations for analysing the temporal aspects of CSCL*

We identified the temporal analysis procedure for CSCL to include six key operations, which are summarised in Fig. 3. The first key operation was to specify the temporal aspects of CSCL that should be studied to address the theoretically framed research aims. The second was to form the context of the study. The third was to decide what process data were collected. The fourth was to conceptualise the events from the collected process data. The fifth was to analyse the events by conducting one or more temporal analysis methods. The sixth was to interpret the outcomes based on the chosen temporal analysis method(s). Possible data and method triangulation provided complementary information, particularly regarding comparative and relational research aims. Fig. 3 also depicts how the included papers implemented key operations.

4.2. *The key operations implemented when analysing the temporal aspects of CSCL*

4.2.1. *Theoretical framework and research aims: Descriptive aims were the most typical*

Fig. 3 shows that the most typical research aim was to describe the temporal aspects of CSCL against the chosen framework ($n = 53$), but relational ($n = 31$), comparative ($n = 23$), and methodological ($n = 17$) aims were also addressed. The included studies did not always have strong theoretical groundings (cf. Hew, Lan, Tang, Jia, & Lo, 2019) even though we found a few frequently used theoretical frameworks through which researchers examined temporal aspects of CSCL: knowledge construction (e.g. Hou & Wu, 2011; Wise & Chiu, 2011), cognitions (e.g. Molenaar and Chiu, 2017; Wu, 2020), regulation of learning (e.g., Järvelä, Malmberg, & Koivuniemi, 2016; Malmberg, Järvelä, Järvenoja, & Panadero, 2015), and also combinations of these (e.g., knowledge construction and cognitions in Wang, Hou, & Wu, 2017; cognitions and regulation of learning in Molenaar & Chiu, 2014). Instead of advancing and extending theoretical frameworks through analysing the temporal aspects of CSCL, researchers were motivated by and justified the analysis of these aspects based on theory: There is a need to examine the characteristics of or interrelations between events over time to understand CSCL better through the theoretical framework. Even though the theoretical framework may include the assumptions of

[1] One study presented two cases: one in a higher education context and another in a secondary school context. Five studies were conducted in professional development contexts. We did not identify the educational level of the participants in two studies.

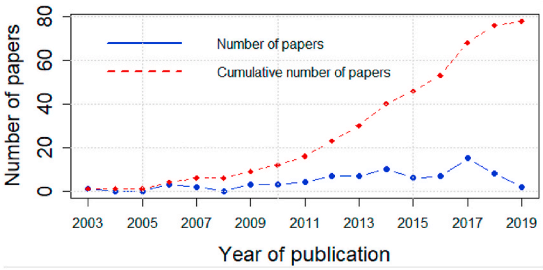

Fig. 2. Both number and cumulative number of published papers as a function of year.

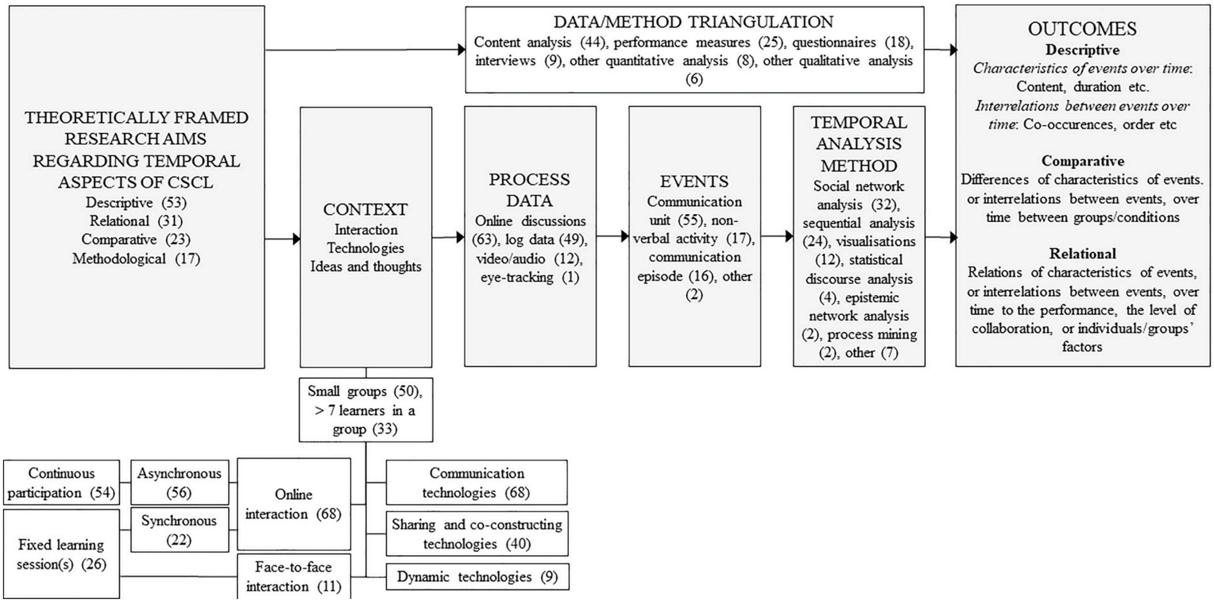

Fig. 3. The temporal analysis procedure for CSCL includes six key operations (highlighted in grey). The numbers in parentheses refer to the number of articles.

CSCL as a process, indicating the characteristics of events or the interrelations between such events over time that need to be studied, the research aims also dictate whether the temporal heterogeneity should be considered in the short or long term.

The following examples show how knowledge construction, cognitions, and regulation of learning framed different types of research aims. First, Chen, Resendes, Chai, and Hong (2017) studied CSCL through a knowledge construction framework. They argued for the need to *describe* interrelations between events over time, namely, the sequences of different types of knowledge-building contributions. In addition to the descriptive aim, Chen et al. also had a methodological aim as they contrasted the sequences revealed by two different sequential analysis methods. Second, Molenaar and Chiu (2017) studied CSCL through low- and high-level cognitive processes. They argued the need to study the *relations* between learners' performance and the interrelations of events over time (sequences of cognitions). Third, Malmberg et al. (2015) studied CSCL through socially shared regulation of learning (SSRL). They highlighted the dependency of SSRL events and the need to focus on their interrelations over time. *Comparing* the differences in these interrelations over time between high- and low-performing groups may indicate the characteristics of successful learning. Research aims and their possible theoretical framing determined how much the researchers should zoom in on or out from CSCL and thus provided the starting point for the implementation of other key operations, such as forming the context of the study (see Fig. 3).

4.2.2. Context: Communication technologies mediated online interaction

The context was built on three main pillars: (a) how the interaction between learners was arranged, (b) what technologies were used to mediate the interaction, and (c) what ideas and thoughts learners were working with (Fig. 3). First, online interactions between learners were asynchronous ($n = 46$), synchronous ($n = 12$), or both ($n = 9$). One study enabled both online interaction and face-to-face interaction. Learners only interacted face-to-face in 10 studies. We found that the duration of continuous asynchronous online discussions were expressed as units, such as a task (Medina & Suthers, 2013); a unit sequence, such as a few tasks (Shukor, Tasir, Van der Meijden, & Harun, 2014); or even a school year (Chen et al., 2017). The duration of a fixed learning session varied from 10 min (Oner, 2013) to 2 h (Chiang, Yang, & Hwang, 2014), and 15 studies focused on multiple fixed learning sessions that even lasted an entire semester (e.g., Hou & Wu, 2011).

The type of interaction may have essential implications for analysing the temporal aspects of CSCL. For example, when analysing the characteristics of or interrelations between events over time in asynchronous online discussions, researchers have to consider that the interactions may not be linear. On the one hand, learners can contribute to many parallel discussion topics. On the other hand, learners can easily interrelate current events to the previous events in a long temporal context in the same discussion thread (e.g., a student may justify their opinion by providing a link to a resource that had been shared weeks ago). Regarding the groups in which the interaction took place, we found that learners generally worked in small groups (2–7 learners; $n = 45$); however, in 28 cases, collaborative learning occurred in larger groups (more than seven learners). In a few cases, learners worked both in smaller and larger groups ($n = 5$; e.g., Tirado et al., 2015). Group size also has important implications for the analysis of the temporal aspects of CSCL. For example, negotiating common ground may be more challenging in larger groups than in smaller groups; thus, larger groups may need to be more explicit about the interrelations between current and previous events.

