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A handheld classroom dashboard: Teachers' perspectives on the use of real-time collaborative learning analytics

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Abstract
In Computer-Supported Collaborative Learning (CSCL) classrooms it may be challenging for teachers to keep awareness of certain aspects of the learning process of each small group or assess whether the enactment of the class script deviates from the original plan. Orchestration tools, aimed at supporting the management of the increasing uncertainty and complexity of CSCL classrooms, have been emerging in response. Similarly, learning analytics innovations hold the promise of empowering teachers by making certain aspects of the classroom visible and by providing information that can prompt actionable responses. However, the active role that data may play in teachers' decision-making and orchestration processes is still not well understood. This paper investigates the perspectives of teachers who used a real-time analytics tool to support the orchestration of a CSCL classroom. A longitudinal study was conducted with a handheld dashboard deployed in a multi-display collaborative classroom during one full academic term. The dashboard showed real-time information about group participation and task progress; the current state of the CSCL script; and a set of text notifications informing teachers of potential students' misconceptions automatically detected. The study involved four teachers conducting 72 classroom sessions during 10 weeks with a total of 150 students. The teachers' perspectives discussed in this paper portray the promises and challenges of introducing new technologies aimed at enhancing orchestration and awareness in a CSCL classroom.

Keywords Small group collaboration · Multi-display · Classroom ecologies · Learning analytics · Dashboard · Data visualisation · Learning design · Tabletops

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Introduction

It is not uncommon for educators to promote the development of collaboration skills by designing and conducting a variety of small group learning tasks in the classroom (Bishop and Verleger 2013; Prieto et al. 2015b). The spatial affordances of the classroom allows students to interact with their peers; perceive and be perceived by others; and generate knowledge and understanding while being closely coached by teachers (Chen et al. 2010; Ni 2013; Stodel et al. 2006). The effective deployment and assessment of collocated collaborative learning tasks is only going to become more critical because collaboration and help-seeking from peers are playing an important role in education (O'Donnell and Hmelo-Silver 2013) and for the development of twenty-first century skills (Beetham and Sharpe 2013; Buckingham Shum and Crick 2016).

In the last couple of decades, emerging classroom technologies have gained considerable attention to promote the development of collocated collaboration skills (Chen et al. 2010; Sottilare et al. 2018; Stahl et al. 2006; Stahl 2017). However, it may be hard for teachers to keep awareness of what is going on within each small group in the classroom (Alavi et al. 2009; Gutiérrez Rojas et al. 2012; Liu and Nesbit 2019) or have a detailed sense of how the task is unfolding according to the original plan (Hernández-Leo et al. 2019; Mangaroska and Giannakos 2018). A number of technologies have been developed to facilitate collaborative learning in the classroom. For example, Computer-Supported Collaborative Learning (CSCL) technologies that provide scripting or scaffolding support have been created with the aim of maximising students' opportunities for learning and developing effective collaboration strategies (Fischer et al. 2007; Ludvigsen et al. 2016). However, the reality is that it may become increasingly challenging for teachers to *orchestrate* these technologies on top of the epistemic, social, and pedagogical aspects of the classroom that they also need to manage (Chen et al. 2009; Dillenbourg 2013; Dimitriadis 2012; Munoz-Cristobal et al. 2015). In response, orchestration technologies have emerged in recent years to help teachers manage the increasing uncertainty and complexity of CSCL classrooms (Dimitriadis 2012).

Classroom orchestration can be described as a regulation loop that consists of two main tasks: *state awareness* and *workflow manipulation* (Dillenbourg et al. 2011). In recent years, some of the practical orchestration tasks that teachers must accomplish have also been targeted by the fast-growing area of learning analytics (LA) (Greller and Drachsler 2012; Scheffel et al. 2014) by exploiting the digital traces that learners may leave behind while collaborating. Dashboards and similar data-intensive applications (such as automated alarms, recommenders or personalised feedback tools) have gained considerable attention as mechanisms that can be used to enhance awareness and make the orchestration of CSCL classrooms more effective (Prieto et al. 2018).

Particularly, teacher-facing dashboards are intended to help educators gain a better understanding of their whole course; reflect on their teaching strategies; or identify learners who may require specific attention (Molenaar and Campen 2017; Verbert et al. 2013). However, although the dashboard metaphor is appealing, some barriers to adoption have already been identified, including the potential misalignment of dashboards with the intended learning goals (Rodríguez Triana et al. 2014); and the orchestration challenges and time constraints teachers commonly face in the classroom (Peiper 2008; Teasley 2017). It has also been reported that the value of teachers' dashboards may depend on the degree to which teachers have been involved in their design (Holstein et al. 2018). Thus, if dashboards are to continue being introduced into CSCL classrooms, we need to gain a better understanding of the critical active role that data may have on the teachers' decision-making process. To achieve this, it is critical to understand teachers' data needs, the particular context of data usage, and how the design of the analytics can be aligned with teachers' pedagogical intentions.

This paper presents the analysis of the perspectives of teachers who used a real-time analytics tool to support the orchestration of a CSCL classroom during several sessions. A longitudinal, authentic study was conducted with a handheld dashboard deployed in a multi-display collaborative classroom during one full academic term. The dashboard was designed, configured, and deployed following a participatory process. The resulting dashboard allowed teachers to manage the workflow and gain awareness of small group CSCL activities. It showed real-time information about group participation and task progress; the current state of the CSCL script; and a set of notifications informing teachers of students' misconceptions automatically detected. The study involved four teachers conducting 72 classroom sessions for ten weeks. Three applications that facilitate open-ended group tasks were used in both terms to support: concept mapping, idea generation, and team meetings. The contribution of this paper is the discussion of teachers' perspectives on real-time analytics in a CSCL classroom. This portrays both the promises and challenges of introducing new technologies aimed at supporting orchestration and awareness.

Background

Classroom orchestration and learning analytics

There is an implicit overlap between learning analytics (LA) and the notion of orchestration that has appeared in a small number of research outputs (e.g. Dillenbourg 2015; Martinez-Maldonado et al. 2016; Prieto et al. 2018; Rodríguez Triana et al. 2014; Verbert et al. 2013). The metaphor of orchestration was proposed to consider the real-time, multi-layered activities that teachers need to perform in the quite dynamic and unpredictable CSCL classrooms (Dillenbourg et al. 2009; Dillenbourg et al. 2011). Orchestration also includes the design of the learning tasks, and the degrees of freedom that teachers have when enacting the instructional plan (Dillenbourg and Jermann 2010; Tchounikine 2013).

Prieto et al. (2015a) provided a detailed analysis of the kinds of teacher's tasks that have been addressed by current orchestration literature. These tasks include: i) d*esign and planning*; ii) *regulation and management*; iii) *adaptation, flexibility and intervention*; and iv) *awareness and assessment.* It can be argued that the increasing use of technology in (and out) the classroom can also increase the complexity of orchestration, particularly for already complex pedagogical approaches such as open-ended collaborative learning (Dimitriadis 2012). *Orchestration technologies* are aimed at alleviating such complexity by providing support to manage or to emphasise salient aspects related to the pedagogical or technical dimensions of the learning activity (Dillenbourg and Jermann 2010).

Emerging LA tools can be seen as a particular type of orchestration technology focused on supporting *awareness and assessment.* Wise and Schwarz (2017) and Stahl (2015) emphasised the opportunities that emerging LA approaches can bring to CSCL in years to come by providing new techniques to aid in the analysis of group processes and to support collaboration. For example, empirical work has suggested the potential active role of LA in CSCL research by augmenting the support that teachers can provide to students in group tasks (Van Leeuwen et al. 2014), increasing the monitoring capabilities of teachers in deploying CSCL scripts (Rodríguez-Triana et al. 2018), and facilitating the assessment of simple constructs such as students' participation within a group (Xing et al. 2014). However, Wise et al. (2020) recently argued that the field still needs to generate understanding about how data traces can be mapped to higher-order CSCL constructs. Moreover, Tchounikine (2019) suggested that, if LA is going to play a key role in CSCL, this should be focused on supporting awareness and recommendation in ways that teachers and students can understand in order to make well-informed decisions. The next subsections show how classroom data may play an important role in supporting teachers' classroom orchestration tasks.

