Author(s): Lämsä, Joni; Hämäläinen, Raija; Koskinen, Pekka; Viiri, Jouni; Mannonen, Joonas

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The potential of temporal analysis: Combining log data and lag sequential analysis to investigate temporal differences between scaffolded and non-scaffolded group inquiry-based learning processes

Abstract

This paper contributes to the ongoing discussion about analysing the temporal aspects of learning processes in the educational technology research field. Our main aim was to advance methods for analysing temporal aspects of technology-enhanced learning (TEL) processes by introducing the temporal lag sequential analysis (TLSA) technique and by combining TLSA with temporal log data analysis (TLDA). Our secondary aim was to illustrate the potential of these two analysis techniques to reveal the differences between the face-to-face technology-enhanced collaborative inquiry-based learning (CIBL) processes of three different conditions (non-scaffolded, writing scaffolded and script scaffolded groups). The study involved undergraduate university students (*N* = 231) in natural sciences. The TLDA was based on timestamps and groups' inputs into a TEL environment, and it focused on the groups' temporal ways of using technological resources. The TLSA was based on screen capture videos and audio recordings of the groups' CIBL processes, and it focused on the inquiry-based learning (IBL) transition patterns (i.e. the transitions between the different IBL phases) discovered by lag sequential analysis and demonstrated by how the IBL transition patterns temporarily emerged. The TLDA findings demonstrated temporal differences regarding how the groups in the different conditions used the available technological resources. The TLSA findings revealed three temporarily distinct IBL transition pattern clusters whose content and temporal emergence varied depending on the condition. Parallel temporal analysis of the log data and the IBL transition patterns indicated that the use of the technological resources temporarily mediated IBL transition patterns. Specifically, we found advantages similar to those of asynchronous online discussions (think before acting) when face-to-face interaction was enhanced with the writing scaffold. The article concludes with a general discussion of the necessity and potential of temporal analysis.

Keywords

- Lag sequential analysis
- Technology-enhanced inquiry
- Cooperative/collaborative learning
- Scaffolding
- Postsecondary education

Abbreviations:
CIBL: collaborative inquiry-based learning
IBL: inquiry-based learning
LSA: lag sequential analysis
TEL: technology-enhanced learning
TLDA: temporal log data analysis
TLSA: temporal lag sequential analysis

Highlights

- We introduced a method combining temporal log data and temporal lag sequential analysis.
- We illustrated the potential of the methods for comparing non-scaffolded and scaffolded CIBL processes in face-to-face setting.
- Temporal analysis revealed differences that would have otherwise remained invisible.
- Three temporarily distinct inquiry-based learning transition pattern clusters were identified.
- Use of technological resources seemed to temporarily mediate inquiry-based learning transition patterns.

Introduction

Learning is a continuous and dynamic process that evolves as a function of time (Kapur, 2011; Mercer, 2008). This fundamental relationship between time and learning has led many researchers to examine the temporal aspects of learning processes in the educational technology research field (Chang, Chang, Liu, Chiu, Fan Chiang, Wen et al., 2017; Chiang, Yang, & Hwang, 2014; Csanadi, Eagan, Kollar, Shaffer, & Fischer, 2018; Kapur, 2011; Knight, Wise, & Chen, 2017; Lin, Duh, Li, Wang, & Tsai, 2013; Popov, van Leeuwen, & Buis, 2017; Reimann, 2009; Wise & Chiu, 2011). The change in methodological orientation can be associated with the ease of collecting and analysing learning process data due to technological developments. For example, when students work in technological learning environments, their log data with events, and even their timestamps can be automatically captured. Moreover, it has been noted that a pure 'coding-and-counting' approach is not enough when analysing complex technology-enhanced learning (TEL) processes (Csanadi et al., 2018; Kapur, 2011). The problem with reporting mere descriptive statistics regarding learning activities is that it makes an implicit assumption about temporal homogeneity of learning (Kapur, Voiklis, & Kinzer, 2008) that may lead to inadequate or even incorrect conclusions about learning processes (Csanadi et al., 2018).

In the context of technology-enhanced collaborative inquiry-based learning (CIBL), for example, the dynamic interplay of different aspects of learning (e.g. related to content or related to technological resources; see Oner, 2013) can become visible as a non-linear process between the different phases of inquiry-based learning (IBL) (e.g. Lämsä, Hämäläinen, Koskinen, & Viiri, 2018), which cannot be captured with the help of descriptive statistics. While different types of scaffolds have been provided for students to handle this dynamic interplay and to achieve the many advantages of technology-enhanced CIBL (Bell, Urhahne, Schanze, & Ploetzner, 2010; Jensen & Lawson, 2011; Sins, Savelsbergh, van Joolingen, & van Hout-Wolters, 2011), few studies have examined the temporal aspects of the learning processes behind the observed changes in learning outcomes or the descriptive statistics of learning activities (Balgopal, Casper, Atadero, & Rambo-Hernandez, 2017; Chen, Wang, Grotzer, & Dede, 2018; Gijlers & de Jong, 2013; Hsu, Chiu, Lin, & Wang, 2015; Rau, Bowman, & Moore, 2017; Saab, van Joolingen, & van Hout-Wolters, 2012; Yücel & Usluel, 2016). Focusing on temporal aspects of scaffolded technology-enhanced CIBL processes, however, can reveal how students use the scaffolds, which indicates whether the actual usage differs from the designed usage of the scaffolds. This kind of information can provide valuable insights into how to redesign and implement scaffolds to enhance students' learning processes further.

In this paper, we first advance methods to analyse the temporal aspects of TEL processes. Second, we illustrate the potential of these novel methods when comparing non-scaffolded and scaffolded technology-enhanced CIBL processes taking place in face-to-face interactions (the focus has previously been on temporal aspects of online discussions) (Chang, Chang, Liu et al., 2017; Kucuk & Sisman, 2017; Liao, Chen, & Shih, 2019; Tawfik, Giabbanelli, Hogan, Msilu, Gill, & York, 2018; Wang, Duh, Li, Lin, & Tsai, 2014; Yang, Li, & Xing, 2018; Zhang, Liu, Chen, Wang, & Huang, 2017). In the following, we present the theoretical framework for our study. We start by elaborating the need for new methods that can be used to analyse temporal aspects of TEL processes. We follow that by introducing the context in which the potential of new methods is illustrated, i.e. technology-enhanced CIBL enhanced by two different scaffolds.

Theoretical framework

Temporal analysis

Recently, there has been a growing interest in analysing the temporal aspects of learning processes in various contexts in the educational technology research field (Chang, Chang, Liu et al., 2017; Chiang et al., 2014; Lämsä et al., 2018; Lin et al., 2013; Popov et al., 2017; Sobocinski, Malmberg, & Järvelä, 2017; Wang et al., 2014; Wise & Chiu, 2011). As there are different definitions of ‘temporality’ (Knight et al., 2017), it is important to pinpoint the kind of temporality the analysis method focuses on. The temporality can refer to behaviour patterns in learning processes without indicating the instant of time or mutual order of the patterns (Knight et al., 2017). As an example of this kind of method, lag sequential analysis (LSA) Bakeman & Gottman, 1997) has recently been conducted in online learning contexts to reveal two or more episodes (called *lags*) that occur in a sequence more often than would be expected by chance (Chang, Chang, Liu et al., 2017; Kucuk & Sisman, 2017; Liao et al., 2019; Tawfik et al., 2018; Wang, et al., 2014; Yang et al., 2018; Zhang et al., 2017). Although current discussion has provided insights on productive or unproductive patterns of learning processes, little attention has been paid to the mutual order or the averaged time instants of the identified patterns. These aspects, however, can play a crucial role in learning processes: for example, Kapur et al. (2008) found that the first third of technology-enhanced collaborative learning processes may predict the eventual learning performance. Thus, we need to advance the LSA method so that it takes into account another understanding of temporality, namely, that temporality can also refer to the explicit monitoring of time from the viewpoint of timestamps or the duration of the specific learning activity (Knight et al., 2017).