Second, the technologies used in 68 papers to mediate the interaction were communication technologies (e.g., Wu & Zhou, 2014). In 36 studies, these communication technologies were complemented by dynamic technologies ($n = 4$; e.g., simulations in Chang, Chang, Chiu, et al., 2017), and sharing and co-construction technologies ($n = 34$; e.g., wikis in Su, Li, Hu, & Rosé, 2018; student blogs in Sharma & Tietjen, 2016; websites where learners looked for information in Swigger, Hoyt, Serce, Lopez, & Alpaslan, 2012; or tools used to increase the awareness of CSCL among learners in Järvelä et al., 2016). Dynamic technologies were the only technological resource used in four studies (e.g., Lämsä, Hämäläinen, Koskinen, & Viiri, 2018), whereas five studies enhanced CSCL with sharing and co-construction technologies only (e.g., Schneider & Pea, 2014), and one study used both of these (Rasmussen & Damşa. 2017). Besides interaction, technologies dictate what characteristics of or interrelations between events over time are analysed. For example, if dynamic technologies are used, nonverbal activities that are related to tinkering with the technological tool may be relevant. Altogether, the context of the study also had a significant role in the process data that was collected in the third key operation.

4.2.3. Process data: Online discussions captured CSCL

Most studies focused on online interactions; thus, the process data typically included these online discussions. We found that 18 studies used online discussions as the only source of process data (e.g., Chen et al., 2017). Moreover, 41 studies used log data related to these discussions (e.g., timestamps of messages, Kapur, 2011). Even though online discussions, combined with related log data, can capture various characteristics of or interrelations between events over time concerning verbal interactions between learners, understanding how CSCL unfolds over time may require other process data as well. To complement the process data that focused on the verbal interactions, 18 studies used log data related to nonverbal CSCL activities, which learners performed in online learning environments (e.g., editing or viewing content, adding a new topic or a link; Mansur, Yusof, & Basouri, 2016). Two studies used video or audio data in addition to online discussions or log data [e.g., Lin, Hou, and Tsai (2016) used screen-captured videos for capturing learners' online searching behavior to complement an analysis of discussions in online learning environments]. Schneider and Pea (2014) studied synchronous online interactions by using video and eye-tracking data. In face-to-face interactions, transcripts based on video or audio data were used as the only process data source ($n = 9$; e.g., Lin, Duh, Li, Wang, & Tsai, 2013). Sobocinski, Malmberg, and Järvelä (2017) complemented the codings of the transcriptions, particularly the type of interaction and self-regulation phase, by using log data to characterise CSCL sessions as low or high challenge. The type of process data also plays a role in revealing the relevant characteristics of or interrelations between events over time. For example, while the duration of events is typically essential in eye-tracking data, it may not matter in asynchronous online discussions. Despite the type of process data, this data was rarely useable for analysing the temporal aspects of CSCL. As our definition of the temporal aspects of CSCL implies, conceptualising events from the process data stands at the core of analysing these aspects (see Fig. 3).

4.2.4. Events: Communication units were conceptualised

As depicted in Fig. 3, typical events were a communication unit ($n = 55$; a message, utterance, sentence, or similar; e.g., Lin, Duh, et al., 2013) or a communication episode ($n = 16$; a thread from messages or utterances; e.g., Shukor et al., 2014). This finding revealed that researchers typically captured the temporal aspects of CSCL with the help of verbal events. Nonverbal activities in learning logs were deemed as events that were then used to study the mediating role of technologies in the interaction and to complement the analysis of online discussions ($n = 10$; e.g., Chang, Chang, Liu, et al., 2017). Seven studies used these nonverbal activities as the only process data source in further analyses (e.g., Liu, Chen, & Tai, 2017). Two studies conceptualised an event so that it did not fit any of the codes depicted in Fig. 3 (e.g., challenge-strategy pairs in Malmberg et al., 2015). Collecting process data and conceptualising events do not necessarily make the analyses "temporal," but the events have to be analysed by using one or more temporal analysis methods. Depending on which characteristics of or interrelations between events over time the researchers wanted to reveal, a variety of different temporal analysis methods were utilised.

4.2.5. Temporal analysis method: Social network analysis and sequential analysis revealed the sequences of events

The temporal aspects of CSCL were analysed by conducting a social network analysis (SNA; $n = 32$), a sequential analysis ($n = 24$), different types of visualisations ($n = 12$), a statistical discourse analysis (SDA; $n = 4$), an epistemic network analysis (ENA; $n = 2$), process mining ($n = 2$), and other techniques ($n = 7$; e.g., qualitative analysis). A common feature of all the temporal analysis methods is the premise that the characteristics of or interrelations between events over time are more important than the presence or absence of the events in isolation. Distinctions between these different temporal analysis methods concern, for example, the characteristics of or interrelations between events over time that the methods reveal: Whereas SNA may focus on sequences of communication units or episodes that deal with participation and social modes of co-construction (Weinberger & Fischer, 2006) of individual learners (see

Saqr, Viberg, & Vartiainen, 2020), sequential analysis may focus on sequences of communication units or episodes that deal with epistemic or argument dimensions (Weinberger & Fischer, 2006) of group communication. In Table 1, we summarise the conjunctive and distinctive features of the temporal analysis methods found in the included studies that may help to find a suitable method for the specific study. In the following, we briefly describe the temporal analysis methods individually.

An **SNA** reveals the structure of relations (called edges) between a group of actors [called nodes; see a review of the concepts in Dado and Bodemer (2017)] by considering event sequences (e.g., a learner posts a message after which another learner replies to the message that considers the short-term temporal heterogeneity of CSCL). These relations can be directed (the order of events in the sequence is considered) or nondirected (the order of events is ignored). In SNA, essential questions ask which actors are active and how their activeness emerges (de Laat, Lally, Lipponen, & Simons, 2007) instead of focusing on the content of the messages. These questions are addressed by reporting descriptive statistics about the networks, visualisations of the networks called sociograms (see an exception in Stepanyan, Mather, & Dalrymple, 2014), or both. The descriptive statistics can include network metrics associated with an individual actor (with local measures such as the centrality of the learner) or a group as a whole (with global measures such as cohesion).

A **sequential analysis** includes a lag sequential analysis (LSA), which reveals the event sequences that occur more often than would be expected by chance (Bakeman & Gottman, 1997), and frequent sequence mining (FSM), which discover which event sequences occur most frequently (Chen et al., 2017). In a sequential analysis, the order of events in the sequence matters. In the following description, we focus on LSA because it was the most popular sequential analysis method in the included articles. The amount of data usually restricts the length (l) of analysed event sequences because the number of possible sequences increases exponentially as a function of l. Thus, researchers typically focus on the sequences of two events (lag 1, $l = 2$) that are statistically significant. In general, these statistically significant sequences are not the most frequent sequences (cf. FSM). Moreover, the results of an LSA do not reveal the actual progress of CSCL: LSA provides the sequences of interest without information about the mutual order or the time instant of the sequences and thus ignores the long-term temporal heterogeneity of CSCL.

Visualisation, a method in its own right, reveals the characteristics of or interrelations between events by focusing on content, duration, order, or co-occurrences of events so that the temporal heterogeneity of CSCL may be considered in the short and long terms. When interpreting large data sets, visualisations may also reveal trends and regular fluctuations (cf. time series analysis) that are hard to capture otherwise. Despite the various characteristics of or interrelations between events over time, which can be studied with the help of visualisations, there are also restrictions. Namely, similarities and differences between visualisations cannot be tested statistically, but visualisations are frequently used in conjunction with other methods. In fact, visualisations are frequently seen as "an intermediary step," as Langley (1999, p. 702) explained, between raw data and more abstract conceptualisations of the phenomenon.