CSCL dashboards in the classroom

Evidence of the growing interest in using dashboards and similar visual aids to support CSCL can be found in LA reports by Bodily and Verbert (2017) and Teasley (2017), with a noteworthy appearance of CSCL dashboards in a LA review by Schwendimann et al. (2017). A recent discussion paper on CSCL dashboards by Liu and Nesbit (2019) points at the critical importance of adopting an iterative, user-centred design approach to design for the complexity of CSCL awareness. User-centred approaches are common in CSCL (Kirschner 2002) however, Liu and Nesbit (2019) warn that multiple forms of data can be captured in CSCL settings which creates an ample design space for data representation that needs to be explored.

Although the idea of visualising CSCL data has been explored by some researchers who have mostly focused on fully-mediated, online CSCL settings (see review in Liu and Nesbit 2019), the idea of using dashboards to augment teacher's awareness in the physical classroom is relatively new. Improvements in network technologies made the deployment of interconnected desktop computers or Tablet PCs feasible and easy to achieve. These provided opportunities for teachers to conduct collocated collaborative tasks in the classroom (Zurita and Nussbaum 2004) as it was originally conceived by pioneering CSCL projects (Bruce and Rubin 1993; Nicolopoulou and Cole 1996). Subsequently, classroom dashboards started to be experimentally deployed (e.g. Kamin et al. 2009; Peiper 2008). Initial prototypes provided minimal information about the status of the software used by individual learners in real-time (Gutiérrez Rojas et al. 2012) or overviews of what learners did for post-class revision (Kamin et al. 2009). As emerging technologies that invite shared usage started to make their way into classrooms (for example, interactive tabletops, digital whiteboards and smart portable devices) more complex dashboard prototypes particularly tailored to supporting CSCL activity started to appear. For example, Do-Lenh (2012) presented a reflection tool that allowed the teacher to guide classroom reflection based on CSCL task progress visualisations generated from data automatically captured from small tangible tabletop devices. NumberNet, was also a multi-tabletop environment for supporting CSCL activities (Mercier 2016). A dashboard presented to the teacher a list of correct or incorrect mathematical expressions automatically identified in the tables where students were working. More recent systems, based on tablet devices (Kreitmayer et al. 2013; Wang et al. 2015) and personal computers (Looi and Song 2013) also exploited data generated by the devices running a CSCL system to provide interfaces for teachers to monitor progress at a class, small group, or individual levels.

The interest in finding effective ways to communicate student data through visual representations for in-classroom real-time use is gaining momentum in CSCL. This is reflected by the proliferation of CSCL classroom dashboard ideas (see Tissenbaum et al. 2016) and current attempts to create classroom orchestration interoperability frameworks (e.g. Muñoz-Cristóbal et al. 2014; Phiri et al. 2016). Some off-the-shelf products are already incorporating certain elements of real-time monitoring. An example is Learning Catalytics (Schell et al. 2013) which provides visualisations to teachers about students' progress and their misconceptions while collaborating in the classroom using their own mobile devices. Monitoring tools such as Edquire (edquire.com) gather student usage information from local applications during a lesson which is then made visible to the teachers in real-time. Looking into the future, inroads have been made to go beyond dashboards displayed on a screen by embedding 'the dashboard' into the whole classroom by using mixed reality glasses (Holstein et al. 2018).

Learning analytics technologies for classroom orchestration

Most of the classroom dashboards mentioned above have been designed with the main purpose of supporting the orchestration of CSCL tasks in real-time. In terms of *workflow manipulation,* they have provided different ways to control the pace of the class macro-script, for example, by moving the class through the activity as a whole (Looi and Song 2013; Mercier 2016; Wang et al. 2015) or by allowing certain students advance at a different pace (Olsen 2017; VanLehn et al. 2016). Some of those dashboards also allowed to interrupt the execution of the task if needed (e.g. Mercier 2016). A deeper review and discussion of these controlling functionalities was conducted by Olsen (2017). Although control functionalities are important for orchestration, in this paper the emphasis is on data and the *state awareness* features that can play a critical role in the classroom. This is important because teacher-facing dashboards emerged as one of the first direct applications of LA but the effects of their use still need deeper scrutiny (Teasley 2017).

Based on the works discussed above, three types of data that can support orchestration in the CSCL can be identified:

1) *The state or progress of particular groups*. This has been tackled through the use of minimalistic representations such as progress bars (e.g. Do-Lenh 2012; Wang et al. 2015); descriptive text (e.g. Wang et al. 2015) or by displaying the students artefact for whole class discussions (e.g. Do-Lenh 2012; Looi and Song 2013; Mercier 2016).
2) *The state of the workflow or time left according to the lesson plan.* This has been achieved by alerting the teacher of the time left through a timer (Kreitmayer et al. 2013) or a timeline visualisation (Martinez-Maldonado et al. 2015a).
3) *The presence of mistakes or misconceptions in learners' artefacts*. This has been explored by presenting teachers with lists of errors automatically detected (e.g. Mercier 2016).

Most of these previous studies have been carried out under experimental conditions and during short periods of time. Progress has been done towards trying to understand how teachers can make sustainable use of dashboard technologies to orchestrate their classrooms. The closest work towards achieving this purpose is the FACT project (Cheema et al. 2016; VanLehn et al. 2016). In this project, a similar handheld teacher dashboard to the one presented in following sections has been prototyped to be used in school classrooms. The authors of the FACT project discussed their experiences in terms of monitoring and orchestration as a result of a series of preliminary classroom trials with their toolset. Although not much empirical evidence from a teacher's perspective has been provided, these authors pointed at a number of critical design considerations that can make an orchestration tool successful by providing the right kind of support to teachers. They have also suggested the importance of providing just the right amount and type of data to enhance teacher's awareness through functionalities such as stealth assessment, notifications and information visualisations.

In sum, previous work CSCL dashboards deployed in the physical classroom suggest that data can play a critical role in augmenting teachers' awareness in terms of learners' activity and workflow management. However, most of the previous studies have been conducted under experimental conditions or involved authentic classroom interventions of short durations. From these studies, it still is unclear what would teachers' perspectives on data be after an extended period of use of such dashboards. The case study presented in this paper goes beyond previous work by generating understanding of teachers' perspectives after an extended usage of a dashboard in a complex, technology-rich CSCL classroom.

Design

This section first presents the classroom setup and the learning context in which the dashboard was used. Then, the design principles and the features of the dashboard interface are described.

Classroom technical setup

The classroom in the current study endorses the vision of embedding computational capability into the classroom furniture. Interactive tabletops have been proposed as promising pervasive technologies that, if accompanied with the right pedagogical practices, can be used to support collaborative learning (Dillenbourg and Evans 2011; Higgins et al. 2011). Although tabletops have not reached a level of maturity needed to become a mainstream technology, they belong to a family of surface technologies which are already making their way into classrooms in the form of vertical touch displays and tablets. The teacher dashboard was deployed in a multi-tabletop classroom. This is comprised of five multitouch tabletops that allow up to five students to collaborate around each of them (Fig. 1).

This learning space was used in the University of Sydney to conduct small-group activities for regular classes. The tabletops were enhanced with Kinect sensors facing down from the ceiling to add touch identification capabilities. This way, all actions performed by students on the tabletops could be differentiated. The three vertical displays in the room could be used by the teacher to display slides or for showing the final output of certain groups of students for discussion (e.g. see Fig. 2-left). Microphone arrays were located on each table, but due to expected classroom noise, the information captured by these was not presented to the teacher in real-time but analysed for research purposes.