Temporal lag sequential analysis (TLSA), introduced and implemented in this study, advances LSA to determine the averaged time instant for each identified pattern, which provides several advantages. First, TLSA reveals the mutual order of the identified patterns, which can increase our understanding about the progression of learning processes. Without information about the mutual order of the patterns, it can be tempting to draw non-justified conclusions about the actual progress of learning processes; for example, if specific patterns are expected to be consecutive, LSA alone is not enough to guarantee what is the actual order of the patterns. Second, TLSA can reveal what kind of patterns are ‘clustered’ together (i.e. emerge close to each other in the timeline). These clusters can guide researchers and teachers to find broader phases of learning processes as individual patterns may sometimes be problematic to interpret (Csanadi et al., 2018). Studying the mutual order of the patterns and the formed clusters may also provide added value when comparing the learning processes between different groups. For example, when visualising the identified patterns as a function of time, we can identify whether differences between the groups arise at the beginning of learning processes or during the learning processes. While TLSA provides insights on the behaviour patterns of the learning processes, the mutual order of the patterns and the evolvement of the learning processes, it does not elucidate any explanations behind these findings. Thus, methodological triangulation can provide added value to the analyses. In technology-enhanced contexts, learning process data can be automatically captured in the form of log data with events and timestamps. The log data continuously capture students' use of the technological resources, which plays an important role in their learning patterns (Chang, Chang, Liu et al., 2017; Chang, Chang, Chiu, Liu, Fan Chiang, Wen et al., 2017; Chiang et al., 2014; Lämsä et al., 2018; Lin et al., 2013; Wang et al., 2014; Wu, 2019). Thus, TLSA and temporal log data analysis (TLDA) could potentially supplement each other.

One advantage of TLDA is that it enables the study of a large number of students over different time frames compared to more traditional and time-consuming analysis of videos and audio recordings. Many authors (Chang, Chang, Liu et al., 2017; Chang, Chang, Chiu et al., 2017; Wu, 2019) have already illustrated the potential of combining TLDA and LSA by examining the use of technological resources in the context of collaborative problem solving. This methodological triangulation may have also dispelled the doubts related to the use of log data; for example, Wise and Schwarz (2017) saw the log data and related methodological approaches as one of the deniable issues in the community of technology-enhanced collaborative learning. We argue that the full potential of this kind of methodological triangulation can be achieved by combining TLDA and TLSA. This combination enables us to pay attention both to the use of technological resources and to the identified behaviour patterns as a function of time (cf. Oner, 2013). Even though this kind of analysis does not allow the identification of causal relationships between the use of resources and the behaviour patterns, it can function as a theoretical lens to illuminate more explicitly how these two aspects are interrelated. In the present study, we illustrate the potential of combining TLDA and TLSA in the context of technology-enhanced CIBL.

Technology-enhanced collaborative inquiry-based learning

We refer to CIBL as a process in which students in a group follow the practices of scientists to learn scientific content and to apply skills to acquire scientific knowledge together with others and understand the nature of science better (Bell et al., 2010; Jensen & Lawson, 2011; Sins et al., 2011). The essential aspects of CIBL can be captured with the help of five inquiry phases—orientation, conceptualisation, investigation, conclusion and discussion—as presented by Pedaste, Mäeots, Siiman, de Jong, van Riesen, Siswa et al. (2015). In the orientation phase, students stimulate interest and curiosity in relation to the problem. They also identify the main concepts of the assignment and become familiar with technological resources. In the conceptualisation phase, students determine the dependent and independent variables that are needed to solve the problem. In this phase, generating research questions and hypotheses are essential. In the investigation phase, students plan data collection and explore, collect, analyse and interpret data. In the conclusion phase, students offer and evaluate solutions to the research questions and hypotheses. In the discussion phase, students communicate and elaborate their findings and conclusions. This phase is also characterised by reflection of either the entire IBL process after its completion or a single phase during the process.

In natural sciences, such as physics, CIBL has traditionally been conducted as a part of hands-on laboratory work in order for technological resources to support data collection, analysis and reporting (Andersson &

Enghag, 2017). Moreover, collaboration between students might have been technology mediated. It has recently become more typical that phenomena themselves are discovered with the help of technological resources such as simulations (Chang, Chang, Liu et al., 2017) or programs for numerical problem solving (Kortemeyer & Kortemeyer, 2018). This change has been associated with the technological development that has simultaneously made these resources available for most students. Despite various possibilities and benefits to implement technology-enhanced CIBL activities, Alfieri, Brooks, Aldrich, and Tenenbaum (2011) noted that the full potential of IBL can be achieved only when the learning is assisted. In addition, many studies (e.g. Ibáñez & Delgado-Kloos, 2018; Lämsä et al., 2018; Rau et al., 2017) have corroborated that scaffolds are needed to enhance technology-enhanced CIBL processes.

Scaffolding

Due to the complex nature of technology-enhanced CIBL, the many ways to scaffold these learning processes have been implemented and studied. In general, scaffolding refers to a process in which an agent (e.g. teacher, peer and/or computer software) helps a student with tasks that are challenging to complete (Wood, Bruner, & Ross, 1976). In this study, *scaffold* refers to procedural support in a TEL environment that guides students to engage in CIBL (see Kim & Hannafin, 2011; Quintana, Reiser, Davis, Krajcik, Fretz, Duncan et al., 2004; Sharma & Hannafin, 2007). As an example of this kind of scaffold, integrating writing tools into learning environments—where students write down planned steps for IBL processes—could help students by externalising their understanding (Gijlers, Saab, van Joolingen, de Jong, & van Hout-Wolters, 2009; Hmelo-Silver, Duncan, & Chinn, 2007; Sharma & Hannafin, 2007). For example, van Joolingen and de Jong (1991) discovered that when students have problems in conceptualising the inquiry problem at hand, hypothesis scratchpads have proven to be useful in writing hypotheses. The externalisation of their own thinking may make it easier for everyone in a group to follow the joint CIBL process and express differing opinions (Chen et al., 2018; Gijlers & de Jong, 2013).

As another example of these procedural scaffolds, many studies have illustrated the positive effects of socio-cognitive scaffolding via collaboration scripts (De Wever, Hämäläinen, Voet, & Gielen, 2015; Fischer, Kollar, Stegmann, & Wecker, 2013; Rau et al., 2017; Vogel, Wecker, Kollar, & Fischer, 2017; Wang et al., 2017). To enhance productive collaboration activities, such as students asking each other questions and each student explaining his or her own understanding, the potential of collaboration scripts has also been recognised in CIBL contexts (Kollar, Fischer, & Slotta, 2007; Mäkitalo-Siegl, Kohnle, & Fischer, 2011; Raes, Schellens, De Wever, & Vanderhoven, 2012). Collaboration scripts aim to ‘facilitate both social and cognitive processes of learning by shaping the way learners interact with each other’ (Kobbe, Weinberger, Dillenbourg, Harrer, Hämäläinen, Häkkinen et al., 2007, p. 211). In the technology-enhanced CIBL context, *activities* (Kobbe et al., 2007) described in the script can be based on the IBL phases (e.g. orientation, conceptualisation, investigation, conclusion and discussion, Pedaste et al., 2015) so that each student is given *a role* based on one of the IBL phases (five *participants*) with hints to use the available technological *resources*.

