

MTFeedback: Providing Notifications to Enhance Teacher Awareness of Small Group Work in the Classroom

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Abstract—The teacher has very important roles in the classroom, particularly as manager of most resources for learning activities and in providing timely feedback that can enhance learning. But teachers need to be aware of students' achievements and weaknesses to decide how to time feedback. We present MTFeedback, a system that harnesses the new affordances of interactive tabletops to generate automatic notifications about small group collaborative tasks for the teacher in real-time. We deployed the system on a teacher's hand-held dashboard, which supports orchestration of a multi-tabletop environment, the MTClassroom. We validated our approach in authentic (in-the-wild) classroom activities, with 95 higher education students and three teachers across two sets of six classroom sessions. We evaluated the impact of presenting notifications on feedback that teachers provided to students. The notifications were based on qualitative comparisons of students' artefacts against a representation of both expert knowledge and a set of common misconceptions. We demonstrate that our approach can successfully be deployed in the classroom to generate notifications that help the teacher direct their attention more effectively to provide relevant feedback to their students in small group learning activities.

Index Terms—Collaborative learning tools, classroom, interactive tabletops, teaching support, real-time visualisations

1 INTRODUCTION

TEACHERS have a critical role in the classroom as they manage the class and typically design and facilitate the learning activities [10], [41]. They need to ensure a productive use of time; prepare the learning materials and provide attention to each student [39]. They *orchestrate* multiple activities in the learning environment, one of which is the provision of feedback, an essential part of effective learning [19], [43]. It has been demonstrated that providing quality feedback is positively correlated with learning achievement more than any other teaching action [4], [43], [45]. Many field studies have also demonstrated the value of feedback when it is delivered during or soon after finishing the relevant learning task [40], [43]. This can give students the opportunity to use the feedback to improve subsequent performance or to reflect on the learning activity. For example, a teacher may intervene in a student's activity if students need immediate help (*immediate feedback*) or the teacher can delay the feedback until the students complete the task [43] (*delayed feedback*; e.g. at the end of a class).

Overall, it has been suggested that the provision of feedback, particularly in higher education, is most effective when it is timely, relevant and constructive, and lets

students know how they are doing. Moreover, feedback is effective when understandable, such as when the teacher offers suggestions for improvement that are within the student's grasp [5], [44]. Feedback should not only focus on what the student did not do *correctly*, but also should give positive encouragement, as this helps students improve their performance [18]. However, to give effective feedback, the teacher needs to know about students' progress, including achievements and difficulties [40]. In the classroom, the teacher needs to acquire this information while the learning activity is still underway, so they can decide on timely action. Moreover, it has been demonstrated that the provision of instructive feedback does not create large demands on instructional time [50].

Unfortunately, despite the importance of providing timely feedback, teachers can be overwhelmed by multiple *orchestration* responsibilities and not be able to provide feedback, let alone in a timely fashion to students who need it most. This issue is exacerbated when students work in groups, because learning activities are combined with collaborative activities and group tasks are usually more complex.

Effective use of technology to support teacher awareness and help them provide improved feedback in the classroom is still an issue to be tackled, both for individual and group learning tasks [7], [16], [33]. Emerging pervasive devices have the potential to help teachers become aware of aspects of learning that are not otherwise visible within the constraints of a class. Research indicates that in order to provide effective feedback some sort of integrated assessment is needed [6]. But teachers often cannot assess the quality of students' artefacts or their collaborative interactions *on-the-fly* while managing the other aspects of the learning activity.

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Fig. 1. Multi-tabletop pervasive classroom for small group collaboration.

This opens up an opportunity to harness emerging technologies that can unobtrusively capture key aspects of students' activity and then automatically alert teachers about significant events that would normally escape their attention [35].