A **SDA** reveals the event sequences, including the order of events, by utilising a regression analysis and demonstrating how the previous events predict the events under interest (temporal heterogeneity in the short term). A SDA combines (a) the identification of time periods of learning processes via breakpoints; (b) multilevel logistic regressions; and (c) tests for serial correlation (Chiu & Khoo, 2005). First, identifying distinct time periods of the learning processes via breakpoints captures differences across time periods. These distinctions follow the assumption of temporal heterogeneity in the long term (Kapur et al., 2008). Second, conducting a multilevel logistic regression analysis aims to model differences across learners or groups, learning sessions, and time-period-specific effects. The multilevel models are needed when learners, groups, and learning sessions are heterogeneous. Third, testing serial correlation reveals whether the events resemble other recent events because events in a sequence may not be independent.

An **ENA** reveals event co-occurrences by modelling "patterns of association in any system characterised by a complex network dynamic relationships among a relatively small, fixed set of elements" (Shaffer, Collier, & Ruis, 2016, p. 10). In an ENA, the focus in learning contexts is on the co-occurrence of learning events instead of learning events per se. Researchers must characterise the co-occurrence, or "stanzas," after which the events in the same stanza are connected, whereas the events in different stanzas are not (Shaffer et al., 2016). The findings of an ENA are illustrated with networks, so that nodes correspond to the learning events and edges indicate the frequency of event co-occurrences. Even though these networks consider the short-term temporal heterogeneity of CSCL, one method to examine the long-term temporal heterogeneity is monitoring the position of the network's centroid over time. Determining the centroid of the networks also allows a comparison between different networks. An advantage of analysing the whole network, however, is that the analysis may reveal differences between the networks that are not visible when one focuses on mere descriptive statistics.

Process mining refers to a set of data mining methods that build on a process model (Bannert, Reimann, & Sonnenberg, 2014) that may be used to examine both the long-term and the short-term temporal heterogeneity of CSCL. Depending on the specific method, process mining can reveal both the event sequences, including the order of events, and co-occurrences by identifying, confirming, or extending process models based on events (see Reimann, 2009). Because process mining has different methods for analysing events, the choice of the method has consequences for the interpretations of the findings (Bannert et al., 2014). For example, if process models are built inductively, it may be challenging to infer whether differences in the models between two or more groups are significant. Instead, methods of conformance checking can be conducted for theory-based models, illustrated as a Petri net, for example. In educational research contexts, process-mining techniques have been seen as tools "for model and theory development rather than statistical testing" (Bannert et al., 2014, p. 181).

The choice of the temporal analysis method guides what kind of outcomes relating to the temporal aspects of CSCL can be achieved, such as whether the outcomes consider short- or long-term temporal heterogeneity of CSCL and how CSCL is illustrated as a process (see Table 1). In the following section, we demonstrate how the different temporal analysis method provides different kinds of lenses to examine knowledge construction in CSCL settings.

Table 1
Distinctions between the different temporal analysis methods.

Method/ Characteristic	Social network analysis	Sequential analysis	Visualisations	Statistical discourse analysis	Epistemic network analysis	Process mining
Characteristics of events or interrelations between events over time	Sequences of events	Sequences of events, including the order of the events	Depends on the research aims, context, process data, and events	Sequences of events, including the order of the events	Co-occurrences of events	Sequences of events, including the order of the events; co-occurrences of events
Assumptions about the CSCL as a process	Sequential process; the social networks indicate the information flow amongst learners in CSCL	Sequential process; the sequences are random realisations of an underlying stochastic process	Depends on the research aims, context, process data and events	Sequential process; events in sequences are dependent and data, which captures the process, has heterogeneity	The process is the transformation of an epistemic network that includes temporally connected (co-occurring) events; the events and their connections change over time	Sequential process; latent, even deterministic process governs these event sequences
Consideration of the temporal heterogeneity (the size of the temporal context)	Short-term (sequences of a few consecutive events)	Short-term (sequences of a few consecutive events)	Short- or long-term or both that depends on the research aims, context, process data, and events (the CSCL as a process is typically considered holistically)	Short- and long-term (breakpoints divide the process into parts, in which the sequences of a few consecutive events are analysed separately)	Short-term (determined by the size of the stanza in which events are considered to co-occur) and long-term (determined by the position of the network's centroid over time)	Short- and long-term (the CSCL as a process is considered holistically)
Illustration of the CSCL as a process	Sociograms	Transition diagrams	Depends on the research aims, context, process data and events	Transition diagrams	Epistemic network graphs	Transition diagrams from the beginning of CSCL to the end of CSCL
Possibility for multilevel modelling	No	No	No	Yes	No	Yes, but not used in the included studies
Possibility for comparing groups/conditions statistically	Yes	No	No	Yes	Yes	No/yes
Research aims addressed in the included studies	Descriptive: 21 Comparative: 11 Relational: 13 Methodological: 7	Descriptive: 17 Comparative: 11 Relational: 7 Methodological: 3	Descriptive: 10 Comparative: 0 Relational: 5 Methodological: 5	Descriptive: 1 Comparative: 0 Relational: 4 Methodological: 0	Descriptive: 0 Comparative: 1 Relational: 1 Methodological: 2	Descriptive: 2 Comparative: 1 Relational: 1 Methodological: 0

4.2.6. Outcomes: Better understanding on learner interaction, thoughts and ideas developed in the interaction, and use of technological resources in short temporal contexts

The included papers used various theoretical frameworks and methodologies, but, in general, the outcomes focused on the temporal aspects of CSCL (i.e., characteristics of and interrelations between events over time) so that the events are related to (a) learner interaction (e.g., who is talking), (b) thoughts and ideas developed in the interaction (e.g., what is talked about), and (c) use of technological resources to mediate the interaction (e.g., what nonverbal activities are conducted). We also found that 65 studies complemented an analysis of the temporal aspects of CSCL with data and method triangulation (Fig. 3). Researchers conducted content analysis ($n = 44$[2]), performance measures ($n = 25$), questionnaires ($n = 18$), interviews ($n = 9$), other quantitative analysis (including descriptive statistics, $n = 8$), and other qualitative analysis ($n = 6$). As the most frequent temporal analysis methods (SNA and sequential analysis) considered the short-term (as opposed to the long-term) temporal heterogeneity of learning (see Table 1), the outcomes in particular provided insights into productive sequences of a few consecutive events in CSCL.

In terms of the events related to learner interaction, Tirado, Hernando, and Aguaded (2015) conducted an SNA and found positive associations between global SNA measures, which consider the short-term temporal heterogeneity of learning (a sequence of sent and received messages), and the quality of the collaborative knowledge construction. Namely, both cohesion and centralization of a group positively correlated with social and cognitive presence in knowledge construction. Regarding events related to thoughts and ideas developed in the interaction, Wise and Chiu (2011) conducted an SDA and increased understanding of both long-term and short-term temporal heterogeneity of collaborative knowledge construction. For long-term temporal heterogeneity, Wise and Chiu identified pivotal posts from student discussions that divided the discussion into several segments: In the latter segments, the more high-level knowledge construction usually occurred than the former segments. For short-term temporal heterogeneity, they also found associations between the characteristics of current and previous events with the level of collaborative knowledge construction. For events related to the use of technological resources to mediate the interaction, Chang, Chang, Chiu, et al. (2017) conducted an LSA and studied the short-term temporal heterogeneity in learners' collaborative problem-solving that they found to be rooted in construction of shared knowledge and understanding of the problem. They noted that poorly performing groups unsystematically first tested and then tried various solutions, whereas better-performing groups systematically first planned and then executed clear actions to solve the problem.

5. Discussion

In addition to addressing the questions regarding what learning occurs, CSCL research should also focus on how learning occurs (Ludvigsen & Steier, 2019). To address these how questions and to better understand the building blocks of productive CSCL, many researchers have recognised the need to examine the temporal aspects of CSCL. Despite the advantages of analysing the temporal aspects of CSCL, the lack of procedure for addressing how learning occurs reduces the comparability and commensurability of the studies (Knight, Wise, & Chen, 2017; Molenaar, 2014). Thus, valuing and addressing the question how learning occurs, CSCL research calls for more systematic and theoretically and methodologically motivated actions to advance future studies. To address this aim, we first performed a systematic literature review and defined the temporal analysis procedure for CSCL. The procedure included a set of six dependent key operations (1. proposing theoretically framed research questions regarding the temporal aspects of CSCL; 2. setting up the context; 3. collecting process data; 4. conceptualising events from the process data; 5. conducting one or more temporal analysis methods; 6. interpreting the outcomes with the temporal analysis and possible data/method triangulation) that may form established practices of conducting the temporal analysis of CSCL in the future (RQ1; Fig. 3). Finally, we studied how the key operations were implemented in the included papers (RQ2; Fig. 3).