The effect of different scaffolds (e.g. writing tools for the specific phases of IBL or enhancing CIBL with collaboration scripts) on technology-enhanced CIBL processes have been examined from the viewpoint of learning outcomes and cumulative frequency counts of learning processes (Balgopal et al., 2017; Chen et al., 2018; Gijlers & de Jong, 2013; Hsu et al., 2015; Rau et al., 2017; Saab et al., 2012; Yücel & Usluel, 2016). A recent meta-analysis indicated clear positive effects on cognitive outcomes, especially among adults, regardless of the type of computer-based scaffold used (e.g. whether generic or context specific, explicitly added or faded, etc.) (Belland, Walker, Kim, & Lefler, 2017; Lazonder & Harmsen, 2016). Even though these studies indicate that there is a change in learning outcomes or activities associated with the scaffolds provided, they do not describe how the change took place (Kapur, 2011; Mercer, 2008; Stahl, 2017). This information, however, can be essential from the viewpoint of designing and implementing scaffolds in order to understand better how students perceive and use the scaffolds.

When designing and implementing procedural scaffolds for technology-enhanced CIBL, a certain type of progress in IBL transition patterns (discovered with TLSA) is fostered (cf. Pedaste et al., 2015). Because our previous findings indicated that the groups' ways of using technological resources may trigger these IBL transition patterns (Lämsä et al., 2018), we continue studying the interplay between the use of the technological resources and the progress of IBL transition patterns. Namely, in the present study, TLDA and TLSA function as a lens for understanding possible differences between scaffolded and non-scaffolded technology-enhanced CIBL processes taking place in face-to-face interactions.

Aims

The main aim of our study was to advance methods for analysing temporal aspects of TEL processes by introducing the TLSA technique. Moreover, we supplemented TLSA with TLDA. *A secondary aim was to illustrate the potential of these two temporal analysis techniques in the context of technology-enhanced CIBL, which was enhanced by two different scaffolds*. We investigated how the scaffolds (facilitation of IBL through writing and facilitation of CIBL with collaboration scripts) were associated with the use of technological resources and the IBL transition patterns of the scaffolded groups (conditions 1 and 2, respectively) compared to the non-scaffolded groups (condition 3) when the groups were working face-to-face. For this illustration, we addressed the following research questions (RQs):

1. How are the technological resources used in three different conditions, and what are the temporal distinctions between these conditions?
2. What kinds of IBL transition patterns do the three different conditions exhibit, and how do the IBL transition patterns differ between these conditions?
3. How do the IBL transition patterns temporally emerge in the three different conditions, and what are the temporal distinctions between these conditions?

Material and methods

Context and participants

Our study was conducted in an introductory thermodynamics course at a European University (for a detailed description of the course structure, see Koskinen, Lämsä, Maunuksela, Hämäläinen, & Viiri, 2018). The 231 participants were undergraduate natural science students. The participants were divided into groups of five students at the beginning of the course. In total, there were 46 groups (seven groups included four or six students). The groups were heterogeneous regarding gender, major and performance in the course (measured by the results of pre- and post-tests which are not in the focus of this study). During the course, the groups solved problems collaboratively face-to-face in a TEL environment with a shared laptop computer twice a week. Each session typically contained five to seven problems. No teachers or researchers were present in these group working sessions. In the following section, we will present the procedure of this study in detail. The overview of the procedure is presented in Figure 1.

Figure 1. The procedure of the study.

Procedure

Log data were collected from the TEL environments of all groups and included timestamps and the groups' inputs into the environment. We focused on the problems that included technological resources (simulations, videos, Python programs) which engaged the students in technology-enhanced CIBL. Based on the data of 14 groups ($n_{\text{student}} = 70$; see Figure 1), we identified the most challenging problems by determining the number of correct and incorrect answers based on the log data. For more detailed analysis, we selected the problem to which the groups had devoted the most time: studying how the displacement of an atom in a two-dimensional gas depends on time (Figure 2a). The groups had access to a Python program (Figure 2b) that plotted atom's path and calculated its total displacement (Figure 2c). The students were able to change the values of the variables in the Python program to observe how the changes affected the displacement. The solution of the problem required that the groups (a) run the Python program with different values of N (i.e. the number of collisions, which is directly proportional to amount of time) and (b) run the Python program multiple times with the same value of N to infer the time dependence of the averaged value of the displacement (cf. 'Tasks' in the investigation phase in Table 1).

a)

b)

c)

Figure 2. Screen captures of (a) the random walk problem assignment, (b) Python program (students changed the values of the variables highlighted in red) and (c) output of the Python program that plotted atom's path and calculated its total displacement (path length).

In addition to the log data, 11 randomly selected follow-up groups screen captured and audio recorded their group working sessions by using Screencast-O-Matic software. The screen capture videos revealed the groups' computer use in the TEL environment. We identified challenges in four non-scaffolded follow-up groups' technology-enhanced CIBL processes based on the screen capture videos, as shown in Figure 1 (Lämsä et al., 2018). The challenges were related to the first phases of IBL (especially to orientation and conceptualisation) and to systematic ways of using the technological resources during the investigation phase (see 'Challenges' in Table 1). As Figure 1 suggests, these empirically identified challenges formed the basis for the design of the scaffolds; however, previous research has identified similar challenges in different contexts (Chang, Chang, Liu et al., 2017; Kapur et al., 2008; Koretsky, Brooks, & Higgins, 2016; Wang et al., 2014). The general aim of the scaffolds implemented in the TEL environment was to provide procedural guidance for the CIBL process and hints to use the provided technological resources as part of the students' learning process.

Table 1. Tasks related to the random walk problem in the different phases of IBL, challenges identified in groups' technology-enhanced CIBL processes and two scaffolds designed to address these challenges.

Phase	Tasks	Challenges	Writing scaffold	Script scaffold
Orientation	Identify the main concepts of the assignment (free mean path, path, total displacement) and become familiar with technological resources (video and Python program).	Become familiar with the technological resources provided.	Write down the key physics concepts of the assignment. Consider how these concepts are represented in the video, in the Python program and in the output of the Python program.	For Student 1: Make sure that everyone in the group identifies the key physics concepts of the assignment. Consider how these concepts are represented in the video, in the Python program and in the output of the Python program.
Conceptualisation	Determine the dependent variables (total displacement) and independent variables (number of collisions and amount of time).	Identify dependent and independent variables from the assignment and from the Python program.	Write down how the question (How does the displacement of an atom in a gas depend on time?) relates to the video, the Python program and the output of the Python program. Reason how you should utilise the Python program so that you are able to answer the question.	For Student 2: Make sure that everyone in the group understands how the question relates to the video, the Python program and the output of the Python program. Reason how you should utilise the Python program so that you are able to answer the question.
Investigation	Plan the data collection procedure, implement the procedure and analyse and interpret the collected data.	Plan and implement a proper data collection strategy.	Write down the joint strategy you will implement so that you are able to answer the question.	For Student 3: Make sure that you plan and implement the joint strategy so that you are able to answer the question.
Conclusion	Offer and evaluate solutions to the given question based on the data.	-	-	For Student 4: Make sure that you make justified conclusions to solve the problem.
Discussion	Elaborate the findings and conclusions, reflecting the joint CIBL process.	-	-	For Student 5: Make sure that you reflect upon your activities throughout the process.

In total, 17 groups (n_{student} = 86; video and audio data from three follow-up groups, see Figure 1) were instructed to write down essential aspects of the orientation, conceptualisation and investigation phases in the TEL environment (writing scaffold; see Table 1). We integrated the text boxes into the TEL environment so that, for each phase, the groups had a separate place where one of the students could write down the group's joint answer. Even though the writing scaffold focused on the first three phases of IBL, we also expected it both to enable the groups to make justified conclusions about the problem and to foster discussion in the groups. Respectively, 15 groups (n_{student} = 75; video and audio data from four follow-up groups, see Figure 1) were instructed to adopt student roles (cf. scripting in collaborative learning; Kobbe et al., 2007). As roles are key components of scripting (Dillenbourg & Hong, 2008; Kobbe et al., 2007) and the groups included five students, we created five roles based on the IBL phases (script scaffold; see Table 1). This design choice led us to give non-specific guidelines for the script-scaffolded groups to follow in both the conclusion and the discussion phases. The content of two scaffolds was similar in the orientation, conceptualisation and investigation phases (Table 1).