This paper presents the MTFEedback approach and its implementation. The main goal of the MTFEedback approach is to automatically give teachers notifications about group learning activities in a timely manner during a class. We describe its mechanisms to automatically gather and exploit student data in the classroom. This approach builds upon our initial theoretical ideas presented in Ref. [35]. We also present the implementation of the technological infrastructure that generates notifications based on these student data. We demonstrate how the notifications can be shown, in real-time, to the teachers orchestrating a class in an authentic classroom. In the study described in this paper, the notifications were generated by assessing, in real-time, qualitative aspects of the knowledge artefacts being built by the students (in the form of concept maps) and comparing student maps with the model of *expert knowledge* as well as a set of *common misconceptions* provided by the teacher as part of the design of the learning tasks. We validate the impact of presenting teachers with both visual notifications about positive and negative aspects of student's work through a study *in-the-wild*. The learning environment in which MTFEedback was implemented is a classroom with pervasive technologies, the MTClassroom [30] (see Fig. 1). This system facilitates planning and orchestration of small group activities, making use of five interconnected multi-touch tabletops and three vertical displays.

The key contribution of this paper is the design and evaluation of an approach to enhance teacher awareness of small group collaborative activities. MTFEedback does this by automatically generating notifications for the teacher in a multi-tabletop classroom in real time, during the learning activities.

The rest of the paper is organised as follows. First, we discuss previous related work and the background that our approach is based upon. Then, we describe the context of the learning environment and its technology. Section 4 describes the MTFEedback approach and the study design.

Section 5 presents the evaluation study. Section 6 concludes with a discussion of the key findings and the implications of our approach for future research.

2 RELATED WORK AND BACKGROUND

2.1 Providing Teacher Support

It has been stated that the functionalities of digital technologies to automatically capture and analyse student data can have many potential benefits for learning and instruction [3]. However, as noted above, there has been little research on developing tools focused on assisting teachers by exploiting the traces of students' activity [27], [51]. More attention has been paid to assisting learners and proposing ways to replace teachers and automatically support students without them [3], [14], [24]. This may generate the conditions for technology to impose restrictions on what is to be learned or how it has to be taught [42].

Teachers have a critical role in the classroom [49]. For example, they may have to design the learning activities, decide what technology to be present in the class and how these can be used to achieve the learning goals. There is potential in facilitating instruction by designing systems that consider a teacher's role as a central part of the learning process [21]. Accordingly, our approach directly supports teachers in the classroom by providing a companion tool that can enhance their awareness and help them make informed decisions about which students or group may currently need feedback.

Previous related research has delivered various tools that can enhance teacher awareness and reflection through the use of dashboards and visualisations. Verbert et al. [48] observed that these kinds of tools have been deployed in three very disparate learning contexts: online learning settings, face-to-face lectures and face-to-face small group work within classrooms. Previous work on teacher awareness tools has mostly been for online learning settings and the automated generation of teacher notifications has only been comprehensively explored in that learning context [48].

One example is Yacef's [51] work to provide teachers with tools to monitor how the class is progressing so that

the teacher can improve their interactions with students. Yacef's work was in the context of an intelligent tutoring system that worked as an intermediary between teacher and students. The system enabled teachers to monitor the in-class and after-class progress, and identify frequent mistakes in a computer science course.

Similarly, Mazza and Dimitrova [36] provided information visualisations from the data from an online learning environment. Their system showed important aspects of students' profiles, including indicators of factors such as active learning, motivation, engagement, and simpler measures of progress through an online course.

Chen [9] presented a system that gave intelligent support for the teachers' intervention in an online collaborative task. The system monitored messages sent between group members and offered different levels of information to teachers based on a fixed set of rules: a quantitative summary of activity and more focused advice that may require direct teacher action. Similarly, Casamayor et al. [8] introduced an intelligent agent approach based on pre-defined rules. This monitored students' participation in a distance learning environment and notified teachers when conflicts were detected. The system generated a summary that the teacher could use to identify and attend to groups that were having difficulties collaborating.

For the very different case of face-to-face work in classrooms, an important example is the Tinker Board classroom [10]. This showed information on a large display to support reflection on a small-group activity using tangible horizontal display. The display also helped the teacher to become aware of the progress of students in their task by showing a progress bar of each group.

Similarly, the Tinker Lamp [2], [10] is a gadget that students can manually activate to indicate to the teacher which stage of the activity they are up to or if they require feedback. Based on a similar approach to Tinker Lamp, Gutierrez Rojas et al. [17] proposed the design of a monitoring tool that can be carried by a teacher during a lab session. This awareness tool provides the teacher with information about the performance of the students sitting at the connected terminals in the lab. It also indicates when particular students have requested feedback and which students have already been attended to.