Three tabletop applications could be used in the multi-tabletop classroom. These included: i) a *concept mapping* collaborative editor (Fig. 2-right); ii) a *brainstorming* system that supports rapid idea generation and clustering; and iii) a software development *meetings mediator* that allowed students to get access to their Trac sites (which include a wiki and issue tracking systems - trac.edgewall.org) from the tabletop. A software service, called the *technical orchestrator*, was built to control the devices and the apps. This served as a common operating application that sent commands to any plugged application. The tabletop applications (the concept mapping, brainstorming, and meeting mediator apps) implemented the actions internally. The orchestrator provided a common language of possible actions that the teacher could perform across applications. These included the ability to freeze the tabletops at will, to advance the tables to a next stage of the class script, to broadcast a text message to all

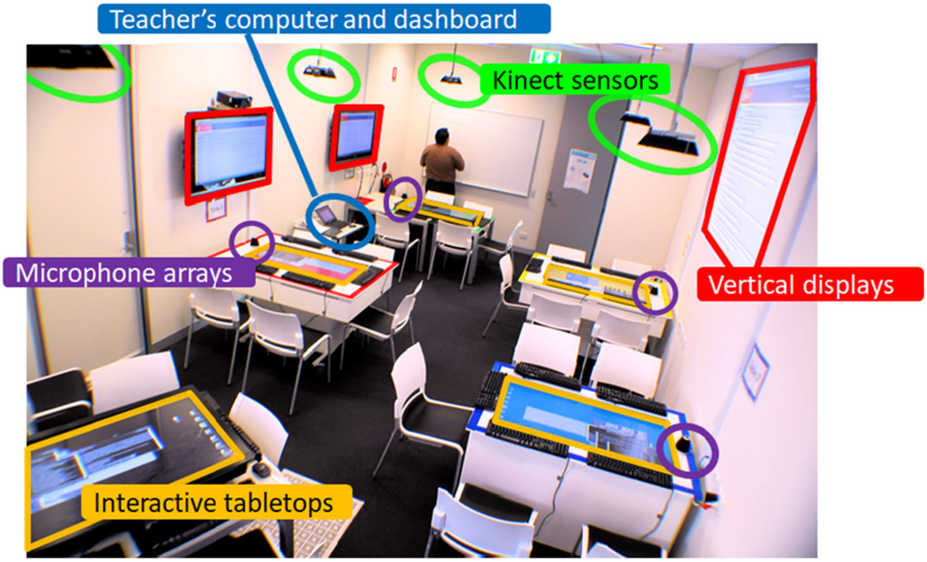


Fig. 1 The technology-enhanced classroom where the teacher-facing dashboard was deployed

the tables, and to send the content of a particular table to the vertical displays. All these actions were inspired by previous work on multi-tabletop classrooms (Do-Lenh 2012; Mercier 2016). Data captured by the individual tabletop apps, the kinects, the microphone arrays, and the orchestrator were recorded into a common database server located in the classroom for real-time database queries to be issued by the dashboard and also to keep the data physically contained in the classroom.

Learning context

The study was conducted as a part of two units of study coordinated by the same teacher: the undergraduate unit *Human-Computer Interaction* and the postgraduate unit *Pervasive Computing*, with a total of 108 and 42 students enrolled in each respectively. These were 13 weeks long and had weekly 1-h tutorial classes where 20–25 students would work on small group activities or on their capstone projects.

Fig. 2 Left: a teacher leading the discussion on one of the students' final artefacts 'sent to the wall'. Right: one team of people illustrating how students could build a concept map at one of the interactive tabletops

Each unit had 6 and 2 tutorials respectively every week which were distributed among four teachers (TE1, TE2, TE3, and TE4, who taught 3, 2, 2, and 1 classes each, every week respectively). Each week, the *coordinator of the unit* provided the instructions to the teachers (tutors) with the topics, tasks and the macro-script that they were intended to enact. Students in both units were organised into small groups of 3–5 members from Week 4. From this week, all classes were held in the multi-tabletop classroom and each group was assigned to one tabletop that they would use for the rest of the term. In each class, one or two out of the three tabletop applications (concept mapping, idea generation, and meeting support) were used in combination with other collaborative tasks such as group reflections and oral presentations.

By the end of the term, all teachers had experienced having access to the classroom data offered by the dashboard. These data included the tabletop activity logs, information about the status of the task or artefacts being built by students, the distance between these artefacts and the ideal solution defined by the coordinator, and the comparison between the class script defined in the learning design and the pace in which each teacher enacted each phase of such script.

Design principles

Inspired by the notion of *social translucence* proposed by Erickson and Kellogg (2000), the dashboard was designed with the purpose of making some aspects of physical group visible. Socially translucent systems are those that make the interactions within a group of people visible to one another. A *translucent classroom* would then be one where evidence can be generated and shown to the teacher or learners to provoke reflection and sense-making, and generate the means for supporting the provision of feedback (fully automated or facilitated by the teacher).

A two-year participatory process was conducted with teachers to explore, design and evaluate a series of analytics visualisations and functionalities that would be useful for making CSCL classroom activity visible in real-time. This process included:

i) Two lab-based design studies using real student data, consisted in presenting a set of low-fidelity (paper-based and digital) CSCL visualisation prototypes to 13 teachers in order to document their reactions and obtain feedback that could be translated into design changes (Martinez-Maldonado et al. 2011a, 2012); and
ii) Two authentic classroom pilot deployments with one teacher in two units of study during two university terms (Martinez-Maldonado et al. 2015b, 2013).

In the lab studies (Martinez-Maldonado et al. 2012), simulated data was used to identify the visual representations that would be more useful for teachers. In the classroom studies (Martinez-Maldonado et al. 2013), the potential impact of the tool on learners was explored by inspecting how students' solution changed as a result of the feedback provided by the teacher. This paper goes beyond this previous work by presenting results of the sustained use of the toolset by a number of teachers in authentic units of study. The paper is focused on the teacher's perspectives rather than on the tool validation as this has been the focus of our previous work.

Table 1 summarises the nine design principles that were identified. Four principles were obtained from the lab-based studies (L1–4) and 5 from the classroom deployments (C1–5).

Table 1 Design principles

L1-The visualisations that may be more suitable for real-time classroom use should allow **rapid comparison** among groups of learners by **aggregating low-level indicators** of group activity or automatically **assessing a higher-order aspects** of the group process.
L2-Teachers want to see data that can serve as evidence related to the task (the **epistemic domain**) and to the individual participation to detect free riders (the **social domain**).
L3-Teachers found it **hard to trust** on the output of a machine learning algorithm intended to compute the high-order aspect of collaboration. They preferred to make sense of the low-level data and find insights by themselves.
L4-Teachers indicated they did not want to see details in the classroom They preferred to get informed of **critical events** that occurred within a group.
eC1- The teacher wanted a way for the tabletop to **automatically assess the content of the students' task** because she could not do this in real-time. This would be helpful since she stated that she *"couldn't easily assess the quality of the students' task on the fly"*.
C2- The teacher asked for showing **text instead of graphical visualisations** because she thought the graph could be redundant if some descriptive text was already present.
C3- The teacher had to repeat the same tutorial several times with different students, thus she wanted to know how consistent she was performing here own **class script design**. In the future, she wanted to know how other teachers would be performing her learning design.
C4- The teacher wanted to **submit to the system an ideal solution of the task** before the class for accomplishing stealth assessment (automatically measuring the deviation of students' solution to hers).
C5- The teacher wanted to get **notified of potential misconceptions** within particular teams.