Analysis

To answer RQ1—How are the technological resources used in three different conditions, and what are the temporal distinctions between these conditions?—we analysed the groups' use of the Python program (see Figure 2b). First, we determined how many different number of collisions (N) values each group used when they ran the Python program. Second, we calculated the average number of times each group ran the Python program with the same value of N. We then compared the results between the different conditions by conducting a Kruskal-Wallis test. A nonparametric test was chosen because the data did not fulfil the assumption of normality. TLDA was based on the timestamps labelled for each run with the Python program. To analyse temporal differences between the conditions, we plotted empirical cumulative distribution functions that visualised the use of the Python program as a function of time in all three different conditions. The empirical cumulative distribution functions show how the relative number of runs with the Python program behaves as a function of time; that is the value of the empirical cumulative distribution (from 0 to 1) indicates the fraction of the total number of runs that have been performed before that time instant. We compared the different conditions by conducting a one-sample Kolmogorov-Smirnov test, which is a nonparametric goodness-of-fit test, to measure how these empirical cumulative distribution functions fit the uniform distribution model with 0 and 1 as the minimum and maximum values. The choice of this uniform distribution is justifiable because the groups could use the Python program or technological resources in general, throughout the inquiry process (Bell et al., 2010). We also conducted a two-sample Kolmogorov-Smirnov test to see if the empirical cumulative distribution functions were similar. Unrounded timestamp values were used to avoid the presence of ties.

To answer RQ2—What kinds of IBL transition patterns do the three different conditions exhibit, and how do the IBL transition patterns differ between these conditions?—we focused on the screen capture videos and audio recordings of 11 follow-up groups. First, we transcribed the groups' talk during the random walk problem (Figure 2). Second, we identified episodes from the transcribed data. We included as many utterances in an episode as required to understand the episode on its own or, as Henri (1992) put it, to capture a 'unit of meaning'. To improve the reliability of this stage of the analysis, we created guidelines which presented five example episodes with the reasoning behind why the episode captured a 'unit of meaning' from the students' talk. Subsequently, two of us independently identified the episodes from the entire data set, then discussed disagreements and finally resolved the disagreements by consulting others as needed. Third, we conducted theory-driven content analysis (Neuendorf, 2002) for all the episodes and coded the episodes according to the different phases of IBL: orientation, conceptualisation, investigation, conclusion and discussion (Pedaste et al., 2015). These phases, with descriptions and example episodes, are presented in the coding manual (Appendix A). One of us coded all the episodes while another independently coded 20% of the episodes. Cohen's kappa indicated substantial inter-rater reliability (κ = .68; 95%

confidence interval = .57–.79). Finally, the disagreements were discussed and completely resolved by consulting others as needed.

To analyse the groups' IBL transition patterns, we performed LSA (Bakeman & Gottman, 1997). In LSA, a unit of analysis is the sequence of two consecutive episodes (coded during the previous step). It was possible for two consecutive episodes to be coded to the same phase of IBL. Next, we tabulated the cumulative number of each IBL transition pattern of the groups separately for each condition. By following a widely used convention, the rows of the table refer to the preceding episode ('lag 0'), and the columns refer to the following episode ('lag 1'). As we focused on five different IBL phases, there were 25 possible IBL transition patterns. We guaranteed that a sufficient data were analysed by checking that the total sample in each condition was at least six times the number of cells (Bakeman & Gottman, 1997, p. 125). We calculated adjusted residuals (*z*-scores) for each IBL transition pattern in each condition. The residuals indicate whether the observed frequency of the IBL transition pattern deviates from its expected value; for statistically significant IBL transition patterns, $z > 1.96$ ($p < 0.05$). As the number of tallies affects the *z*-scores, the use of another index in conjunction with the *z*-scores is recommended when analysing differences between conditions (McComas, Moore, Dahl, Hartman, Hoch, & Symons, 2009; Pohl, Wallner, & Kriglstein, 2016). Thus, we also calculated Yule's *Q* values for the IBL transition patterns (Bakeman & Gottman, 1997). Yule's *Q* indicates the strength of the relationship between dichotomous variables. Therefore, we collapsed 5 × 5 tables, including all the possible IBL transition patterns, into 2 × 2 tables, resulting in a total of 25 2 × 2 tables, one for each IBL transition pattern. For the transition pattern A → B (note that A and B may denote the same IBL phase), the cells of the 2 × 2 tables refer to the frequencies of the transition patterns: (a) A → B, (b) A → not-B, (c) not-A → B and (d) not-A → not-B. Yule's *Q* is calculated as

$$\text{Yule's } Q = \left(\frac{f_{\mathrm{A}\rightarrow\mathrm{B}}}{f_{\mathrm{A}\rightarrow\mathrm{not-B}}} - \frac{f_{\mathrm{not-A}\rightarrow\mathrm{B}}}{f_{\mathrm{not-A}\rightarrow\mathrm{not-B}}}\right) \cdot \left(\frac{f_{\mathrm{A}\rightarrow\mathrm{B}}}{f_{\mathrm{A}\rightarrow\mathrm{not-B}}} + \frac{f_{\mathrm{not-A}\rightarrow\mathrm{B}}}{f_{\mathrm{not-A}\rightarrow\mathrm{not-B}}}\right)^{-1},$$

where $f_{i\rightarrow j}$:s refers to the frequencies in the corresponding cells. From the formula, Yule's *Q* belongs to the interval between -1 and 1. In addition, the margin sums of the IBL transition patterns are not needed when Yule's *Q* is calculated. This property makes it a viable index to analyse the differences between scaffolded and non-scaffolded conditions. If Yule's $Q > 0$, the ratio $f_{\mathrm{A}\rightarrow\mathrm{B}}/f_{\mathrm{A}\rightarrow\mathrm{not-B}}$ is higher than $f_{\mathrm{not-A}\rightarrow\mathrm{B}}/f_{\mathrm{not-A}\rightarrow\mathrm{not-B}}$, which indicates a positive association in the transition pattern A → B. We considered only the IBL transition patterns with a Yule's $Q > 0.3$, which indicates a moderate positive association in the transition pattern A → B (Davis, 1971).

To answer RQ3—How do the IBL transition patterns temporally emerge in the three different conditions, and what are the temporal distinctions between these conditions?—we conducted TLSA by determining the averaged time instants of the IBL transition patterns in each condition. For each follow-up group, we calculated the averaged serial number of the utterance for each IBL transition pattern that had occurred at least once. Group-level averages were normalised by the total number of utterances. For each condition, we calculated weighted averaged points in which the IBL transition patterns took place. The weight was the number of times an IBL transition pattern occurred in a group. Subsequently, we visualised the IBL transition patterns with a Yule's $Q > 0.3$ as a function of time.

Results

We start by providing the overall picture of the duration and outcomes of the technology-enhanced CIBL processes in non-scaffolded, writing scaffolded and script scaffolded conditions. The descriptive statistics of the log data did not show significant differences between the three conditions regarding the time the groups used within each condition to solve the problem (χ^2 = 4.5, df = 2, p = 0.10). Although we found indications that the scaffolds enhanced group performance of technology-enhanced CIBL processes with respect to the relative number of correct answers to the problem, this difference was not statistically significant ($\beta_{\text{writing scaffolded}}$ = 0.36, p = 0.62; $\beta_{\text{script scaffolded}}$ = 0.41, p = 0.59). Detailed results of the descriptive statistics are presented in Table 2.

Table 2. Results based on the log data in three different conditions. Standard deviations are presented in brackets.