Martinez-Maldonado et al. [33] created a classroom environment to capture learner collaboration data on tabletops and to show visualisations of these data to the teacher to help her decide where to devote her attention. Other studies have confirmed that this real-time information can be useful for teachers using both private or public displays [23], and can be integrated with various technologies like tablets [25], smartboards [10] and tabletops.

In all these previous studies, the support provided to teachers was generated based on pre-coded rules. However, what has not been shown is how the *teacher* can define the rules or at least configure aspects at design-time.

2.2 Classroom Orchestration and Learning Design

In a set of related studies described in the previous subsection, some authors [2], [10], [13], [17], [33] have introduced the term, *orchestration*, to describe the way a teacher conducts the whole class. They also point to ways to aid the

teacher in this orchestration, making use of visualisations of class activity, notifications and other support for teacher awareness [10]. Orchestration takes account of the fact that classrooms are variable and complex, and that teachers have a crucial role in adapting technologies and materials for use in their own classes [41]. This perspective empowers teachers as drivers of classroom activities and advocates for the use of simple technologies that may have important effects [11].

The class of educational tools that provide teachers with *real time* support for managing the learning setting is called *orchestration technology* [47]. This includes, for example, interfaces that manage classroom workflow (e.g. [13], [25], [33]) or that enable teachers to monitor, or intervene in, students' work (e.g. [2], [33]). Orchestration technology may also take over the management of the orchestration or some part of it, allowing teachers to focus on other classroom and orchestration issues (e.g. [8]).

Importantly, classroom orchestration commences even before the learning activity occurs; it starts with the design of the learning tasks [39]. According to the approach of *forward-oriented design* [12], whilst learning itself cannot be designed, by either the teacher or the tool designers, several aspects around the learning activity can be designed so they have a positive effect on learning. Consequently, designing for orchestrating such learning activities should consider the complex processes and contingencies that may occur once a design is enacted. In this way, teachers are key actors since they have to design the learning tasks, define the social rules and adapt the technology use to their pedagogical intentions and learning goals for the activity [15]. At run-time, teachers are also essential actors, since they may intervene with respect to the real-time coordination of classroom events [12].

While a design is enacted in the classroom, it may be affected by unanticipated processes and events; this means the teacher must be able to adapt the design at run-time [10], [12], [47]. For example, at design-time, the teacher may have a clear vision for the way they want the learning task to work (represented as a form of expert knowledge). However, in the actual class, students may create quite different solutions, perhaps more complete or taking different approaches. Similarly, the teacher can expect a set of common student's misconceptions at design time; during the class, they may realise that some of these actually make sense for some perspectives on the problem. Our approach to generate notifications seeks to build an orchestration tool to support teachers for the run-time enactment of the designed classroom activities.

When orchestration tools can be adapted or tuned by the teacher, during the design of the tasks, or even at run-time, then we call them *orchestrable technology* [47]. The provision of orchestrable technology may allow teachers to decide, before or during the learning activity, about the coordination of classroom events. This flexibility can enable teachers to create richer pedagogical and learning tasks since they have broader control over the way the technology operates. This approach offers a very promising way to empower the teacher to flexibly manage the design and actual running of the learning activities.

Our work takes an approach based on orchestration, particularly, on aspects of design and awareness. Accordingly, we allow the teacher to define, at design time, those cases about group progress in the learning activity that they want notifications to inform them about. Our approach also provides monitoring support in real time, based on automated notifications. Then, teachers can decide how and when to use these, to provide feedback to students. The next sections discuss how these theoretical principles were given material form in our study.

2.3 Multi-Tabletop Learning Tools in the Classroom

For the case of the use of multi-touch tabletops in the classroom, the earliest research work was the SynergyNet project [1], [20]. The system featured four interconnected multi-touch tabletops, some teacher tools and a vertical class display. In terms of orchestration, the authors explored how the teacher could visualise, interact with or control each group's tabletop from: a teachers' tabletop; a tablet device; or using a series of pre-defined gestures in the air. Notably, the studies for this project were conducted under laboratory conditions, with the students working on tasks outside their regular curriculum and the teachers were not involved in the design of the learning tasks or configuration of the technology.