Papers on analysing the temporal aspects of CSCL are increasing rapidly (Fig. 2). Accordingly, our sample of 78 articles demonstrate great variation regarding how the temporal aspects of CSCL have implicitly been conceptualised and how this research area is developing (RQ2). Particularly, our findings reveal novel understanding on how the temporal aspects of CSCL focus on the characteristics of and interrelations between events over time. First, we found that the events concern (a) learner interaction (e.g., who is talking revealed by SNA in Lin et al., [2015]), (b) thoughts and ideas developed during the interaction (e.g., what is talked about revealed by SDA in Molenaar & Chiu [2014]), and (c) the use of technological resources to mediate the interaction (e.g., what nonverbal activities are conducted, revealed by LSA in Chang, Chang, Liu, et al., [2017]). Second, depending on the temporal analysis method that the researchers perform, "over time" in the definition may refer to consideration of temporal heterogeneous in the short or long term (see Table 1). For example, Lin, Duh, Li, Wang, and Tsai (2013) conducted LSA and examined what kind of ideas and thoughts are followed by high-level knowledge construction (temporal heterogeneous in the short term; cf. Markov chains that assume that the current state depends only on the previous state). Wise and Chiu (2011), in turn, conducted an SDA to identify pivotal posts from students' discussions that divided the whole discussion into segments in which the level of knowledge construction varied (temporal heterogeneous in the long term). If the temporal aspects of CSCL are conceptualised so that the interrelations between events over time refer to the sequences of two or more events (temporal heterogeneous in the short term), caution must be exercised when this information is used to understand CSCL as a process unfolding over time. Namely, without the information about when the event sequences emerge (temporal homogeneous in the long term), researchers may ignore that "a fast, microscopic event can trigger a cascade, an amplifying avalanche of consequences that grows to a much larger, longer-term scale (Lemke, 2000, p. 280) or "critical

[2] A content analysis was frequently used because events (particularly communication units and episodes) were coded according to the coding manual of the study. The nontemporal outcomes of 'coding-and-counting' were also reported.

instances of what makes – learning successful based on the theory" (Malmberg et al., 2015, p. 571) (cf. the pivotal passages in Wise & Chiu [2011]).

Even though our temporal analysis procedure provides a good starting point from which to increase the comparability and commensurability of future studies focusing on the temporal aspects of CSCL, the following limitations have to be considered. First, the interpretation and adaption of the key operations must be carefully adapted to the contexts of various theoretical and methodological frameworks in CSCL research. For example, Van Laer and Elen (2018) proposed a methodological framework for sequence analysis in the field of self-regulated learning. Thus, we call for more research regarding these adaptation processes. Second, in the current systematic literature review, we confined ourselves to peer-reviewed journal articles published in English. We recognise that novel approaches to studying the temporal aspects of CSCL might have already been published elsewhere (e.g., in conference proceedings) since the field is developing rapidly (see Fig. 2). However, the included 78 journal articles offered a solid basis from which to address our research aims, and the overarching features of the included articles probably capture the features of other methodological approaches as well (see Table 1). Third, some of the articles focusing on the temporal aspects of CSCL might not have been captured with our search terms (Table A1), even though we used two phases to identify the journal articles (see section 3.1). For example, we added eight different temporal analysis methods to the search terms in the second phase of our literature search, but the included articles mostly focused on SNA and sequential analysis (Fig. 3). It appears that less frequently conducted temporal analysis methods (e.g., ENA, process mining, and SDA) have so far been used by individual researchers or research groups. However, we considered the characteristics of all the papers and temporal analysis methods when we identified the key operations (RQ1, see also Table 1). An advantage of our review is that we demonstrated the methodological diversity in this field of research, which may help researchers to more suitably implement the key operations to address their research aims regarding the temporal aspects of CSCL.

Despite these limitations, our study provides several implications and opportunities for future research. First, the proposed temporal analysis procedure (RQ1) emphasises that the analysis of the temporal aspects of CSCL starts by proposing theoretically framed research aims regarding these aspects (see the first key operation in Fig. 3). This key operation and the dependency of the following key operations indicate that researchers who work to understand the temporal aspects of CSCL (i.e., the characteristics of and interrelations between events over time) should interpret these aspects according to the utilised theoretical framework (see Wise & Schwarz, 2017). The researchers cannot refer solely to the events when they aim to understand how and why CSCL as a process unfolds over time in a certain manner. Thus, the proposed procedure provides an outline for more theory-driven and theory-advancing CSCL studies.

Second, the temporal analysis procedure (RQ1) may feed the discussion on how information about the temporal aspects of CSCL can complement the findings achieved with other analysis methods (see data or method triangulation in Fig. 3). This kind of discussion may also help make sense of the methodological diversity in CSCL research and inspire novel methodological experiments. For example, Table 1 depicts what temporal analysis methods allow statistical comparison of groups or conditions that could be considered when addressing comparative research aims (Fig. 3). So far, the characteristics of and interrelations between events over time have mostly been analysed with either SNA ($n = 32$) or sequential analysis ($n = 24$; RQ2). A premise of these two and other identified temporal analysis methods (depicted in Table 1) illustrates the shift in CSCL research from the perspective of individual learners to the perspective of groups of learners (Ludvigsen & Steier, 2019; Stahl, 2017): SNA may examine learners' contributions, but the focus is not on individual learners per se but on interrelationships and mutual influence among the learners (Saqr et al., 2020). Sequential analysis, in turn, may reveal what kind of events in the groups trigger desired events instead of examining who is in charge of these events.

Finally, as some key operations were rather similarly implemented across these articles (e.g., the temporal aspects of CSCL have been analysed mostly in online interaction so that communication units have been conceptualised as events, see Fig. 3), the research has apparently proceed with a quite narrow focus, and new implementations of the key operations are needed (see also Dado & Bodemer, 2017): Despite the crucial role of conceptualising the events (the fourth key operation), few studies have examined whether and how different conceptualisations of events taken from the same process data (e.g., a message or speech turn vs. a thread of messages or a few speech turns) change the interpretations of CSCL as a process. These examinations would be essential because the conceptualisation of events defines the temporal graininess of the analysis. For instance, what is the timescale of the events, and to what extent did researchers zoom in or out to address the aims? Moreover, less attention was paid to how utilising different temporal analysis methods (the fifth key operation) changes the interpretations of CSCL as a process (e.g., by considering temporal heterogeneity in the short vs. long term, see Table 1). Finally, future research should particularly focus on the events that center on the use of technological resources to mediate the interaction (e.g., nonverbal CSCL activities; cf. Dado & Bodemer, 2017; Eryilmaz, van der Pol, Ryan, Clark, & Mary, 2013; Ludvigsen & Steier, 2019). A stronger focus on the mediating role of technologies in the interaction could help with identifying the design principles of technologies that harness CSCL.

6. Conclusion

An increasing number of studies focusing on the temporal aspects of CSCL have been published over the last 10 years (see Fig. 2), and they illustrate the general shift in CSCL research from the individual learners' perspective to the group perspective. The temporal analysis of CSCL, however, has not been elaborated upon as is the case with studies focusing on variables (including their variance and co-variance), which makes it possible to conduct meta-analyses. To raise theoretical and methodological standards and thus increase the commensurablity of future studies, we conducted a systematic literature review to both define the temporal analysis procedure for CSCL (RQ1) and to identify how analysing these aspects were conducted in the included papers (RQ2). In the future, by replicating analyses of the temporal aspects of CSCL in various contexts, we can start searching for the "Holy Grail" as Molenaar (2014, p. 21) put it, studying how the temporal aspects of CSCL affect learning. When sufficient knowledge concerning this phenomenon accumulates, it may also be possible to design tools for real-time formative assessments (i.e., assessing performance in context; Shaffer et al., 2009) and to provide timely feedback to and scaffolds for learners by analysing the temporal aspects of CSCL on the fly. Designing novel tools to enhance CSCL calls for multidisciplinary research teams that have strong knowledge of educational theories, sophisticated methodologies, and designing state-of-the-art technologies. Moreover, recent reviews of studies in game-based contexts (Lämsä, Hämäläinen, Aro, Koskimaa, & Äyrämö, 2018) and contexts of learning analytics (Vieira, Parsons, & Byrd, 2018) have indicated that research on technology-enhanced learning and learning in technology-enhanced settings cannot achieve its full potential without crossing disciplinary boundaries.