	Non-scaffolded		**Writing scaffolded**		**Script scaffolded**	
Solution	**Correct**	**Incorrect**	**Correct**	**Incorrect**	**Correct**	**Incorrect**
Number of groups	7	7	10	7	9	6
Average time (min)	24.2 (7.6)	14.0 (7.8)	31.8 (10.6)	21.9 (15.0)	15.3 (7.2)	24.7 (10.9)

Use of technological resources in three different conditions and temporal distinctions between the conditions

The solution of the problem required that the groups (a) run the Python program with different values of N (i.e. the number of collisions) and (b) run the Python program multiple times with the same value of N. Regardless of the condition, these two criteria were (on average) fulfilled as shown in Table 3. No differences between the conditions were found with respect to the number of times the groups used the Python program (χ^2 = 0.92, df = 2, p = 0.63). However, standard deviations illustrated notable variation between the groups within the same condition. With respect to the number of runs with the same value of N, the differences between the conditions were not significant (χ^2 = 0.85, df = 2, p = 0.65).

Table 3. Results based on the log data in three different conditions. Standard deviations are presented in brackets.

	Non-scaffolded	**Writing scaffolded**	**Script scaffolded**
Average number of runs (Python program)	9.5 (5.8)	12.5 (8.0)	14.0 (12.6)
Average number of runs with the same value of *N*	1.5 (0.5)	1.7 (0.6)	1.6 (0.5)

Even though the descriptive statistics of the log data (Tables 2 and 3) did not capture significant differences between the conditions, the temporal analysis of the log data did show that the temporal use of the Python program varied depending on the condition. In Figure 3, we present empirical cumulative distribution functions, which show how the groups in the different conditions ran the Python program as a function of time. Figure 3 shows that the groups with writing scaffolding used the Python program evenly throughout their CIBL processes, whereas the groups in the non-scaffolded and script scaffolded conditions tinkered with the Python program less frequently at the beginning of their CIBL processes. This finding is supported by a one-sample Kolmogorov-Smirnov test, which shows that the uniform distribution model with 0 and 1 as the minimum and maximum values fits the data of the writing scaffolded condition ($D = 0.069$, $p = 0.26$) but not the data of the non-scaffolded ($D = 0.20$, $p < 0.001$) and script scaffolded conditions ($D = 0.15$, $p < 0.001$). Figure 3 also shows that the empirical cumulative distribution functions are similar in non-scaffolded and script scaffolded conditions, which is supported by the two-sample Kolmogorov-Smirnov test ($D = 0.095$, $p = 0.45$). The empirical cumulative distribution function of the writing scaffolded condition differed both from the function of the non-scaffolded condition ($D = 0.25$, $p < 0.001$) and from the function of the script scaffolded condition ($D = 0.21$, $p < 0.001$).

In Appendix B, we present the results separately of the log data for the 11 follow-up groups that recorded their group working sessions. Based on these recordings, we will describe differences in technology-enhanced CIBL processes between the conditions based on the results of LSA, which shows the IBL transition patterns. Subsequently, we will present the results of TLSA for each condition to illustrate how the IBL transition patterns temporally emerge.

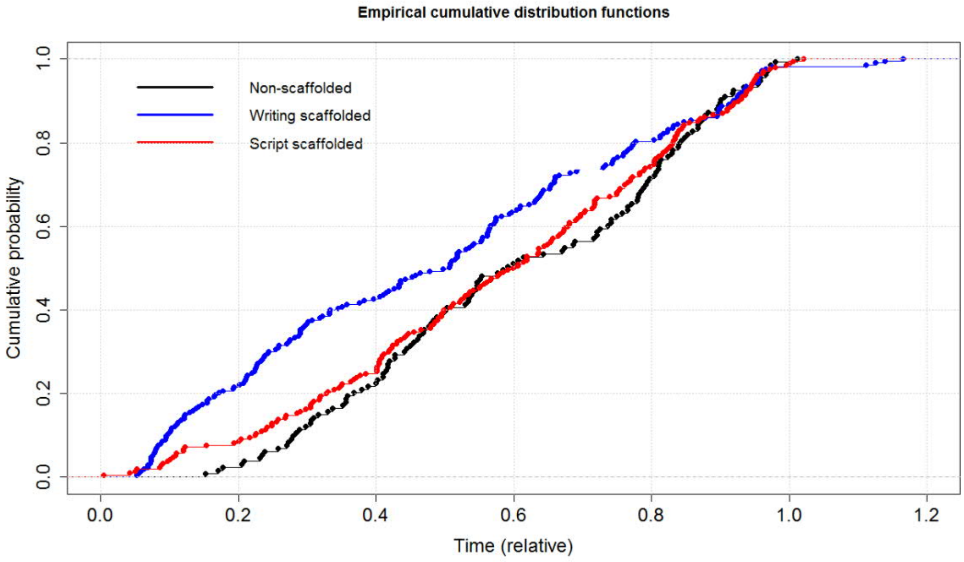

Figure 3. Empirical cumulative distribution functions of the relative number of runs with the Python program for the groups in three different conditions. In the given instant of time, the value of the function is equal to the fraction of the total number of runs that have been performed before that time instant. Time = 0 refers to the moment when the solution to the previous problem was submitted. Time = 1 refers to the moment when the solution to this random walk problem was submitted.

IBL transition patterns in three different conditions and differences in the patterns between the conditions

We found at least moderately positive ($Q > 0.3$) and statistically significant ($z > 1.96$, $p < 0.05$) associations in the IBL transition patterns from all three conditions (see detailed results in Appendix C). These IBL transition patterns are presented in Figure 4, which shows that there are IBL transition patterns to or from all the different IBL phases in each condition. The non-scaffolded groups have three IBL transition patterns associated with the investigation phase, whereas the groups in the other two conditions have one IBL transition pattern to or from the investigation phase. The groups with writing scaffolding have more IBL transition patterns associated with the discussion phase than the groups in non-scaffolded or script scaffolded conditions. In the script scaffolded condition, three of the five IBL transition patterns iterate in the same phase; this is contrary to the groups in the other two conditions in which most of the IBL transition patterns emerged between the different IBL phases.

Figure 4. The IBL transition patterns with Yule's $Q > 0.3$; the statistically significant patterns are marked with asterisks (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

The temporal emergence and distinctions in the IBL transition patterns between three different conditions

We present the IBL transition patterns shown in Figure 4 as a function of time in Figure 5 (see detailed results of TLSA in Appendix C). Based on Figure 5, we identified three temporarily distinct IBL transition pattern clusters from all three conditions. The first transition cluster can be described with the IBL transition patterns associated with the orientation phase. However, this first transition cluster emerged later in the writing scaffolding group than in the groups of the other two conditions. The groups with writing scaffolding also had recurrent IBL transition patterns in the conceptualisation phase in this first transition cluster. The second transition cluster can be described with the IBL transition patterns associated with the investigation phase. While the conceptualisation phase was included in the first transition cluster in the writing scaffolded condition, the conceptualisation of the groups in non-scaffolded and script scaffolded conditions were related to this second transition cluster. Similar to the first transition cluster, the second transition cluster emerged slightly later in the writing scaffolding groups. The third transition cluster can be described with the IBL transition patterns associated with the conclusion and discussion phases. This transition cluster emerged around the same time in all three conditions. Within the writing scaffolding groups, IBL transition patterns occurred back and forth between the conclusion and the discussion phases in the third transition cluster. In addition, we found the IBL transition pattern from the conclusion to the conceptualisation phase. In the non-scaffolded condition, the IBL transition pattern was found from the investigation to the conclusion phases. Figure 5 also shows that there is an IBL transition pattern associated with the discussion phase in all three transition clusters in the writing scaffolded condition. However, the preceding or the following phase depends on time, meaning that the discussion phase is associated with the orientation, investigation and conclusion phases, respectively.