A second relevant study was conducted by Do-Lehn et al. [13]. His work focused on solving issues with orchestration and the usability of the proposed teacher tools. The learning setting for this study featured four tangible tables able to track fiducial markers attached to physical objects. The system offered ways to help a teacher manage the classroom and presented visual information about the progress of the students' at each table. This was done through a large vertical display that showed visualisations of task progress and allowed the teacher to have control over multiple functions (e.g. comparing two groups' tables). The author also explored the use of paper cards as an orchestration mechanism that the teacher could use to control individual tables.

A third relevant study is Tables-in-the-wild [22]. This consisted of six to seven non-connected small tables deployed in a primary school and used for 6 weeks. The goal was to observe students' behaviours and survey teachers' interactions with the technology in order to identify the main requirements for classroom orchestration. The authors of this study recommended that further deployments of multiple tabletops in authentic learning settings should include the provision of tools to help teachers maintain awareness and to manage the technology.

The fourth relevant multi-tabletop environment is MTClassroom [30] (the system used to run the studies presented in this paper). MTClassroom was the first to provide in-class touch differentiation so as to log each individual student's activity [29]. It was also the first where the learning tasks were part of the formal curriculum and the first to be deployed in an authentic tertiary education classroom [33]. The MTClassroom featured a teacher dashboard called the MTDashboard, which could be used to provide teachers with visualisations of collaboration. The MTClassroom also allowed the connection of services to provide access to the data captured by each tabletop. This has been used to

investigate ways to use data mining techniques to automatically detect students' strategies [34]. The data capturing affordances of the MTClassroom make it possible to automatically assess students' work in order to generate visualisations or notifications at run-time. Further details about the system are presented in the next section.

Kharrufa et al. [22] reviewed the state of the art in this area. These authors argued that using interactive tabletops in the classroom may facilitate the workflow of small group learning activities. However, additional challenges may be introduced by using tabletops in the classroom. Teacher awareness and orchestration load may be negatively affected because the teachers have to manage not only students' progress, the tasks and the provision of attention and feedback from an epistemic viewpoint, but also the technology and the learning spaces created by the use of tabletops [23]. Therefore, the system needs to provide the teacher with the means to manage both the students' tasks and the technology itself [22]. Kharrufa et al. [22] also highlighted the under-explored potential of using interactive tabletops in the classroom to capture traces of students' collaborative activity that cannot easily be seen by teachers during run-time. There has been little research work exploring ways that such information can be shown back to the teacher during or after the class.

Our approach goes beyond previous related work as it is the first work we are aware of, that provides teachers not only with visualisations of each group's progress in an authentic classroom, but also automatically triggers notifications based on a set of rules that the teacher can create to define the conditions for alerts about the groups' activity in a multi-tabletop setting [31].

3 CONTEXT OF THE STUDY AND RESEARCH QUESTIONS

As a foundation to defining our research questions, we first introduce the context of our field study. The study was conducted under authentic conditions during an undergraduate course on *Human-Computer Interaction* (HCI) at the University of Sydney in Semester 2, 2013. Classes were held in the MTClassroom [30], a classroom comprising of five interactive tabletops, each designed for face-to-face work in groups of up to five students (shown in Fig. 1). During the semester, three different tabletop applications were used: concept mapping, brainstorming and a meeting support tool.

The study presented in this paper concerns the concept mapping activities organised during Weeks 7 and 13. The MTFeedback system was used and evaluated in the tutorial sessions of Week 13. A total of 95 engineering students were enrolled in the HCI subject and participated in the study. Students were timetabled at the beginning of the semester into six tutorial classes, each with 11 to 20 students and facilitated by a *class teacher*. In Week 4, they were organised into 24 groups of 3, 4 or 5 members. These groups were maintained for the rest of the semester. The same weekly tutorial ran in each of the six classes, with three different class teachers. The *main teacher* (the lecturer and co-author of this paper) had one class and the other two class teachers (teaching assistants/tutors) had two and three classes

respectively. The learning goals for students in the two selected weeks (7 and 13) were similar. Each consisted of a task where each group had to create a concept map that answered a *focus question*.