The dashboard interface

Figure 3 shows the final version of the dashboard used in the study. van Leeuwen et al. (2019) suggested three types of features that CSCL dashboards commonly contain, according to the kind of support that is offered to the teacher: mirroring, alerting and advising. *Mirroring*

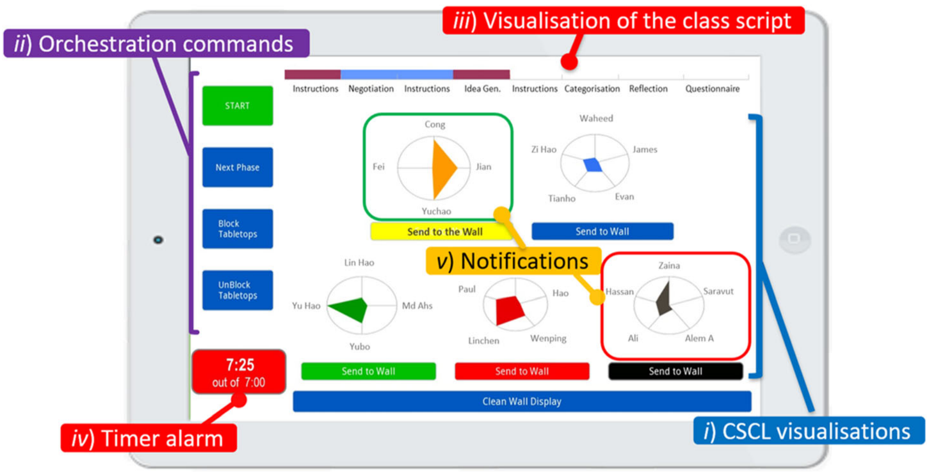


Fig. 3 The handheld dashboard' s main components: i) placeholders for CSCL visualisations, ii) orchestration commands, iii) a visualisation of the class script, iv) a timer alarm of the current task, and v) notifications shown as rounded squares around the CSCL visualisations of certain groups (green for positive and red for negative notifications)

support consists in just showing information to the teacher for him/her to assess and interpreting it. *Alerting support* consists in automatically detecting critical information from the data and communicating it to the teacher. *Advising support* includes the previous two kinds of supports plus aiding in the interpretation for the teacher to take some action. As a result, the final prototype features according to the kinds of support they offer, are presented as follows:

A placeholder for CSCL visualisations or textual information of each group in the classroom (mirroring support) Following the human-centred participatory process, the information about each small group shown to the teachers was selected based on the preferences of the teachers in previous experimental and classroom experiences. At the same time, the kind of information presented is partly limited to the kind of data that the technology available in the classroom could reliably capture. For example, although some basic conversation patterns, such as turn-taking and overlapping, would contribute to understanding some aspects of collaboration (Stahl 2002), and microphone arrays located in each table would ideally automatically detect those (Martinez-Maldonado et al. 2011b), the classroom is too noisy. Current automated solutions have only worked well thus far in experimental settings (Chandrasegaran et al. 2019).

Hence, following the principles L1 and L2 learnt from the lab studies, the dashboard was configured to present information (mirroring) about *individual participation* (see Fig. 3-*i* and Fig. 4-left, spider diagrams) and group *task progress* (see Fig. 4-right, concentric circles representing the size of the group solution and extend of connectedness of ideas in the concept map or brainstorming task). Individual participation within a group has been used as a basic indicator to identify potential collaboration issues, such as marginalisation (Prinsen et al. 2007) and the presence of "ghosts" or "free-riders" (Hämäläinen and Arvaja 2009), in CSCL contexts. Showing task progress of multiple groups has also been a basic construct shown to teachers when monitoring multiple groups (Do-Lenh 2012). In the preliminary lab studies, teachers explained they would not trust in automatically generated assessments of collaboration (L3) and that they would not like to see many details about the groups (L4).

The visualisation of group *task progress* (Fig. 4-left) was, in some classes, presented to teachers just as text, removing the concentric circular areas that represented the 'size' of the

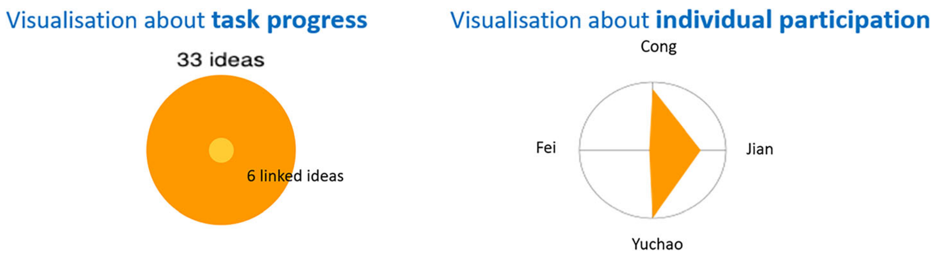


Fig. 4 Visualisations about individual participation (left – spider diagram of the amount of touch interaction per student) and group task progress (right - represented as two concentric circles whose area represents the size of the group solution and the distance to the teacher's solution for the outer and inner circles respectively)

Fig. 5 Visualisations about task progress: graphic (left) and text-based (right) versions

student's artefacts (Fig. 5). This visualisation was tested to follow up on a suggestion by the teacher who participated in our preliminary classroom pilot studies who stated the following: "Maybe instead of having a graph we could have a table with this information: number of concepts created by the group and the links that are relevant to the case study. There is no point of having the same information repeated in text and graphically" (principle C2).

A set of orchestration commands for controlling classroom displays and applications A green button labelled as "START" at the top-left of Fig. 3-*ii* allows the teacher to load the CSCL script at the beginning of the class. The button "Next Phase" advances all the tabletops to the next phase in the script (e.g. negotiation phase, instructions phase, idea generation phase, etc.). The buttons "Block Tabletops" and "Unblock Tabletops" allows the teacher to stop the script, disable the touch interaction of the touch screens and dim the screens in case s/he needed to give particular instructions or interrupt the flow of the script to provide feedback at a class level.

A CSCL macro-script visualisation (mirroring and alerting support) As with the other awareness functionalities, during the previous pilot studies, the teacher highlighted that she "usually didn't stick to the initial plan across classes as the pace of the groups in each class was different, sometimes needing to take more time in certain tasks or even skipping things [she] originally planned" (principle C3). This motivated the provision of information (mirroring) about the enactment of the class macro-script as a timeline and an alarm (alerting) for the teacher to be aware of the time spent in each phase of the script (see Fig. 6-left).

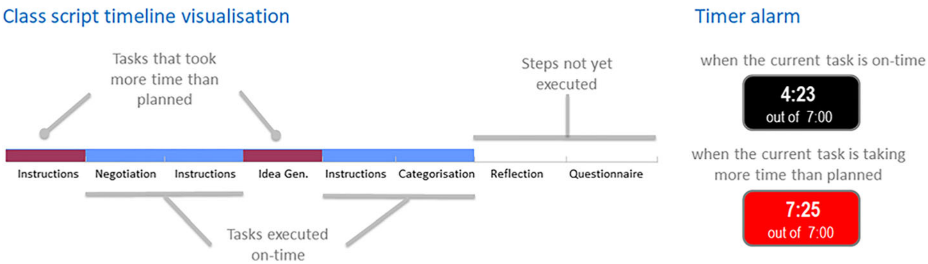


Fig. 6 Real-time feedback on the teacher's enactment of the learning design in the form of a timeline visualisation (left) and an explicit timer alarm (right)

A CSCL macro-script (Dillenbourg and Hong 2008) can be defined in XML format by the teacher or a researcher. This contains the sub-tasks that should be executed by each tabletop application, and their intended duration according to the learning design. Once loaded, the macro-script is executed by the classroom ecology under the control of the teacher, with the flexibility for the teacher to alter the initially planned timings. This flexibility is provided, as the actual events in a classroom are not predictable (Dillenbourg et al. 2018). The class script timeline is shown as a progress bar at the top of the dashboard (Fig. 3-*iii* and Fig. 6, left). It shows a phase in dark red (e.g. initial instructions and idea generation in Fig. 6-left) if it took longer than what was planned in the original script (e.g. phases instructions and idea generation). Those phases enacted below the allocated time appeared as (pale) blue sections of the progress bar.