Discussion

The main aim of this study was to advance methods for analysing temporal aspects of TEL processes by introducing the TLSA technique, which was supplemented with TLDA. In the context of TEL, we see that this kind of methodological triangulation is required to capture interrelated aspects of these learning processes (cf. Oner, 2013). As a secondary aim, we illustrated the potential of these methods to analyse temporal aspects in the context of face-to-face technology-enhanced CIBL processes in three different conditions (non-scaffolded, writing scaffolded and script scaffolded). In this context, parallel analysis of the findings of TLDA and TLSA functions as a lens through which we can see how the use of technological resources (TLDA; RQ1) and IBL transition patterns (TLSA; RQ2–3) are interrelated in different conditions. The actual use of technological resources has been under-represented when studying technology-enhanced CIBL processes (Bernhard, 2018); however, their use during CIBL may be vital for IBL transition patterns (Lämsä et al., 2018). In the following, we elaborate the findings of parallel TLDA and TLSA for non-scaffolded, writing scaffolded and script scaffolded conditions.

Based on the temporal use of technological resources (the Python program) (RQ1) and the temporal emergence of IBL transition patterns (RQ3), the technology-enhanced CIBL processes of the non-scaffolded and script scaffolded groups were similar. In both conditions, the groups used the Python program less frequently at the beginning of their CIBL processes (Figure 3), and their first transition cluster, which was merely associated with the orientation phase, emerged relatively early (Figure 5). These results may indicate that the groups in the non-scaffolded and script scaffolded conditions engaged in the actual inquiry at the very beginning and then started to familiarise themselves with the Python program. Before the midpoint of CIBL processes (after relative time instant 0.3 in Figure 3), these groups started to use the Python program more actively. This change in the slope of the empirical cumulative distribution functions emerged at the same time as the second transition cluster of the non-scaffolded and script scaffolded groups (Figure 5). The second transition cluster included IBL transition patterns associated with the conceptualisation, investigation and discussion phases. These findings indicate that the conceptualisation of the problem was conducted partly simultaneously with the investigation phase in which the Python program was probably used as a data collection tool.

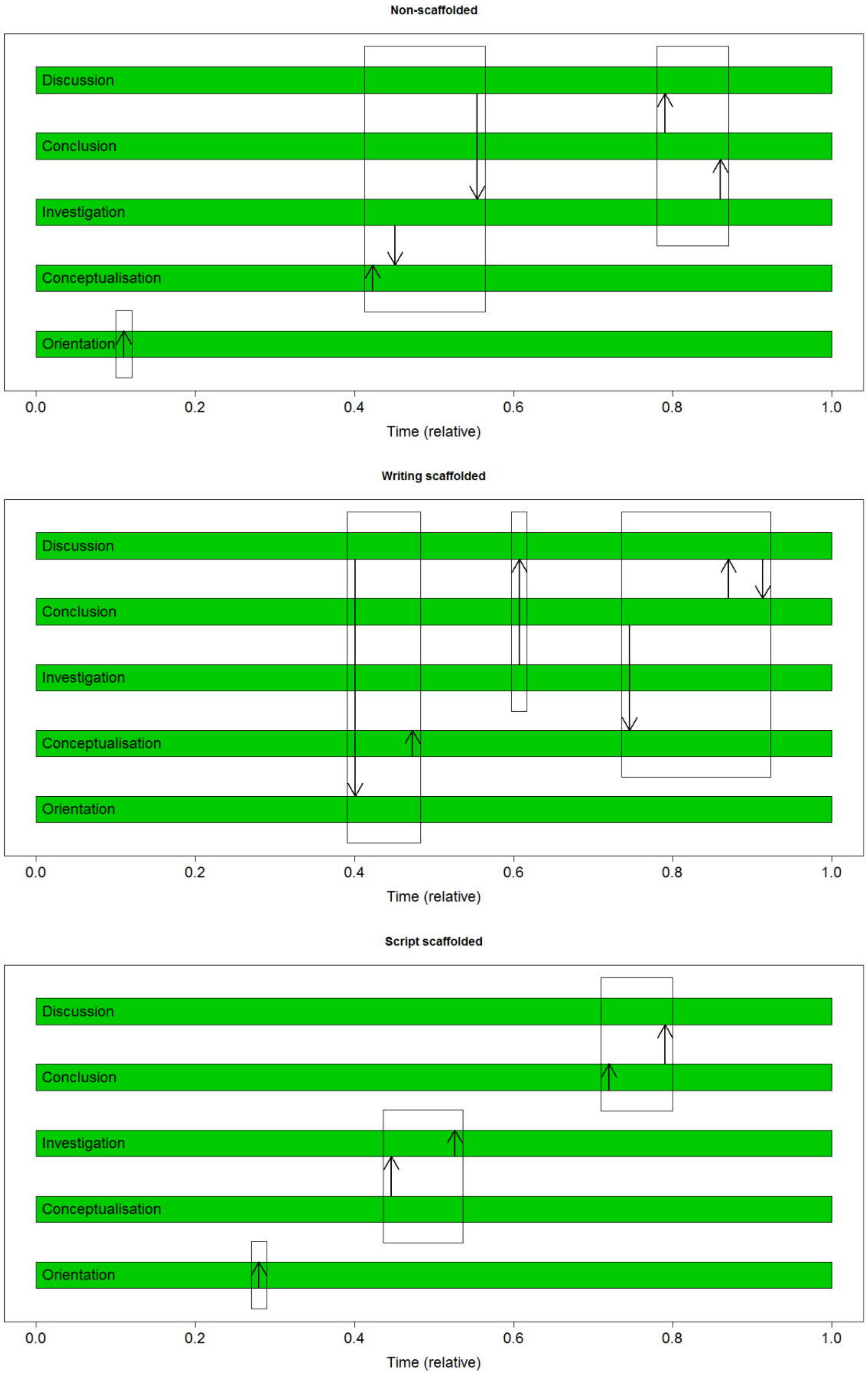

Figure 5. The IBL transition patterns with Yule's $Q > 0.3$ illustrated as a function of averaged time in the different conditions. Three temporarily distinct transition clusters have been marked with rectangles.

Conversely, the groups with writing scaffolding used the Python program more frequently at the beginning of their CIBL processes (Figure 3). Afterwards, these groups did not actively tinker with the Python program (see relative time interval 0.3–0.5 in Figure 3), but their first transitions cluster emerged (Figure 5). These results, in turn, indicate that the writing scaffolding guided students to become familiar with the given Python program before they actually engaged in inquiry. This finding was probably related to these groups' instructions, which asked the students to consider and write down how the Python program represented key concepts of the assignment (see the orientation phase in Table 1). Getting to know the properties of the Python program might also contribute to more diverse IBL transition patterns in the first transition cluster compared to the groups in non-scaffolded and script scaffolded conditions: the groups with writing scaffolding had IBL transition patterns associated with the orientation, conceptualisation and discussion phases in the first transition cluster. The findings of the writing scaffolded condition are reminiscent of those from asynchronous online discussions that provide participants the advantage of being able to think and reflect before they actually take action (Clark, Weinberger, Jucks, Spitulnik, & Wallace, 2003; Cohen & Scardamalia, 1998; Veerman, Andriessen, & Kanselaar, 2000; Zion, 2008; Zion, Michalsky, & Mevarech, 2005). After the midpoint of CIBL processes, the slope of the empirical cumulative distribution function of the writing scaffolded condition started to increase again (Figure 3), which supports the finding of TLSA; these groups also started to investigate and discuss the problem (the second transition cluster in Figure 5).

Even though the script scaffold included guidance for the conclusion and discussion phases (see Table 1), the last transition cluster emerged at the same time in all three conditions, and the last transition cluster was associated with the conclusion and discussion phases (Figure 5). Figure 3 also illustrates that the groups in all conditions took advantage of the Python program until the end of their technology-enhanced CIBL process, including drawing conclusions. The writing scaffold focused on the first three phases of IBL (see Table 1), but it still fostered discussion in the groups as expected. Namely, we found an IBL transition pattern associated with the discussion phase in all three transition clusters in the writing scaffolded condition (Figure 5).