A concept map is a directed graph in which nodes represent the main *concepts* of the subject matter and the edges are labelled with a linking word to form meaningful statements called *propositions* [38]. For example “*heuristic evaluation requires users*” is a proposition that links the concepts *heuristic evaluation* and *users* through the linking word *requires*. Additionally, in weekly homework, students built concept maps individually to summarise materials on various topics; so students knew the technique very well by Week 7.

In Week 7, the classroom activity began with an introduction to the tabletop concept mapping application and how to build a concept map as a group. That week’s focus question was revision for the mid-term quiz and involved identifying the key differences between two major usability techniques. Students were asked to draw a single concept map on the topic named: “Characteristics of GOMS and Think-Aloud”.

In Week 13, the focus question required students to link the main concepts of usability with the phases of a prototype design process. Similar to classes conducted in Week 7, this was a revision activity, this time in preparation for the final exam. Students were asked to draw a group concept map on the topic titled: “Types of prototypes and usability methods”. By this week, students had drawn several more concept maps and had already used the tabletop environment over several weeks.

3.1 MTClassroom and CMate: The Pervasive Learning Environment

As described above, the MTClassroom [33] is a classroom with multiple interactive tabletops that can:

- i) unobtrusively capture data about each learner’s activity, linking it to the learner’s identity;
- ii) provide the basis for offering different orchestration tools to teachers; and
- iii) provide the technological infrastructure to perform real-time student data analysis.

It is composed of five interconnected multi-touch tabletops, each enhanced with the CollAid [28] sensing system. The MTClassroom allows teachers to orchestrate the tabletops through a controller dashboard (MTDashboard). Each tabletop logs the interaction of students with the learning application within each group to a central repository that can be accessed by other services in real-time. One of these services generates visual indicators to enhance the teacher’s awareness and shows them in the MTDashboard. The concept mapping application used in our study, CMate [28], records activity logs, traces of the task progress and information about the group artefacts. For more information about the environment, please refer to the technical papers about CMate [28] and the MTClassroom [33].

3.2 Research Questions of the Study

The overarching aim of the study is to assess the usefulness and impact of presenting negative and positive visual

notifications to teachers in-the-wild, using sources of expert knowledge and misconceptions. We address this by responding to the set of research questions below.

For the first question, we investigate how the information displayed on the dashboard influenced the teacher’s feedback. For this, we assessed if the attention that teachers provided to students ended up affecting their achievement on the task. This question addresses our aim at a general level, considering both the visualisations and the notifications as a whole. Specifically, we compare how teachers divided their attention when a) only visualisations were provided, and b) when visualisations and notifications were provided. Our first question is:

- i) *What is the impact of teacher attention on group achievement as a result of providing a) only visualisations, or b) visualisations and notifications, on the dashboard?*

For the second question, we investigate the particular impact of MTFeedback (notifications). This question is more specific than the first question, by focusing on notifications only. We analyse what occurs after a notification has been displayed on the dashboard and how the information associated with the notification was read by the teachers. Additionally, we analyse the impact on students’ performance immediately after the teacher attends to a notification by providing attention or feedback to the relevant group. The research question is:

- ii) *What did teachers do after receiving a notification and what is the impact of teachers’ interventions on students’ achievement?*

In this case, we address our aim at a more specific level by differentiating between the types of notifications provided. For this, we qualitatively analysed the ways teachers used these notifications by making a distinction between positive and negative notifications. The third research question is:

- iii) *How differently did teachers use the notifications when groups had more misconceptions or when they were closer to expert knowledge?*

4 APPROACH AND STUDY DESIGN

4.1 Approach

Fig. 2 illustrates the context where MTFeedback is deployed and the process that the teacher can follow to design, enact and diagnose, in run-time, the learning activity in the multi-tabletop classroom. This process begins with (1) the teacher designing some elements linked to the learning activity before the classroom sessions. At this stage, based on the principle of forward-oriented design [12] introduced above, the main teacher designs the task to be performed by the students; the pedagogical intentions of the activity; the formulation of a focus question students should respond to in the concept map they construct; a macro-script for the sessions (refer to [30] for an example in tabletop contexts); the source of expert knowledge and the list of common misconceptions. In our study, the last two can be defined by the teacher using CMapTools, a third-party software tool widely used as a concept map editor and builder [38].