An alarm that notifies the teacher in case the current phase is taking longer than planned (alerting support - principles C3 and C5) Beside the coloured sections in the class script timeline, a rounded square located at the bottom-left of the dashboard shows the time that the *current* phase is taking (Fig. 3-*iv*). The colour of the square changes from black to bright red once the phase has taken longer than planned (Fig. 6-right).

A set of notifications automatically triggered when critical events configured by the coordinator occur (advising support) Notifications were provided as a more prescriptive means for teachers to be aware of quality aspects of the group task. The teacher who participated in our preliminary classroom pilot studies said that she "couldn't really identify students' misconceptions since it would take a long time to look at each map, but it would be good for the system to point at suspicious statements students create in the tabletops" (principle C1).

Two types of notifications were created. The first type of notification was triggered when misconceptions were automatically identified in a group's table by matching the students' solution with a list of common misconceptions pre-defined by the coordinator of the units of study (principle C4). The notifications appeared as a red or green square around a group's visualisation (see Fig. 3-*v*). The teacher had to tap on the visualisation to read the details of the notification. Figure 7 shows the text generated for two examples: a 'negative' (red) notification of a misconception detected by the system in the blue table (left), and a 'positive' (green) notification informing the teacher about the progress of the red group (right).

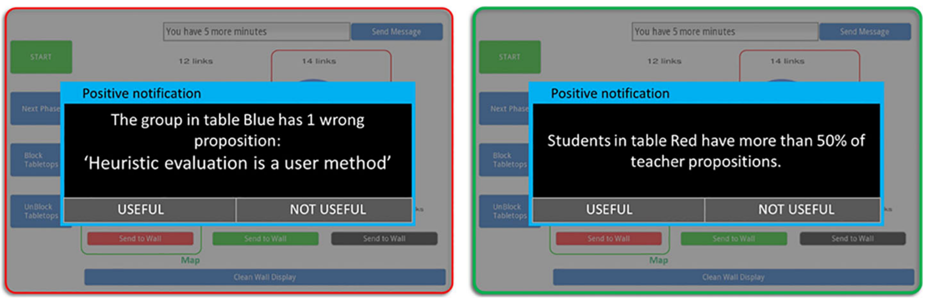


Fig. 7 Notifications appearing as text feedback for the teacher on top of the dashboard interface when the teacher taps on a visualisation surrounded by a square. Left: a notification corresponding to a misconception automatically identified. Right: a notification indicating the progress of one group in completing the task

Study

Based on the current CSCL dashboard developments presented in the Background section; the gap identified in the literature regarding the lack of analysis of the effects of the extended use of teacher-facing dashboards (Teasley 2017) and CSCL dashboards (Liu and Nesbit 2019); and the lessons learnt from our own pilot studies, the aim of this study was to understand the teachers' perspectives on the orchestration and state-awareness functionalities of the real-time analytics dashboard after extended use.

The following sub-questions serve to investigate the different features of the dashboard:

- RQ1: what are teachers' perspectives on having real-time access to CSCL visualisations?
- RQ2: what are teachers' preferences in terms of interpreting visualisations versus text?
- RQ3: what are teachers' reactions to the notifications?
- RQ4: what are teachers' perspectives on the scripting visualisation and alarm?
- RQ5: what are teachers' perceived advantages and challenges in carrying a handheld device?

Illustrative episode of the dashboard usage

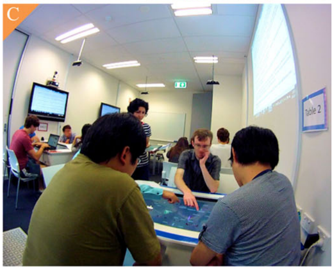
The following episode that occurred during the last class of the unit of study *Human-Computer Interaction* (in Week 13) illustrates how the teacher used the dashboard. In the following excerpt (Table 2), the groups of students had already been working for several minutes on a concept mapping activity. They were asked to build a concept map that reflected a number of usability methods in the context of a usability study they had to plan during this class. This episode was recorded by following the teacher's moves in the classroom with a video camera during her class. The video was transcribed, and the dialogue excerpts were enriched with descriptions of the teacher's and students' actions. This teacher's class was randomly chosen amongst all the classes available and also because all students in this class consented to be video recorded.

Due to practical and orchestration limitations, not all the classes could be recorded in this way since *all* students had to give permission to be video recorded (including signing an ethics consent form). It was also not practical to follow all teachers with a video camera in all their classes. Thus, this example is limited to illustrate how teachers could use the dashboard during their classes. Whilst this example focuses on a concept mapping class, other collaborative tasks that students performed included brainstorming and project meetings.

Analysis

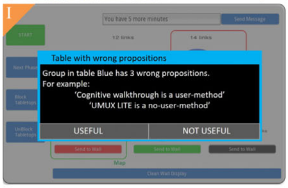
The brief episode described in Table 2 illustrates the complex orchestration tasks carried out by the teacher and the influential role that the dashboard can have. A series of semi-structured individual interviews were conducted with the four teachers in week 7 (the middle of the term) and week 13 (the end of the term). The duration of the interviews was from 40 to 60 min. In each interview, teachers were asked to describe their own experience regarding each of the functionalities and visualisations of the dashboard. The structure of the interviews corresponded to the research questions

Table 2 Illustrative episode of the dashboard usage

The teacher stands by the **Blue table** for about a minute (see Figure A at the right) until she starts a conversation with students, as follows: Teacher: *Are you going to connect all these concepts that you have here?* (see Figure B) L_Blue1: *Yeah, we started to generate some ideas but now we don't know how to connect all of these.* L_Blue2: *We were just discussing about these.* L_Blue1: *We were wondering what usability method would be good to apply if we want to only build three prototypes.* Teacher: *Why don't you group all the user methods together? I thought this method you have in here is a user method. For this method you can build prototypes at an initial phase without users to then validate it with users.* L_Blue3: *Ok, let's move these (*students 3 and 1 start deleting connections and making new connections, see Figure C). L_Blue 4: *What should the linking word be?* … (…students keep working by themselves. The discussion continues while the teacher goes to see what students in the **Red table** are doing)	  
The teacher only stays with this group (**Red table**, see Figure D) for a few seconds and then she walks towards the **Black table**.	

(RQ1–5) listed above. Teachers were asked to reflect on their experience in: i) having real-time access to CSCL visualisations in the classroom; ii) making sense of visual versus textual information; iii) reacting to automated notifications; iv) having real-time access to a scripting visualisation and an alarm; and v) in carrying the handheld device. All interviews were fully transcribed. A total of 115 reflective statements were identified (these are reflections, composed by one or more utterances, that talk about one or more dashboard functionalities, design requirements, or orchestration activities). These were clustered into themes corresponding to each RQ. The next section presents the results of this analysis.