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CRediT authorship contribution statement

Joni Lämsä: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Raija Hämäläinen:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Pekka Koskinen:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Jouni Viiri:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Emilia Lampi:** Data curation, Methodology, Visualization.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.edurev.2021.100387.

Appendix

Table A1
The search terms used in the first and second phases of identifying articles.

	First phase	Second phase
Temporality	temporal*	"Sequential analysis" OR "Network analysis" OR "Sequence mining" OR "Time-series analysis" OR "Statistical discourse analysis" OR "Event-centred analysis" OR "Process discovery method" OR "Time variant analysis"
Collaborative learning (according to van Leeuwen & Janssen, 2019)	"Collaborative learning" OR "cooperative learning" OR "small group learning" OR "peer-assisted learning" OR "peer-based learning" OR "collaborative instruction" OR "collaborative work" OR "collaborative interaction" OR "collaborative methods" OR "cooperative instruction" OR "cooperative work" OR "cooperative interaction" OR "cooperative methods" OR "small group instruction" OR "small group interaction" OR "small group methods" OR "peer-assisted instruction" OR "peer-assisted work" OR "peer-assisted interaction" OR "peer-assisted methods" OR "peer-based instruction" OR "peer-based work" OR "peer-based interaction" OR "peer-based methods" OR "group work" OR "collaborative dialogue" OR "small-group learning" OR "small-group discussions" OR "peer-to-peer debates" OR "small-group argumentation" OR "student collaboration" OR "cooperative-learning" OR "collaborative networked learning" OR "group discussions" OR "synchronous discussions" OR "small-group work" OR "peer discussion" OR "collaborative reasoning" OR "CSCL"	
Computer-supported learning	online OR computer OR technology OR application OR software OR virtual OR simulation OR synchronous OR asynchronous OR "learning analytics" OR "educational data mining"	

Table A2
Items that were identified in the included articles by two authors (not all items were relevant in the case of each article).

Item	Description
Theory	Whether there is a theoretical framework in the study.
Aims	Research questions or aims (if stated).

(continued on next page)

Table A2 (*continued*)

Item	Description
Hypotheses	Whether there are hypotheses to be tested in the study.
Design	Research design of the study.
Interaction	The mode of learner interaction upon which the analysis of the temporal aspects of CSCL is based.
Duration[1]	Duration of CSCL session or sequence of sessions.
Technology	Technologies used to support collaborative learning.
Sample size	The number of learners in the study
Educational level	Educational level of participants
Group size	The number of learners (without teachers or tutors) in the groups whose temporal aspects of CSCL are studied.
Data	Process data that is collected to study the temporal aspects of CSCL.
Unit of analysis	The events that are conceptualised from the process data and upon which the analysis of the temporal aspects of CSCL is based.
Methods	Temporal analysis methods that are used in the study.
Illustration of temporality	The ways how temporality is illustrated and presented in the findings of the study.
Triangulation	Methods or data that are used to triangulate the findings based on the temporal analysis.
Findings	Answers to the research questions or aims.
Methodological implications	Methodological implications of the study.
Practical implications	Practical implications of the study.
Theoretical implications	Theoretical implications of the study.
Future directions	Identified opportunities for future research.
Limitations	The identified limitations of the study and challenges when interpreting the findings.

[1] In the coding manual (Table A3), we present the input for this item under 'Participation'.

Table A3
Coding manual with items, codes, their definitions, examples, and Cohen's kappa and Shaffer's rho values

Item	Code	Definition	Example	Kappa	Rho
Aims	Comparative	Comparing the temporal aspects of CSCL between groups or conditions.	An aim was to examine the differences in social knowledge construction behavioral patterns between the high- and low-quality discussion groups (Hou & Wu, 2011).	0.82	<0.01
	Descriptive	Describing the temporal aspects of CSCL.	How does sense making conceived as participation in moment-by-moment actions adhere to a larger timescale? (Rasmussen & Damşa, 2017)	0.91	<0.01
	Methodological	Advancing or testing data or method to study the temporal aspects of CSCL.	Does the moving stanza window method provide information about group discourse that the conversation method does not? (Siebert-Evenstone et al., 2017)	0.92	<0.05
	Relational	Finding the associations of the temporal aspects of CSCL with a measure (e.g., performance).	How much are student final grades correlated with their centrality in the discussion forum network? (Traxler, Gavrin, & Lindell, 2018)	0.87	<0.01
Interaction	Face-to-face	The temporal analysis of CSCL is based on learners' face-to-face interaction.	Learners' classroom discussions whose temporal aspects are analysed	0.57	0.47
	Online, asynchoronous	The temporal analysis of CSCL is based on learners' computer-mediated interaction that occurs asynchronously.	Discussion forums in Moodle and other similar learning environments	0.86	<0.01
	Online, synchoronous	The temporal analysis of CSCL is based on learners' computer-mediated interaction that occurs synchronously.	Chat, Facebook Messenger, Whatsapp, Zoom, Skype, Teams	0.79	<0.05
Participation	Continuous participation	The temporal analysis of CSCL is based on learners' interaction that occurs freely during the set period of time and that is based on learners' spontaneous contributions.	The discussion area as a tool of collaborative learning is an important asynchronous communication medium for learners, which can be used outside the classroom (Wu & Zhou, 2014)	1	<0.001
	Fixed learning session(s)	The temporal analysis of CSCL is based on learners' interaction that occurs during the set period of time so that the learners are available at the same time.	Experiments lasted for 45 min each in 90-min class periods with teachers present (Reychav, Raban, & McHaney, 2018)	0.94	<0.001
Group size	2–7 learners	The number of learners in the groups, whose temporal aspects of CSCL are studied, is 2–7 without teachers or tutors.	In collaborative project work, the group included seven learners and one tutor (Laat et al., 2007)	0.92	<0.001
	>7 learners	The number of learners in the groups whose temporal aspects of CSCL are studied is ≥ 8 without teachers or tutors.	A study group was analysed and the selected group consisted of 83 learners (in this case, they were in-service teachers) participating in a professional development program (Zhang, Liu, Chen, Wang, & Huang, 2017)	0.95	<0.001
Technology Codes modified	Communication technologies	The technology has the affordance of communication with other learners, and	Online discussion areas for communication (e.g., chats, asynchronous forums, possibilities for commenting in blogs)	0.61	0.35

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Table A3 (*continued*)