From a technical perspective, the source of expert knowledge is represented as a concept map that contains “crucial”

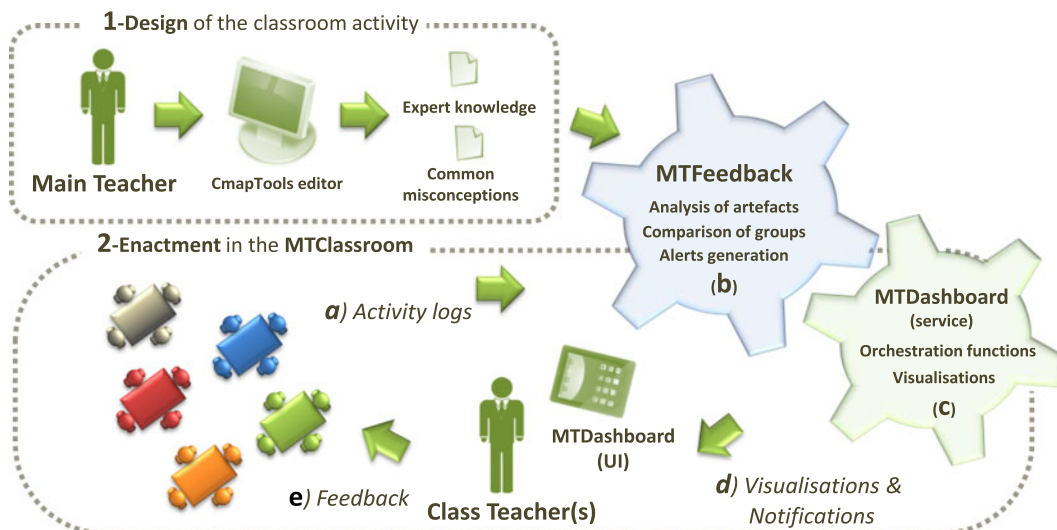


Fig. 2. MTFeedback context: conceptual diagram of the approach.

propositions, those that the teacher considers the students should have in their maps. Common misconceptions that the teacher wants to track are defined separately, as a set of propositions. Examples of common misconceptions defined by the teacher are “*The think aloud method—evaluates—efficiency*” or “*Heuristic evaluation—is a—user method*”. While these pre-defined elements come from the teacher, the learning activity remains open so that students can freely discuss the task, defining concepts and linking terms of their own choice.

Then, the designed activity is enacted in the classroom (2). The classes can be conducted by the teacher who designed the learning task or others (e.g. teaching assistants or tutors), as was the case for two tutors in our case. In the classroom, teachers commonly follow an orchestration loop [10] where small group activities can be described as follows: the teacher monitors the groups, assesses their performance to decide which group or groups may need support, attends to the chosen group and starts the cycle again. At the same time, the teacher needs to attend to any other unpredicted events, for example responding to students’ questions or clarifying misunderstandings.

Our approach aims to support the teacher’s decision making process about which groups most need their immediate attention by enhancing their awareness of each group’s progress in this orchestration loop. We describe this as the following process (refer to Fig. 2):

- a) Activity logs: the pervasive technology (interactive tabletops) along with our sensing technology can capture differentiated students’ actions and the status of the learning artefact. As described above, the MTClassroom infrastructure synchronises and gathers activity logs of all tabletops, making the data available to be accessed at run-time through a central repository. In the study presented in this paper, our approach focuses on analysing the changes made on the students’ learning artefacts only.
- b) Analysis of artefacts. MTFeedback compares each group’s logged activity against the expert knowledge and the list of misconceptions. To do this, the system

implements a simple technique presented by Taricani et al. [46] for automatically scoring the similarity between two maps. This technique is based on the use of a two dimensional graphic network representation of a concept map, considering that this can be reduced to a relationship matrix. According to the original method, the relationship data is compared with a referent master concept map to produce a score that represents how “similar” the assessed concept map is to the master map, linked to the number of propositions they have in common. This automatic technique proved successful and very close to ratings performed by manual human annotation. In our study, we apply the same technique to identify the propositions added by students in their maps that are also included in the teacher’s definition of expert knowledge (an expert map) and the propositions that are commonly identified misconceptions.