Table 2 (continued)

The teacher stays at the **Black table** for about 1 minute in total, just looking at what students are saying and doing with their concept map while holding the dashboard (see Figure E). Then, she looks at the dashboard more carefully and decides to go to the **Yellow table**. As shown in Figure F, the dashboard shows the smallest circles for tables **Yellow** and **Black**, followed by the **Red** and **Blue** tables, at this exact moment. This may indicate these two groups may be falling behind compared with other groups in the class.	 
The teacher goes to the **Yellow table** and listens to students' conversation (see Figure G). Then, she decides to start a conversation: Teacher: *Have you gotten to the design of your user test?* L_Yellow1: *Yes, and we got more things than what we can test with users.* Teachers: *How many users do you think you would need?* L_Yellow2: *About 50 users. We need six for a usability test.* L_Yellow1: *Then, we need 10 for this other system. And we need 35 for the following prototypes.* Teacher: This sounds fine, just make sure you start adding all this to your concept map.	
The Teacher walks back to the **Black table**. However, before engaging with the learners in that table, she notices that there is a notification coming from the **Blue table** (see Figure H) pointing at the presence of a few misconceptions automatically detected (see detail in Figure I).	 
The teacher walks to the **Blue table** instead and engages with the students as follows: Teacher: *I think you have some non-user methods marked as user methods.* L_Blue1: *We have been moving things around, and also deciding on the number of users we need.* Teacher: *Yes, but I don't think you need users for a cognitive walkthrough.* L_Blue2: *Oh! That one is in here. We think this is a user method* L_Blue1: *Or at least, that's what we decided.* Teacher: and what about UMUX? L_Blue3: We have it here! [pointing at another section of the concept map at the tabletop]. (…students start to negotiate their claims made in the concept map but, eventually, the teacher makes them see why these propositions were wrong)	 

Results

Teachers' perspectives on the CSCL visualisations (RQ1)

Teachers were provided with the visualisations about group *task progress* and *individual participation*. The following reflection illustrates how a teacher interpreted the first visualisation of *task progress* (e.g. Figure 4, right):

> [the visualisations] were useful, you could tell by looking at them that this group [pointing at a visualisation in the screen], the 'black group' was far behind at that moment. Sort of I would know that I should go and help them. Sometimes I couldn't help them, so I couldn't make them look better in the dashboard, but at least I knew what I was dealing with in that class. In this case, I wouldn't have worried about other groups as much, but I would still go and confirm that they were fine. (Teacher TE1)

This suggests that the tool invited the teacher to find out more about what is going on with a particular group. As teachers may find hard to assess each group's solution "on the fly", providing task-related information to teachers in real-time may have enhanced awareness. For this teacher, it was up to her what to do with these data.

Other teachers were similarly optimistic about this type of visualisation, since it helped them in "being able to quickly compare groups at a glance" (TE3) and "making better decisions in later stages of the class" (TE1). However, they also recognised the limitations of the data provided and the need for alternative sources of information to get a better picture of what was happening with each small group. For example, TE2 summarised this as follows:

It was really good to see how groups were progressing straight away. I could quickly stand in the middle of the classroom and get a sense of what groups were making progress and which were not. However, it didn't give me any information about who was doing the work, their strategies, or if there was fair collaboration.

This points out at the need for other sources of evidence that would allow the teacher to make better assessments of the groups in the classroom and decide which group may need more help.

TE2 also suggested the following "It would have been good to have collected information about talking too, but I am not sure if this would be feasible to be collected in the classroom". This teacher justified the importance of knowing about this dimension of interaction as follows: "maybe the people who were doing all the talking wouldn't be adding ideas physically but this way I could have a better picture about identifying those individuals". This kind of commentary was expected as it is in line with the results of our lab studies, in which presenting differentiated speech summaries along with logged individual contributions in a single visualisation was highly valued by teachers. Although audio levels were collected through the microphone arrays located in each table in the classroom, the quantitative measure of speech in the classroom is still technically challenging in terms of accuracy (e.g. filtering the classroom 'noise') and unobtrusiveness. Some recent work in this area is attempting to automatically capture turn-taking patterns in the classroom (Noel et al. 2018). However, correctly differentiating group members' voices from noise coming from other groups still needs further research and development work to be able to make reliable assessments.

TE2 and TE3 also highlighted the value of summarised information but pointed at the lack of information of individual contributions for the *task progress* visualisation:

It was really good to see who was stuck and who was doing really well, but not much information about individuals, which I don't know if it is really useful on-the-fly. Maybe I can just do by sitting next to them for a bit to get a good sense of who is leading the work. (TE3).

This was compared with the reflections on the visualisation of *individual participation*, which depicted the names of students seated at each table (see Fig. 4, left). The same teacher (TE3) valued that through this second visualisation she "could [for example] see that two students were really active, but one was not active at all". At the same time, another teacher recognised the challenge of processing the details in real-time. TE4 described his classroom experience and suggested design changes that could make the visualisation more effective:

In the classroom, it was really hard to notice the student names. I just looked at the shapes. Maybe only highlighting particular students in need would be useful. If I knew this information I would go particularly to talk with that student and try to motivate him [her] to express some ideas.

This suggests the potential need for a design adjustment in which teachers could be able to select what visualisation to see or a visualisation that includes both types of information about participation and task progress.

In sum, the CSCL visualisations presented in the dashboard to the teachers during an extended period triggered reflections and ideas for further development of the tool. Interestingly, teachers understood the value but also recognised the limitations of the role of data in the classroom. Interestingly, they highlighted how the data can play an important role in their pedagogical practice but also that the way in which information can be explored or selected for rapid sensemaking is critical. This was explained by one of the teachers as follows:

I had one girl in my tutorials that didn't talk much. I remember looking at this graph [the individual participation visualisation] and realising there was someone who had not added anything. It is just that I didn't read her name, but I knew who she was from the actual tabletop interface which had the ideas colour-coded. I went there, and I remember she generated one idea while I was there. She was there doing nothing just looking. I think having this information more explicit would have been very helpful (TE3).

This suggests that further work is critical for creating CSCL visualisations that explain potential issues that the teacher should look at rather than just presenting information that invites the teacher to analyse the data on the fly. This is in line with recent research in the area of learning analytics suggesting that educational visualisations should be explanatory rather than just exploratory (Echeverria et al. 2018).

Teachers' preferences on interpreting visualisations versus text (RQ2)

As expected, teachers generally preferred the graphic version since "it is easier to compare sizes" (TE3), whilst for the text version, it "takes more time to do calculations to compare the task progress" (TE3) or simply "all numbers cannot be read at the same time making it hard to figure out which group is progressing more" (TE1). This is aligned to foundational information visualisation literature (Treisman 1985) which points at the benefits of visualising information using graphs instead of text to take advantage of human's preattentive processing (visual properties are processed by our sensory memory without our conscious thought) (Yoo et al. 2015). However, as argued by Knaflic (2015), under certain conditions text itself may be more effective than graphs.

Teachers reflected on learning situations where they preferred the text version. TE3 explained one of these cases as follows:

> the text version was useful for the task where students were asked to only link 10 ideas together. In this way, I just looked at the number of linked ideas. The linked ideas text was very simple and was presented in big fonts, bigger than the graphic version so it was easier to interpret linked ideas through this visualisation. I think it all depends on the task students were doing.

This confirms that the request by the teacher in the pilot studies made sense for the particular kind of CSCL task being enacted in the classroom. TE3 also requested design additions that could direct the teacher's attention and that could be applied to the graph or to the text versions, such as "a marker indicating which team had the max or min number of ideas or concepts". In short, simply showing text should not be dismissed as an option to communicate data to the teacher in the classroom but it depends on the intentions of the learning design. Still, graphs can communicate information more rapidly, especially when comparing aggregated data.

Teachers' reactions to the notifications as narrative feedback (RQ3)

The 'positive' notifications were made available to teachers in the second part of the term as a response to one of the teacher's comments at the middle of the term:

> the interface sorts of guides you towards the students who may be not doing so well. It would be great if the interface can also emphasise when students are doing alright. I would notice that if I hear them talking about other stuff or if they look bored, but it would be also nice to confirm it from the data you are already collecting (TE1).

Teachers in the study acted as a result of reading both types of notifications as it was commented by one of the teachers as follows:

> I think both types of notifications were useful. The red ones are useful because I can easily identify if there is a problem in a group and try to fix it. I can tell the group, as soon as I can see it, that there is some problem, so they can immediately take action or make some suggestions, so they can figure out what is the problem and learn something. Although the 'green' notification had the lowest priority, I still used to go to the group and let that group know that they were progressing positively (TE3).

Other pedagogical strategies emerged over time as teachers became more familiarised with the notifications. For example, TE4 used the notifications to provide delayed feedback at a class level. This was described by the teacher as follows:

> If all the groups eventually had the same problem, I could stop the whole class for a short time and explain to the whole class any misunderstanding. Or at the end, in the discussion phase, I could say for example: all of you had this problem. For the 'green' ones I preferred to provide them immediate feedback to encourage groups to keep motivated.