Item	Code	Definition	Example	Kappa	Rho
from Jeong et al. (2019).[1]		this affordance is used in the study to support collaborative learning.			
	Dynamic technologies	The technology has the affordance of presenting the information in dynamic form that could be manipulated, and this affordance is used in the study to support collaborative learning.	Simulations or programming tools (e.g., augmented/virtual reality, Geogebra, PhET-simulations, Python programs)	0.86	<0.05
	Sharing and co-construction technologies	The technology has the affordance of sharing or co-constructing, and this affordance is used in the study to support collaborative learning.	Awareness tools; Tools to insert and share multimedia (e.g., photo, audio, video); Wiki tools (i.e. possibilities to revise each others' contributions)	0.62	0.31
Process data	Eye-tracking	Learners' gaze is collected to study the temporal aspects of CSCL.	Eye-tracking data was collected during a collaborative learning activity (Schneider & Pea, 2014)	One study	
	Log data related to nonverbal CSCL activities	Learners' nonverbal activities in technological learning environments (stored as log files) are collected to study the temporal aspects of CSCL.	Log data capture the nonverbal activities performed by the group participants on the shared workspaces (Daradoumis, Martínez-Monés, & Xhafa, 2006).	0.54	0.48
	Log data related to online discussions	Learners' actions related to their verbal online communication (excluding the content of verbal activities itself) are collected to study the temporal aspects of CSCL.[2]	Log data extracted were user ID, forum ID, parent forum, author of the post (source), author of the reply (target), time created, time modified, subject, post content and learner group (Saqr, Fors, & Tedre, 2018).	0.57	0.45
	Online discussions	Learners' verbal online communication asynchronously or synchronously with other learners are collected to study the temporal aspects of CSCL.	Data were text communication messages between learners during an online course (Jahng, Chan, & Nielsen, 2010)	0.80	<0.05
	Video/audio	Collaborative learning situations of learners are video or audio recorded, and these recordings are used to study the temporal aspects of CSCL.[3]	Transcripts based on video and audio recordings of learners' interactions were analysed (Lämsä, Hämäläinen, Koskinen, & Viiri, 2018).	0.73	0.11
Event[4]	Communication episode	Analysis of the temporal aspects of CSCL is based on an interpretative thread in learners' verbal communication, such as a few sentences, speech turns, or messages, which are conceptualised from the process data.	A certain number of learners' utterances or pieces of dialogue that reflected individual or group-level regulation of the learning activity (Su et al., 2018)	0.84	<0.05
	Communication unit	Analysis of the temporal aspects of CSCL is based on an unambiguous unit in learners' verbal communication, such as one sentence, speech turn, or message, which are conceptualised from the process data.	A message that may contain multiple sentences and paragraphs (Wu, 2020)	0.86	<0.01
	Nonverbal activity	Analysis of the temporal aspects of CSCL is based on an individual activity in the technological learning environment that is not related to learners' verbal communication. The activities are conceptualised from the process data.	Nonverbal CSCL activities in a wiki, such as add topic or edit and view content (Mansur, Yusof, & Basori, 2016)	0.66	0.23
	Other	Analysis of the temporal aspects of CSCL is based on a conceptualised entity from the process data that does not address the previous definitions and is present in only a few studies.	A challenge-strategy pair (Malmberg et al., 2015)	0.56	0.51
Temporal analysis methods	Epistemic network analysis	A form of network analysis for assessing epistemic frames and that focuses on event co-occurences.	(see, e.g., Siebert-Evenstone et al., 2017)	1	0.26
	Process mining	A set of data mining methods that build on a process model.	(see, e.g., Sobocinski et al., 2017)	1	0.23
	Sequential analysis	Methods that focus on the sequences between consecutive events so that the order of events is considered.	see, e.g., lag sequential analysis in Kapur (2011)	1	<0.001
	Social network analysis	A form of network analysis that focuses on relational ties between a group of actors in a community.	(see, e.g., Liu et al., 2017)	0.97	<0.001
	Statistical discourse analysis	A method that combines (a) the identification of time periods of learning processes via breakpoints; (b) multilevel logistic regressions; and (c) tests for serial correlation.	(see, e.g., Lu, Chiu, & Law, 2011)	0.88	0.09
	Visualisation			0.55	0.52

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Table A3 (*continued*)

Item	Code	Definition	Example	Kappa	Rho
		A method that visualises temporal aspects of CSCL. The visualisation refers to a method in its own right, not visualising the results of another method (e.g. sequential analysis or social network analysis).	see, e.g., visualisations of the epistemic synchronization index as a function of time in Ding, Wei, and Wolfensberger (2015)		
	Other (e.g. other qualitative methods)	Other methods that do not address the previous definitions and that are present in only a few studies.	see, e.g., a methodological approach for studying the coordination of social and content-related resources in Oner (2013)	0.80	0.09
Data/method triangulation Codes modified from Dado and Bodemer (2017)	Content analysis	Data is analysed by conducting qualitative or quantitative content analysis so that the results are presented (e.g., as frequencies of the different codes in quantitative content analysis). Content analysis may also be conducted in conjunction with a temporal analysis method (e.g., with sequential analysis).	The percentages of different discussion activities were reported based on the results of content analysis (Wu, Hou, Hwang, & Liu, 2013).	0.64	0.24
	Interviews	Asking questions verbally from individual learners or groups (e.g., their experiences on some aspects of CSCL).	Critical-event recall interviews (de Laat, Lally, Lipponen, & Simons, 2007)	0.86	<0.05
	Performance measures	Individual learners or groups' performance, outcomes, or achievement are analysed by using instruments or products or outputs of CSCL.	To compare learners' achievement in terms of their post-text scores between experimental and control groups, a *t*-test was conducted (Lin, Duh, et al., 2013).	0.94	<0.001
	Questionnaires	Questionnaires or surveys are conducted to examine background information on learners or groups; or individual learners or groups' experiences on some aspects of CSCL.	A questionnaire regarding the quality of the teamwork was filled (Chang, Chang, Liu, et al., 2017).	0.77	<0.05
	Other qualitative analysis	Qualitative analysis methods that do not address the previous definitions and that are present in only a few studies.	Discourse analysis (Sharma & Tietjen, 2016)	0.58	0.41
	Other quantitative analysis	Quantitative analysis methods that do not address the previous definitions and that are present in only a few studies.	The descriptive statistics of the problem-solving activities (based on the log data) are reported (Chang, Chang, Chiu, et al., 2017).	0.50	1

1Technologies used for data collection (e.g., screen-capturing software) were not taken into account.

[2] The analysis of the temporal aspects of CSCL may be based on the log data, and the content of the discussions and comments is analysed with method triangulation.

[3] If the video or audio was used to show that the interaction was only computer-mediated, other codes were used.

[4] The unit of analysis may be different in the method triangulation.

Table A4
The included papers listed according to the conducted temporal analysis methods.

Methods	Authors	Year	Title	Journal	Aims
Epistemic network analysis	Siebert-Evenstone, A.L.; Irgens, G.A.; Collier, W.; Swiecki, Z.; Ruis, A.R.; Shaffer, D.W.	2017	In Search of Conversational Grain Size: Modelling Semantic Structure Using Moving Stanza Windows	Journal of Learning Analytics	Methodological
Epistemic network analysis, Social network analysis	Gašević, D.; Joksimović, S.; Eagan, B.R.; Shaffer, D.W.	2019	SENS: Network analytics to combine social and cognitive perspectives of collaborative learning	Computers in Human Behavior	Comparative, Methodological, Relational
Process mining	Sobocinski, M.; Malmberg, J.; Järvelä, S.	2017	Exploring temporal sequences of regulatory phases and associated interactions in low- and high-challenge collaborative learning sessions	Metacognition and Learning	Descriptive, Relational
Process mining	Malmberg, J.; Järvelä, S.; Järvenoja, H.; Panadero, E.	2015	Promoting socially shared regulation of learning in CSCL: Progress of socially shared regulation among high- and low-performing groups	Computers in Human Behavior	Comparative, Descriptive
Sequential analysis	Wu, S.-Y.; Chen, S.Y.; Hou, H.-T.	2015	A Study of Users' Reactions to a Mixed Online Discussion Model: A Lag Sequential Analysis Approach	International Journal of Human-Computer Interaction	Relational
Sequential analysis	Chang, C.-J.; Chang, M.-H.; Liu, C.-C.; Chiu, B.C.; Fan Chiang, S.-H.; Wen, C.-T.; … Chai, C.-S.	2017	An analysis of collaborative problem-solving activities mediated by individual-based and collaborative computer simulations	Journal of Computer Assisted Learning	Comparative, Descriptive
Sequential analysis	Chang, C.-J.; Chang, M.-H.; Chiu, B.-C.; Liu, C.-C.;	2017		Computers & Education	Descriptive, Relational

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Table A4 (*continued*)