Despite the similarities in the content of the writing and script scaffolds (Table 1), differences in the groups' technology-enhanced CIBL processes between these two conditions may be mostly explained by the way the students perceived the scaffolds. Namely, the writing scaffold may have been seen more as a part of the problem than as a kind of support. Even though the text boxes in the TEL environment were explicit support from the teachers' perspectives, the videos and audio recordings indicated that students might perceive those as 'faded' (the contrary to explicit scaffolds). This notion is supported by previous studies reporting students using scaffolds in ways that differed from their design (Balgopal et al., 2017; Roll, Butler, Yee, Welsh, Perez, Briseno et al., 2018). On the other hand, the script scaffold with the assigned roles was perceived more like additional guidelines that students dismissed: the videos and audio recordings revealed that although students read the descriptions of the different roles, they did not commit to their own role. This may relate to the established routines for inquiry and collaboration as we focused on the data from the midpoint of the course. The results of the study also support this notion as the technology-enhanced CIBL processes in non-scaffolded and script scaffolded conditions resembled each other based on TLDA (two-sample Kolmogorov-Smirnov tests) and TLSA. Thus, analysing temporal aspects of learning processes may be one way to investigate differences between the 'ideal' script (the learning activities that the script is expected to produce; cf. Kobbe et al., 2007) and the 'actual realised' script (what actually happens in the script scaffolded condition; Dillenbourg & Jermann, 2007).

Methodologically, LSA is one of the emerging methods of studying learning processes in authentic settings. We took LSA one step further by introducing the TLSA technique, which enabled us to capture the differences between the conditions from two viewpoints: (a) the differences between patterns (see Figure 4) and (b) the temporal emergence of patterns (see Figure 5). We also used the results of TLDA in addition to TLSA to form a more comprehensive picture of the role of the two scaffolds in groups' technology-enhanced CIBL processes. Even though this research was the first attempt to study whether and how TLDA and TLSA can supplement each other, we were able to find indications that this kind of data triangulation may help make more reliable inferences about the temporal aspects of technology-enhanced CIBL processes without exhaustive content analysis methods. Parallel TLDA and TLSA functioned as a lens to reveal otherwise invisible differences between the conditions. Namely, the scaffolds guided groups to use the technological resources (RQ1) differently, which temporarily mediated different IBL transition pattern clusters (RQ2–3). Our method can also be applied to other contexts as the growing need for temporal analysis in educational research has been widely recognised (Barbera, Gros, & Kirschner, 2015; Csanadi et al., 2018; Kapur, 2011; Ludvigsen, Cress, Rosé, Law, & Stahl, 2018; Mercer, 2008; Stahl, 2017). However, we invite researchers to pinpoint the kind of temporality they refer to—namely, whether they refer to explicit monitoring of time from viewpoint of timestamps (RQ1 and RQ3), for instance, or patterns in learning processes without indicating the instant of time or mutual order of the patterns (RQ2). The potential of parallel TLDA and TLSA highlights the need for temporal analysis techniques in which the temporality refers to the explicit monitoring of time.

In addition to the methodological contribution, our study also has other implications. Theoretically, the results of TLSA showed that technology-enhanced CIBL processes taking place in face-to-face contexts in all three conditions were divided into three distinct IBL transition pattern clusters with respect to the temporality and the content (Figure 5). Even though it is well-known that IBL processes are not linear, and there are IBL transition patterns back and forth between the different IBL phases (Pedaste et al., 2015), TLSA was able to capture the general progress of the technology-enhanced CIBL processes. Namely, IBL transition pattern clusters were associated with the orientation phase first, then with the investigation phase in the middle and, finally, with the conclusion and the discussion phases at the end in all three conditions. The condition, however, seemed to play a role regarding the precise content of the IBL transition pattern clusters as well as the clusters' temporal emergence. Practically, the outcomes of this study may be useful to enhance the future development of technological learning environments regarding adaptive scaffolds. As an example, real-time monitoring of groups' technology-enhanced CIBL processes based on log data (Figure 3; e.g. Rau et al., 2017) could trigger scaffolds to use available technological resources if the system monitors undesired behaviour (such as no activities for some threshold time interval or exceptional frequent use of resources indicating unsystematic actions, cf. Popov et al., 2017).

The limitations with regard to the findings of the study are, first, that TLDA (RQ1) was based on 46 group inputs and timestamps in the technological learning environment while TLSA (RQ2 and RQ3) was conducted based on 11 follow-up group screen capture videos and audio recordings. Thus, only three or four follow-up groups in each condition restrict the generalisation of our findings. To demonstrate that the follow-up groups in each condition were close to the average, we presented their results separately in Appendix B. The second point, which restricts the generalisation of our findings to other contexts, is that we only focused on a limited amount of data (one problem shown in Figure 2). The third point restricting the generalisation of our findings is our choice to empirically design the writing scaffold and the script scaffold based on our previously identified challenges (cf. Table 1 and Lämsä et al., 2018). However, there is evidence that the identified challenges may not be context specific (Chang, Chang, Lui et al., 2017; Kapur et al., 2008; Koretsky et al., 2016; Wang et al., 2014). The fourth limitation is that the measurement of time was not completely commensurable between the TLDA and TLSA. When analysing the log data, the time was calculated in relation to the start points and end points of the timestamps. The dimension of time in TLSA was based on the serial number of utterances. There also was a small uncertainty regarding the exact point of the IBL transition pattern because of the method we used to identify episodes based on 'unit of meaning' (Henri, 1992). However, the offset between these two methods of measuring time was not notable.

Conclusions

In this research, we first advanced methods for analysing the temporal aspects of TEL processes by introducing the TLSA technique and by supplementing TLSA with TLDA. Subsequently, we illustrated the potential of these two temporal analysis techniques in the context of technology-enhanced CIBL by investigating how two scaffolds (facilitation of IBL through writing and facilitation of CIBL with collaboration scripts) were associated with the technology-enhanced CIBL processes of the scaffolded groups compared to the non-scaffolded groups when the groups were working face-to-face. Regarding RQ1, we found that despite the similarities in descriptive statistics of the log data, there were temporal differences in the manner in which the groups in the different conditions used the technological resources. Regarding RQ2 and RQ3, we found three temporarily distinct IBL transition pattern clusters in each condition. Furthermore, there were temporal differences when each of these IBL transition pattern clusters emerged. By supplementing TLDA (RQ1) with TLSA (RQ3), we found indications that the scaffolds were associated with the use of the technological resources, which in turn temporarily mediated IBL transition patterns. Specifically, the writing scaffold seemed to guide the students to familiarise themselves with and use the available technological resources before they actually engaged in the inquiry and vice versa for the groups in non-scaffolded and script scaffolded conditions. Thus, it seems that the advantages of asynchronous online discussions (e.g. think and reflect before acting) were partly achievable when face-to-face interaction was enhanced by writing tools. In our study, the writing scaffold provided procedural support for the students. Future studies could investigate whether other types of writing scaffolds (e.g. conceptual, metacognitive or strategic; Kim & Hannafin, 2011) have similar advantages and what temporal distinctions exist between different types of writing scaffolds.

Even though the TLDA on its own inhibits making detailed interpretations of learning processes, it remains a potential method to study a large number of students over different time frames. Our study presented novel ways of analysing and visualising log data in conjunction with other learning process data. In this study, we gained a more in-depth picture of group technology-enhanced CIBL processes by using video and audio data. In the future, rapidly developing tools to capture other sorts of learning process data (e.g. eye-tracking data, face recognition data, physiological data or prosodic data) will make it possible for researchers to study temporal aspects of learning processes from various viewpoints. The significance of temporal aspects will probably further increase in the future as automatic analyses of learning processes (e.g. speech recognition and content analysis on the fly) develop and enable educational technologies to provide scaffolds for students in a timely manner.