The information provided by the notifications about misconceptions could also be used to provide better feedback to particular groups as described by TE3:

> Because at the end students had to share their solutions with the class, I could give them more adequate [delayed] feedback to that group not just from their explanation but from what it happened during the whole activity as informed by the notifications. I could even have skipped interventions during the activity and still be aware that some problems existed. However, I also used the notifications during the tutorials to provide immediate feedback.

Interestingly, TE4 used the positive notifications not only to encourage students but also to make them notice that she was aware of their progress. This was phrased by the teacher as follows:

> I was using the 'green' ones to motivate students but also to make them see the benefits of using the tabletops to make them positively accountable, so they can feel that I can see what they are doing. For example, one student even asked me surprised: how do you know what we are doing? For them, this would be a positive motivation since they know that I can have an idea of what they are doing even if I attend other groups. I think in this way they were more interested in continuing with the activity.

In regard to the negative notifications, TE4 explained that sometimes the misconception automatically identified as wrong, could be acceptable in the context of the solution that students were constructing or because of slightly different wording they were using. This was explained by the teacher as follows "If I identified there was a potential wrong proposition I would go to the table and try to help them fix that by talking with them. In a couple of cases, two groups convincingly justified why their statement was correct". The examples in this section show that both types of notifications were not used just to do a summative assessment of students' solution but rather used as a tool to drive attention and prompt dialogue.

Teachers' perspectives on the scripting visualisation and alarm (RQ4)

In general, teachers reacted positively to having access to information about the intended design and the enactment of the class script. For example, TE2 explained the following: "it makes it much easier to know how I am going with the script rather than spending all the time and realising at the end of the tutorial that we have to skip the last tasks that were in the plan". Another teacher (TE3) explained how this information helped her figure out when she had to compensate the duration of certain tasks: "for example, if I could see many red sections (over-timed tasks) I knew I had to consider that for the current stage". This suggests how the real-time access to this information helped her in managing the time of the whole class.

At the same time, teachers pointed at certain limitations. The first is not necessarily associated with the toolset or the visualisations but with the flexibility needed to make their changes to the learning design more permanent. Although the same learning design was provided to all the teachers, they all mentioned that commonly, the timing of the phases (proposed by the coordinator of the unit of study) had to be adjusted. TE2 explained this as follows: "In terms of usefulness I think this functionality was awesome, but in terms of the timing configuration it may improve. Obviously, this has to be with the plan given by the unit coordinator rather than the technology itself". TE4 suggested a possible local solution to carry local knowledge across her own classes as follows:

> After teaching the first class I knew that for some tasks we needed more time and for others we could go through faster. It would be great if the dashboard lets me modify the original plan myself after the first class. Based on this I could also get an idea early on to skip some bits if I was getting rid of time.

This suggests that making more permanent changes to the learning design can potentially enhance the effectiveness of this tool in the classroom.

Notably, a couple of teachers requested slightly more intrusive ways to alert them if they were spending too much time in a certain task. TE2 stated the following:

> I could allow the interface to warn me by beeping or vibrating if I have been talking too much with a student. Sometimes this happened in some classes. The students would also notice we are getting rid of time, so they could focus on their work and let us move on.

Another teacher explained that she wanted to keep awareness of certain alarms even if she was not looking at the dashboard interface: "I stopped looking at the screen when it became obvious what the next phase was or if I was talking with a student, but I still wanted to be reminded if I was over time" (TE1).

In short, presenting visual information of the enactment of the class script can be useful for teachers but the system needs to be flexible for them to adjust the class design on the fly or to suggest more permanent changes to be carried to the following classes.

Advantages and challenges in carrying the handheld device (RQ5)

Although presenting the dashboard on a tablet allows the teacher freedom of movement around the room (Mercier 2016), carrying a handheld device while teaching can produce fatigue over time. In previous studies where tablets were handed to teachers for orchestration, including our own pilot studies, teachers did not continually use the device during a full term. In our longitudinal study, similar potential issues were identified, but also advantages. Besides fatigue, one of the clear shortcomings of showing the dashboard on a handheld device is that teachers "cannot use their hands, making it hard in times when [they] need, for example, two hands to revise papers or other devices that students want [them] to look at" (TE4). TE1 also commented the following: "It was slightly annoying that I have one hand occupied. Students sometimes wanted to show me their prototypes so it was a bit hard to keep holding the dashboard on one hand and their laptop on the other. Having said that, I still prefer access to that data".

Possible solutions were hinted by teachers, for example, TE3 described her strategy to use the dashboard only when needed: "I would also put the dashboard down when I had a very good sense of how the class was going and what things I had to deal with. I still wanted to come back and see how well I was doing with time". TE4 suggested that she would be happy to carry the dashboard on her mobile, but that she definitively did not want it shown in a public space that everyone can see as this would be distracting for students: "I prefer that the teacher is the only that can see this information" (TE4). TE1 summarised the advantages of having the dashboard available on a mobile device as follows: "It's good having the tablet because you decide when to check visualisations no matter where in the classroom you are", however, alternative solutions can be found. Ongoing work is exploring the feasibility of using augmented reality lenses to get the right balance between portability and availability (Holstein et al. 2018).

Overview of the results

Table 3 summarises the key insights obtained from the interviews with teachers.

Discussion

Kaendler et al. (2015) proposed that teachers need to have a set of competencies to effectively foster student learning in CSCL environments. The most relevant of these competencies related to the design of dashboards to support teaching in CSCL classrooms is that of *monitoring* student interactions. Visual and textual means to augment the monitoring capabilities of teachers are not new within CSCL (see classic work and review by Soller et al. 2005).

Table 3 Summary of results

Research questions	Key insights
RQ1: what are teachers' perspectives on having real-time access to CSCL visualisations?	• Visualisations of group *task progress* and *individual participation* helped teachers to quickly **compare** groups and **identify** those groups that needed closer attention. • Teachers requested more specific information such as **automatically highlighting** top contributors or particular students who needed help. • Teachers requested information about **speech content**. • Some teachers suggested more **flexibility** for them to configure what information to show in the dashboard and **explanatory visualisations** that automatically highlight potential issues found in the data.
RQ2: what are teachers' preferences in terms of interpreting visualisations versus text?	• Teachers preferred to interact with **graphs instead of text** while using the dashboard in the classroom. • **Text** can be used to communicate **specific information** (e.g. insights from the data or numeric values) that teachers can use to provide tailored feedback to students**.**
RQ3: what are teachers' reactions to the notifications?	• Teachers used both types of notifications (of detected misconceptions and positive progress) to provide **immediate feedback to specific groups**. • Some teachers used the notifications to gain awareness of the state of the class and provide **delayed feedback** on commonalities across groups.
RQ4: what are teachers' perspectives on the scripting visualisation and alarm?	• Both the visualisation and alarm of the class script allowed some teachers to **adjust the enactment of the class script** *on-the-fly*. • Some teachers indicated it was easier to identify current issues with the calibration of the class script to be considered for **re-design.** • Some teachers suggested **more intrusive ways to be notified** about critical issues such as spending too much time in specific tasks or with particular students or groups.
RQ5: what teachers' perceived advantages and challenges in carrying a handheld device?	• Teachers appreciated making the dashboard available through a **personal device** for **private use**. • Some teachers preferred to have both of their **hands free,** but still wanted to have **access to the data**. • Some teachers suggested using their **mobile phones** instead, or other means to endorse both portability and data availability.