Methods	Authors	Year	Title	Journal	Aims
	Chiang, S.-H. F.; Wen, C.-T.; … Chen, W.		An analysis of student collaborative problem solving activities mediated by collaborative simulations		
Sequential analysis	Lin, T.-J.; Duh, H. B.-L.; Li, N.; Wang, H.-Y.; Tsai, C.-C.	2013	An investigation of learners' collaborative knowledge construction performances and behavior patterns in an augmented reality simulation system	Computers & Education	Descriptive
Sequential analysis	Wang, H.-Y.; Duh, H. B.-L.; Li, N.; Lin, T.-J.; Tsai, C.-C.	2014	An Investigation of University Students' Collaborative Inquiry Learning Behaviors in an Augmented Reality Simulation and a Traditional Simulation	Journal of Science Education and Technology	Comparative, Descriptive
Sequential analysis	Winter, J.W.	2018	Analysis of knowledge construction during group space activities in a flipped learning course	Journal of Computer Assisted Learning	Relational
Sequential analysis	Wu, S.-Y.; Hou, H.-T.; Hwang, W.-Y.; Liu, E. Z.-F.	2013	Analysis of learning behavior in problem-solving-based and project-based discussion activities within the seamless online learning integrated discussion (SOLID) system	Journal of Educational Computing Research	Comparative
Sequential analysis	Lin, P.-C.; Hou, H.-T.; Wang, S.-M.; Chang, K.-E.	2013	Analyzing knowledge dimensions and cognitive process of a project-based online discussion instructional activity using Facebook in an adult and continuing education course	Computers & Education	Descriptive, Relational
Sequential analysis	Wang, S.-M.; Hou, H.-T.; Wu, S.-Y.	2017	Analyzing the knowledge construction and cognitive patterns of blog-based instructional activities using four frequent interactive strategies (problem solving, peer assessment, role playing and peer tutoring): a preliminary study	Educational Technology Research and Development	Descriptive
Sequential analysis	Lin, C.-L.; Hou, H.-T.; Tsai, C.-C.	2016	Analyzing the Social Knowledge Construction and Online Searching Behavior of High School Learners During a Collaborative Problem Solving Learning Activity: a Multi- Dimensional Behavioral Pattern Analysis	The Asia-Pacific Education Researcher	Comparative, Descriptive
Sequential analysis	Hou, H.-T.; Wu, S.-Y.	2011	Analyzing the social knowledge construction behavioral patterns of an online synchronous collaborative discussion instructional activity using an instant messaging tool: A case study	Computers & Education	Comparative, Descriptive, Relational
Sequential analysis	Lan, Y.-F.; Tsai, P.-W.; Yang, S.-H.; Hung, C.-L.	2012	Comparing the social knowledge construction behavioral patterns of problem-based online asynchronous discussion in e/m-learning environments	Computers & Education	Comparative, Descriptive
Sequential analysis	Eryilmaz, E.; van der Pol, J.; Ryan, T.; Clark, P.M.; Mary, J.	2013	Enhancing student knowledge acquisition from online learning conversations	International Journal of Computer-Supported Collaborative Learning	Comparative, Relational
Sequential analysis	Su, Y.; Li, Y.; Hu, H.; Rosé, C. P.	2018	Exploring college English language learners' self and social regulation of learning during wiki-supported collaborative reading activities	International Journal of Computer-Supported Collaborative Learning	Comparative
Sequential analysis	Shukor, N.A.; Tasir, Z.; Van der Meijden, H.; Harun, J.	2014	Exploring Students' Knowledge Construction Strategies in Computer-Supported Collaborative Learning Discussions Using Sequential Analysis	Educational Technology & Society	Descriptive
Sequential analysis	Hou, H.-T.	2010	Exploring the Behavioral Patterns in Project-Based Learning with Online Discussion: Quantitative content analysis and progressive sequential analysis	Turkish Online Journal of Educational Technology	Descriptive, Methodological
Sequential analysis	Wu, S.-Y.; Hou, H.-T.	2015	How Cognitive Styles Affect the Learning Behaviors of Online Problem-Solving Based Discussion Activity: A Lag Sequential Analysis	Journal of Educational Computing Research	Comparative, Descriptive
Sequential analysis	Wu, S.-Y.	2019	Incorporation of Collaborative Problem Solving and Cognitive Tools to Improve Higher Cognitive Processing in Online Discussion Environments	Journal of Educational Computing Research	Descriptive
Sequential analysis	Chen, H.-L.; Chang, C.-Y.	2017		Educational Technology & Society	Relational

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Table A4 (*continued*)

Methods	Authors	Year	Title	Journal	Aims
			Integrating the SOP2 Model into the Flipped Classroom to Foster Cognitive Presence and Learning Achievements		
Sequential analysis	Järvelä, S.; Malmberg, J.; Koivuniemi, M.	2016	Recognizing socially shared regulation by using the temporal sequences of online chat and logs in CSCL	Learning and Instruction	Descriptive
Sequential analysis	Chiang, T.H.C.; Yang, S.J.H.; Hwang, G.-J.	2014	Students' online interactive patterns in augmented reality-based inquiry activities	Computers & Education	Comparative, Descriptive
Sequential analysis	Kapur, M.	2011	Temporality matters: Advancing a method for analyzing problem-solving processes in a computer-supported collaborative environment	International Journal of Computer-Supported Collaborative Learning	Methodological
Sequential analysis	Chen, B.; Resendes, M.; Chai, C.S.; Hong, H.-Y.	2017	Two tales of time: uncovering the significance of sequential patterns among contribution types in knowledge-building discourse	Interactive Learning Environments	Comparative, Descriptive, Methodological
Sequential analysis, Social network analysis	Zhang, S.; Liu, Q.; Chen, W.; Wang, Q.; Huang, Z.	2017	Interactive networks and social knowledge construction behavioral patterns in primary school teachers' online collaborative learning activities	Computers & Education	Descriptive
Social network analysis	Wu M.; Zhou X.	2014	A case study of social network analysis of the discussion area of a virtual learning platform	World Transactions on Engineering and Technology Education	Descriptive
Social network analysis	Daradoumis T.; Martínez-Monés A.; Xhafa F.	2006	A layered framework for evaluating on-line collaborative learning interactions	International Journal of Human Computer Studies	Descriptive
Social network analysis	Park J.; Ji H.; Jo J.; Lim H.	2016	A Method for Measuring Cooperative Activities in a Social Network Supported Learning Environment	Wireless Personal Communications	Descriptive
Social network analysis	Liu, C.-C.; Chen, Y.-C.; Tai, S.-J. D.	2017	A social network analysis on elementary student engagement in the networked creation community	Computers & Education	Descriptive, Relational
Social network analysis	Claros, I.; Cobos, R.; Collazos, C. A.	2016	An Approach Based on Social Network Analysis Applied to a Collaborative Learning Experience	IEEE Transactions on Learning Technologies	Descriptive, Methodological
Social network analysis	Reychav, I.; Raban, D. R.; McHaney, R.	2018	Centrality Measures and Academic Achievement in Computerized Classroom Social Networks: An Empirical Investigation	Journal of Educational Computing Research	Relational
Social network analysis	Manca, S.; Delfino, M.; Mazzoni, E.	2009	Coding Procedures to Analyse Interaction Patterns in Educational Web Forums	Journal of Computer Assisted Learning	Comparative, Methodological
Social network analysis	Jahng, N.; Chan, E. KH.; Nielsen, W. S.	2010	Collaborative Learning in an Online Course: A Comparison of Communication Patterns in Small and Whole Group Activities	Journal of Distance Education	Comparative, Relational
Social network analysis	Stepanyan, K.; Mather, R.; Dalrymple, R.	2014	Culture, Role and Group Work: A Social Network Analysis Perspective on an Online Collaborative Course	British Journal of Educational Technology	Descriptive, Methodological
Social network analysis	Sharma P.; Tietjen P.	2016	Examining Patterns of Participation and Meaning Making in Student Blogs: A Case Study in Higher Education	American Journal of Distance Education	Comparative, Descriptive
Social network analysis	Saqr, M.; Fors, U.; Tedre, M.; Nouri, J.	2018	How social network analysis can be used to monitor online collaborative learning and guide an informed intervention	PLOS ONE	Comparative, Methodological
Social network analysis	Saqr, M.; Fors, U.; Tedre, M.	2018	How the study of online collaborative learning can guide teachers and predict students' performance in a medical course	BMC Medical Education	Descriptive, Relational
Social network analysis	de Laat, M.; Lally, V.; Lipponen, L.; Simons, R.-J.	2007	Investigating Patterns of Interaction in Networked Learning and Computer-Supported Collaborative Learning: A Role for Social Network Analysis	International Journal of Computer-Supported Collaborative Learning	Descriptive
Social network analysis	Macfadyen L. P.; Dawson S.	2010	Mining LMS data to develop an "early warning system" for educators: A proof of concept	Computers & Education	Descriptive
Social network analysis	Aviv R.; Erlich Z.; Ravid G.; Geva A.	2003	Network analysis of knowledge construction in asynchronous learning networks	Journal of Asynchronous Learning Network	Comparative, Descriptive