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Appendices

A. Coding manual based on the phases of inquiry-based learning

Phase	**Description**	**Example episode**	**Comment**
Orientation	- Stimulating interest in and curiosity about the problem. - Identifying the main concepts of the assignment. - Becoming familiar with technological resources.	Ville: 'What does the [Python] program look like?' Leena: 'Let's run the [Python] program, as there is no need to make any modifications to it.' Paavo: 'Yeah, that's true. Running . . . . A path emerged.' Ville: 'It looks like a protein sequence. The output is a bit silly.'	Group is becoming familiar with the Python program and its output.
Conceptualisation	- Proposing research questions or hypotheses. - Determining the dependent and independent variables that are needed to solve the problem.	Ville: 'If it [the total displacement] is proportional to t [time], then it will always move in the same direction, won't it?'	Ville proposes a hypothesis that connects the dependent variable [the total displacement] and the independent variable [time].
Investigation	- Planning data collection. - Exploring, collecting, analysing and interpreting data.	Paavo: 'How does the [total] displacement depend on time? Let's see, this [the number of collisions] is 50. And this [atom] almost moved to its [original] position. When it goes longer . . . The more often it moves . . . If I input 10 times longer, for example, or five times [changing the value of the number of collisions] . . .'. Leena: 'Is it [the total displacement] proportional to t [time], to the square root of t or to t squared?' Paavo: 'Now it already moves 15 units.'	Paavo collects data with the Python program by running the program with a different value of the number of collisions.
Conclusion	- Offering and evaluating solutions to the research	Satu: 'Is that a square root [of time]?' Ville: 'I would believe so.'	Satu offers a solution, (i.e., the total displacement is

	questions and hypotheses.		proportional to the square root of time), which Ville accepts.
Discussion	- Communicating and elaborating findings and conclusions. - Reflecting either the entire IBL process after its completion or a single phase of the IBL process in real-time.	Ville: ‘I am already prepared to answer it [the total displacement is proportional to the square root of time].’ Satu: ‘It cannot be. . . . It cannot be that proportional [to time].’ Ville: ‘That would mean that it [the atom] practically moves in the same direction all the time.’ Leena: ‘Yeah.’ Satu: ‘It cannot be.’	The group communicates and then elaborates upon their conclusions by excluding one of the options, i.e., the total displacement cannot be proportional to time.

B. The results of the follow-up groups

Table B.1. The results of the follow-up groups based on the log data

Group index	**Scaffold**	**Solution to the problem**	**Time (min)**	**Number of runs (Python program)**	**Number of runs with the same value of number of collisions**
1	No	correct	22.1	18	2.6
2	No	wrong	17.6	4	1.3
3	No	correct	16.3	9	1.5
4	No	correct	15.5	6	1.2
5	Writing	correct	41.0	9	1.3
6	Writing	wrong	19.0	12	1.5
7	Writing	correct	30.0	6	1.2
8	Script	correct	17.6	3	1
9	Script	correct	17.3	6	1
10	Script	wrong	34.5	22	1.6
11	Script	wrong	20.1	13	1.6

C. Detailed results of temporal lag sequential analysis: The values of *z*-scores, *Q*-values, and averaged time instant of the IBL transition patterns

Non-scaffolded

Table C.1. Standardized residuals (*z*-scores) of the IBL transition patterns in non-scaffolded condition.

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	3.55***	-0.56	0.17	-0.4	-2.33
	Conceptualisation	-0.88	1.53	0.84	-1.52	-0.29
	Investigation	-0.78	1.92	-2.38	1.6	0.47
	Conclusion	-1.7	-0.69	-1.01	-0.18	2.93**
	Discussion	-0.59	-2.11	2.16*	0.06	-0.05

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

Table C.2. Yule’s Q values of the IBL transition patterns in non-scaffolded condition (the value -1 indicates that the frequency of the observed transitions is zero).

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	0.67	-0.18	0.04	-0.16	-0.56
	Conceptualisation	-0.32	0.5	0.21	-1	-0.08
	Investigation	-0.21	0.43	-0.54	0.43	0.09
	Conclusion	-1	-0.35	-0.37	-0.1	0.69
	Discussion	-0.15	-0.64	0.4	0.02	-0.01

Table C.3. Averaged (relative) points (0 = start; 1 = end) in which the IBL transition patterns took place in non-scaffolded condition.

	Lag 1	Orientation	Conceptualisation	Investigation	Conclusion	Discussion
Lag 0	Orientation	0.11	0.27	0.35	0.76	0.26
	Conceptualisation	0.20	0.42	0.57	NA	0.51
	Investigation	0.47	0.45	0.27	0.86	0.51
	Conclusion	NA	0.87	0.80	0.59	0.79
	Discussion	0.42	0.53	0.55	0.69	0.78

Writing scaffolded

Table C.4. Standardized residuals (*z*-scores) of the IBL transition patterns in writing scaffolded condition.

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	1.01	0.43	0.07	-1.39	-0.44
	Conceptualisation	-1.79	2.17*	0.53	0.48	-0.18
	Investigation	-1.39	0.48	-1.07	0.06	1.97*
	Conclusion	-1.9	0.59	-0.43	-0.9	2.31*
	Discussion	2.21*	-2.23	0.9	1.48	-2.52

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

Table C.5. Yule’s Q values of the IBL transition patterns in writing scaffolded condition (the value -1 indicates that the frequency of the observed transitions is zero).

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	0.2	0.16	0.01	-0.6	-0.08
	Conceptualisation	-1	0.76	0.19	0.26	-0.07
	Investigation	-0.31	0.17	-0.23	0.02	0.35
	Conclusion	-1	0.31	-0.17	-1	0.64
	Discussion	0.39	-1	0.17	0.42	-0.44

Table C.6. Averaged (relative) points (0 = start; 1 = end) in which the IBL transition patterns took place in writing scaffolded condition.

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	0.17	0.34	0.34	0.65	0.44
	Conceptualisation	NA	0.47	0.37	0.76	0.66
	Investigation	0.42	0.60	0.62	0.87	0.61
	Conclusion	NA	0.75	0.90	NA	0.87

	Discussion	0.40	NA	0.71	0.91	0.60

Script scaffolded

Table C.7. Standardized residuals (*z*-scores) of the IBL transition patterns in script scaffolded condition.

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	2.98**	0.72	-0.98	-0.56	-1.41
	Conceptualisation	0.06	-1.1	1.1	-0.33	-0.23
	Investigation	-2.31	0.37	1.45	-0.93	0.8
	Conclusion	-1.14	-1.28	-1.46	1.02	2.31*
	Discussion	0.54	0.56	-0.28	0.85	-1.03

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

Table C.8. Yule's Q values of the IBL transition patterns in script scaffolded condition (the value -1 indicates that the frequency of the observed transitions is zero).

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	0.61	0.25	-0.26	-0.22	-0.34
	Conceptualisation	0.02	-1	0.32	-0.17	-0.07
	Investigation	-0.67	0.12	0.28	-0.3	0.15
	Conclusion	-0.52	-1	-0.5	0.34	0.54
	Discussion	0.13	0.17	-0.05	0.22	-0.19

Table C.9. Averaged (relative) points (0 = start; 1 = end) in which the IBL transition patterns took place in script scaffolded condition.

	Lag 1	**Orientation**	**Conceptualisation**	**Investigation**	**Conclusion**	**Discussion**
Lag 0	**Orientation**	0.28	0.49	0.37	0.60	0.16
	Conceptualisation	0.48	NA	0.45	0.63	0.56
	Investigation	0.47	0.48	0.53	0.73	0.50
	Conclusion	0.35	NA	0.56	0.72	0.79
	Discussion	0.29	0.48	0.54	0.74	0.56