Yet, different visualisation techniques keep being used to track individual participation within a group (e.g. Sirbu et al. 2019), and group progress (Noguera et al. 2018), mainly in online systems. Regarding mirroring and alerting about the enactment of the CSCL script, not many real-time visualisations exist (Mangaroska and Giannakos 2018). In a way, this means that the design of the dashboard itself is innovative as it provides live information about various of the CSCL classroom in ways that have not been possible before. However, we cannot understand teachers' and learners' practices and needs that can be addressed using data if those are not analysed over time (Brown 1992). The longitudinal study presented above allowed us to identify some tensions in the way teachers used the dashboard, which can become into sources of inspiration for innovation and design. It is expected that more learning analytics innovations will keep making its way into CSCL environments (Liu and Nesbit 2020). This means that a design stance strongly grounded in learners' and teachers' needs will be essential to ensure the alignment between, on the one hand, emerging data-intensive technologies and, one the other hand, best pedagogical practices and foundational CSCL theory.

The notion of *Collaborative Learning Analytics* has been proposed to explain the natural convergence between learning analytics and CSCL (Wise et al. 2020). This has pointed at the need to map from low-level data to pedagogically meaningful group constructs that make sense to non-experts (Echeverria et al. 2019). The information provided by our dashboard included basic constructs related to the progress of the task indicated by the size of the students' solution, the extent of participation within each group, notifications about the correctness of the content of students' artefacts, and the extent to which the teacher follows or deviates from the original plan. Yet, higher-order issues were discussed by the teachers who experienced the use of the dashboard for an extended period of time. Although some of these evidently go beyond what our handheld dashboard could offer, they shed light on aspects that need further exploration in authentic CSCL dashboard design. In the following lines, these issues are discussed.

The natural incompleteness of classroom data The data made available to teachers for real-time consumption were incomplete since not all aspects of the learning and collaboration process could be automatically captured. Still, teachers were provided with information which they commonly do not have to be able to make their own decisions. However, the incompleteness of the data can potentially lead teachers to make erroneous assumptions (Bienkowski et al. 2012), particularly since the visualisations shown to them do not embrace the complexity of collaborative learning (van Leeuwen et al. 2015). Slade and Prinsloo (2013) identified that this situation may easily make the data available in the classroom vulnerable to misinterpretation and bias. In our longitudinal study, teachers were enthusiastic about the data but also pointed at the need for more sources of evidence to be able to have a better picture of what happened in each small group. In a dystopian scenario, there is the potential risk that a teacher may want to consider the visualisations of individual participation that we showed in the dashboard as the basis for assessment of performance. Hence, this paper must be seen as one of much more CSCL work that is needed to start understanding how data traces can most usefully serve to augment teachers' awareness in CSCL physical spaces. This has been proposed as one of the top priorities for CSCL by Wise and Schwarz (2017).

The trade-off of immediateness In our study, all teachers mentioned that they tended to take immediate action after receiving a notification. In some cases, teachers decided to delay the feedback to gain a better understanding of what was happening in the classroom and provide well-informed feedback to all the students. While the provision of immediate feedback may lead to better learning outcomes (Hattie and Timperley 2007), there is a risk that teachers may take corrective actions too soon, based on partial representations of the students, or without letting students tackle the problem by themselves first. The trade-off of providing immediate or delayed feedback has been explored in CSCL (Gweon et al. 2007) and teamwork (Walton et al. 2014) settings with varied results strongly depending on task settings, groups, and pedagogical approaches. Ultimately, a teacher's pedagogical stance is critical, and its effects depend on the learning situation. For example, Loibl and Rummel (2014) found that delayed feedback is quite effective if accompanied with pedagogical strategies such as comparing and contrasting students' outputs. The ethical dilemma here is that teachers cannot afford not to use classroom data anymore if these data can be readily available (Slade and Prinsloo 2013). A critical question is: how to effectively use such data for pedagogical purposes? Further research needs to be done to develop the technological means and the pedagogical practices to find the right balance between the provision of immediate or delayed feedback based on evidence depending on the context.

The risk of increased orchestration load The risk of overloading the teacher with information is evident. There may be a well-intentioned attempt of making many aspects of the classroom and students' activity visible. Too much information or a poorly designed dashboard can increase the *orchestration* load of the teacher (van Leeuwen 2015). The concept of orchestration load has been defined as the effort that the teacher needs to put in coordinating multiple learning activities (Prieto et al. 2015c). But the risk is not only in the amount of information but also the type of visual encodings used in a CSCL analytics tool that may impose more *cognitive* load (Card et al. 1999). Thus, introducing a new analytics tool in the classroom may increase the orchestration and cognitive load of the teacher. This can be addressed through effective Information Visualisation design (Spence 2001) and by trying to understand how teachers would gain insights from specific data representations (Yi et al. 2008). Emerging multimodal analytics approaches to quantify orchestration load are emerging (Prieto et al. 2017), but much work still needs to be done to measure the impact of a learning analytics dashboards on both orchestration and cognitive load.

The trade-off of access and disruption In our authentic classroom experiences, data played a major role in the classroom dynamics. As stated by the teachers, different actions were triggered as a result of looking at the visualisations, notifications, and alarms. The coordinator of the unit of study also changed her behaviour as she created more explicit CSCL scripts to be visualised by the dashboard, which is not necessarily a common practice. In sum, we provided enough evidence that the data given in real-time to teachers had the potential to *disrupt* the orchestration of the classroom. Data became another component that needed to be orchestrated with the support of the research team. The trade-off here is that data and real-time analytics can be disruptive as they can drive the teacher to perform actions that may (negatively or positively) affect the learning process. Although any computer system can disrupt the CSCL (Bannon 1995) or orchestration processes (Dillenbourg et al. 2011), the role of data in the CSCL classroom can directly influence important decision making processes that can strongly shape how collaborative learning unfolds (Rodríguez Triana et al. 2014). The positive or negative effects of this disruption would depend on factors such as the interpretation of data and the pedagogical actions taken as a result. In our classroom experience, it was up to the teacher to decide on the orchestration actions taken after each interaction with the dashboard. Further work needs to be done to understand the impact of each of these interventions on learning.

Future work There is an evident trade-off between generalisability and contextualisation since the data capture was facilitated by the specific type of technology used: large multi-touch tabletops enhanced with kinects to differentiate students' actions. This setup is hard to replicate in conventional classrooms even if similar hardware, such as vertical displays, are used (Clayphan et al. 2016). Nonetheless, results from the analysis of teachers' perspectives are already informing the next round of iterative improvement and implementation of the functionalities of the dashboard. For example, current work in this line of research is focusing on providing teachers with timer alarms to alert them about the time spent at each group in regular CSCL classrooms by using proximity sensors (Author 2019). Similar visualisations of group activity are being co-designed with both teachers and students to be used in classrooms in healthcare education in which multiple teams work around patient beds (instead of tabletops) as they are monitored by a teacher (Author, 2018). As sensing capabilities are rapidly improving, the lessons learnt from teachers' perspectives on the dashboard use are serving to define the features of the next generation of CSCL classroom dashboards, that include visualisations of conversation patterns, physiological aspects, localisation, and differentiated actions to be used by both teachers and students (see preliminary work in Echeverria et al. 2019).

Conclusion

As technology advances, particularly in the area of pervasive computing and multimodal sensing, capturing traces of collocated collaboration activity, which has been considered ephemeral and invisible to computational analysis, is becoming feasible. This will open new opportunities to support collaborative learning and instruction in collocated, complex learning spaces. However, to gain a better understanding of, and effectively support learning in CSCL classrooms, we need to identify how data may interplay with CSCL pedagogy and theory. Understanding teachers' perspectives after they use learning analytics innovations during an extended period of time is critical to designing interfaces that can be orchestrated by the teacher and that can effectively support their monitoring needs. In this paper, we discussed the tensions highlighted by teachers as a result of their authentic experience in the context of using real-time data to orchestrate a multi-tabletop classroom. As illustrated, what a teacher chooses to do with information is highly personal and often depends on factors such as the dynamics of the classroom, the students attending the class, the lesson plan of the day, and the teacher's skills and experience. We envisage that, as emerging sensing and interactive technologies mature, it will become even more feasible to build systems that support teachers, from mirroring information to communicating insights effectively, in the physical CSCL classroom.

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