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Table A4 (*continued*)

Methods	Authors	Year	Title	Journal	Aims
Social network analysis	Traxler, A.; Gavrin, A.; Lindell, R.	2018	Networks Identify Productive Forum Discussions	Physical Review Physics Education Research	Comparative, Methodological, Relational
Social network analysis	Tirado-Morueta R.; Maraver-López P.; Hernando-Gómez Á.	2017	Patterns of Participation and Social Connections in Online Discussion Forums	Small Group Research	Comparative, Relational
Social network analysis	Lin, J.-W.; Mai, L.-J.; Lai, Y.-C.	2015	Peer Interaction and Social Network Analysis of Online Communities with the Support of Awareness of Different Contexts	International Journal of Computer-Supported Collaborative Learning	Comparative
Social network analysis	Jimoyiannis, A.; Tsiotakis, P.; Roussinos, D.	2013	Social Network Analysis of Students' Participation and Presence in a Community of Educational Blogging	Interactive Technology and Smart Education	Descriptive
Social network analysis	Martínez, A.; Dimitriadis, Y.; Gómez-Sánchez, E.; Rubia-Avi, B.; Jorrín-Abellán, I.; Marcos, J. A.	2006	Studying Participation Networks in Collaboration Using Mixed Methods	International Journal of Computer-Supported Collaborative Learning	Descriptive, Methodological
Social network analysis	Lambropoulos, N.; Faulkner, X.; Culwin, F.	2012	Supporting Social Awareness in Collaborative E-Learning	British Journal of Educational Technology	Comparative, Descriptive, Relational
Social network analysis	Mansur, A.B.F., Yusof, N., Basori, A.H.	2016	The analysis of student collaborative work inside social learning network analysis based on degree and eigenvector centrality	International Journal of Electrical and Computer Engineering	Descriptive
Social network analysis	Tirado, R.; Hernando, Á.; Aquaded, J. I.	2012	The Effect of Centralization and Cohesion on the Social Construction of Knowledge in Discussion Forums	Interactive Learning Environments	Descriptive, Relational
Social network analysis	Rienties, B.; Tempelaar, D.; Van den Bossche, P.; Gijselaers, W.; Segers M.	2009	The role of academic motivation in Computer-Supported Collaborative Learning	Computers in Human Behavior	Relational
Social network analysis	Rienties, B.; Giesbers, B.; Tempelaar, D.; Lygo-Baker, S.; Segers, M.; Gijselaers, W.	2012	The role of scaffolding and motivation in CSCL	Computers & Education	Comparative
Social network analysis	Echeverría, L.; Cobos, R.; Machuca, L.; Claros I.	2017	Using collaborative learning scenarios to teach programming to non-CS majors	Computer Applications in Engineering Education	Descriptive
Social network analysis	Saqr, M.; Fors, U.; Nouri, J.	2018	Using social network analysis to understand online problem-based learning and predict performance	PLoS ONE	Relational
Social network analysis	Lu, J.; Churchill, D.	2014	Using Social Networking Environments to Support Collaborative Learning in a Chinese University Class: Interaction Pattern and Influencing Factors	Australasian Journal of Educational Technology	Descriptive, Relational
Social network analysis, Visualisations	Iiskala, T.; Volet, S.; Lehtinen, E.; Vauras, M.	2015	Socially Shared Metacognitive Regulation in Asynchronous CSCL in Science: Functions, Evolution and Participation	Frontline Learning Research	Descriptive, Relational
Social network analysis, Visualisations	Lakkala, M.; Ilomäki, L.; Palonen, T.	2007	Implementing Virtual Collaborative Inquiry Practises in a Middle-School Context	Behavior & Information Technology	Descriptive
Statistical discourse analysis	Wise, A.F.; Chiu, M.M.	2011	Analyzing temporal patterns of knowledge construction in a role-based online discussion	International Journal of Computer-Supported Collaborative Learning	Descriptive, Relational
Statistical discourse analysis	Lu, J.; Chiu, M.M.; Law, N. W.	2011	Collaborative argumentation and justifications: A statistical discourse analysis of online discussions	Computers in Human Behavior	Relational
Statistical discourse analysis	Molenaar, I.; Chiu, M.M.	2014	Dissecting sequences of regulation and cognition: statistical discourse analysis of primary school children's collaborative learning	Metacognition and Learning	Relational
Statistical discourse analysis	Molenaar, I.; Chiu, M.M.	2017	Effects of Sequences of Cognitions on Group Performance Over Time	Small Group Research	Relational
Visualisations	Murphy, G.D.	2016	An MBA cohort' use of an enterprise social network for collaborative learning	e-Journal of Business Education & Scholarship of Teaching	Descriptive
Visualisations	Wise, A.F.; Hausknecht, S. N.; Zhao, Y.	2014	Attending to others' posts in asynchronous discussions: Learners' online "listening" and its relationship to speaking	International Journal of Computer-Supported Collaborative Learning	Descriptive
Visualisations	Otake, K.; Shinozawa, Y.; Uetake, T.	2017			Descriptive, Methodological

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Table A4 (*continued*)

Methods	Authors	Year	Title	Journal	Aims
			Proposal of the Support Tool for After-Class Work based on the Online Threaded Bulletin Board	International Journal of Advanced Computer Science and Applications	
Visualisations	Hurme, T.-R.; Merenluoto, K.; Järvelä, S.	2009	Socially shared metacognition of pre-service primary teachers in a computer-supported mathematics course and their feelings of task difficulty: a case study	Educational Research and Evaluation	Relational
Visualisations	Swigger, K.; Hoyt, M.; Serçe, F.C.; Lopez, V.; Alpaslan, F. N.	2012	The temporal communication behaviors of global software development student teams	Computers in Human Behavior	Descriptive, Methodological, Relational
Visualisations	Koh, E.; Lim, J.	2012	Too Early, Too Bad: Uncovering and Understanding the Initial Participation Paradox in Technology-Mediated Learning Teams	IEEE Transactions on Professional Communication	Relational
Visualisations	Schneider, B.; Pea, R.	2014	Toward collaboration sensing	International Journal of Computer-Supported Collaborative Learning	Descriptive, Methodological, Relational
Visualisations	Ding, N.; Wei, J.; Wolfensberger, M.	2015	Using Epistemic Synchronization Index (ESI) to measure students' knowledge elaboration process in CSCL	Computers & Education	Descriptive, Methodological
Visualisations	Lämsä, J.; Hämäläinen, R.; Koskinen, P.; Viiri, J.	2018	Visualising the temporal aspects of collaborative inquiry-based learning processes in technology-enhanced physics learning	International Journal of Science Education	Descriptive, Methodological
Visualisations, Other	Slakmon, B.; Schwarz, B.B.	2014	Disengaged students and dialogic learning: the role of CSCL affordances	International Journal of Computer-Supported Collaborative Learning	Descriptive
Other	Jahng, N.	2012	An Investigation of Collaboration Processes in an Online Course: How do Small Groups Develop over Time?	The International Review of Research in Open and Distance Learning	Descriptive
Other	Oner, D.	2013	Analyzing group coordination when solving geometry problems with dynamic geometry software	International Journal of Computer-Supported Collaborative Learning	Descriptive, Methodological
Other	Popov, V.; van Leeuwent, A.; Buis, S.C.A	2017	Are you with me or not? Temporal synchronicity and transactivity during CSCL	Journal of Computer Assisted Learning	Relational
Other	Lin, Y.-M.; Laffey, J.	2006	Exploring the Relationship Between Mediating Tools and Student Perception of Interdependence in a CSCL Environment	Journal of Interactive Learning Research	Descriptive, Relational
Other	Rasmussen, I.; Damşa, C.I.	2017	Heterochrony through moment-to-moment interaction: A micro-analytical exploration of learning as sense making with multiple resources	International Journal of Educational Research	Descriptive
Other	Medina, R.; Suthers, D.	2013	Inscriptions Becoming Representations in Representational Practices	Journal of the Learning Sciences	Descriptive

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