- c) Generation of notifications: notifications may be generated according to a set of configurable rules. Once these notifications are generated they are sent to the MTDashboard service which is in charge of defining how they will be shown to the teacher.
- d) Visualisations and notifications: the MTDashboard UI displays the visualisations and notifications generated in real time on a handheld device that the teacher can carry whilst walking around in the classroom. A full description of the user interface is provided below.
- e) Monitoring: the teacher looks at the dashboard and decides whether a certain group needs feedback or not. Our research questions mainly focus on the actions taken by the teacher at this point and the impact of the provision of attention of feedback to groups as a result of the teacher inspecting the notifications.

4.2 Positive and Negative Notifications

It has been found that receiving too many notifications can produce a negative effect on users, as it makes it hard to



Fig. 3. Notifications in the teacher user interface. Each circle shows the number of propositions created that group; the inner circle indicating ones matching the teacher's set. The colour matches the table colour ID. Fig. 1 (right) shows the yellow table.

readily determine what has changed over time [26]. To avoid overwhelming teachers with too many notifications, we defined three types of configurable notifications. We provided two types of negative notifications and one positive notification; the choice of these was defined by the main teacher's pedagogical requirements that were focused on qualitative aspects of students' tasks. The three types of notifications provided are:

Misconception notification (MN). Concept maps are actually hard for a teacher to quickly assess to detect misconceptions [46]. Addressing this problem, this negative notification was triggered for the group that had the most misconceptions in the classroom. MTFEEDBACK assessed groups every 30 seconds by comparing the students' solution at each table with the list of common misconceptions defined by the teacher, deciding which group, if any, justified a new notification. The comparison was performed applying Taricani et al. [46]'s approach. Once the teacher attended to the corresponding group, the system would then perform the assessment only considering the remaining groups. This way, the teacher could eventually determine whether all groups had recurrent misconceptions or if the whole class needs a clarification of the activity.

Slow-group notification (SN). For this negative notification, MTFEEDBACK compared the progress of all the groups in the classroom in terms of the number of propositions created, flagging a group as being left behind if it had less than half of the propositions created by the most prolific group. This rule was pre-tested on a dataset collected in sessions run in previous semesters [33], proving to be effective in detecting large differences among groups within a class.

Positive notification (PN). This notification was generated to inform the teacher when groups had included a certain proportion of the expert knowledge into their solution. As the concept mapping task allows students to use their own vocabulary to represent their solution, the notifications were generated when a group had at least $P\%$ of their propositions matching the expert knowledge, where P could be defined by the teacher ($P = 50\%$ in our study). The comparison was performed applying Taricani et al.'s [46] approach.

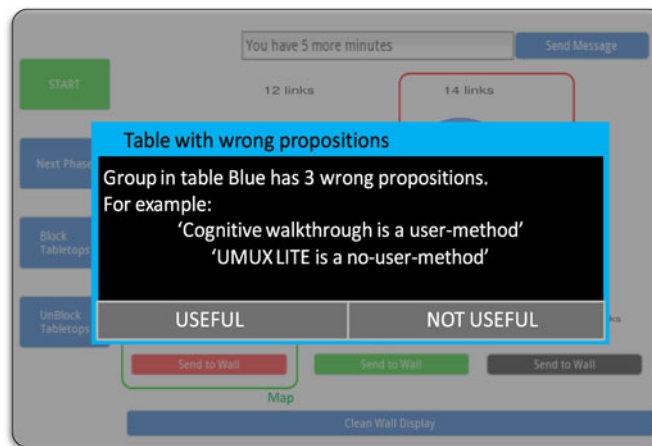


Fig. 4. Notifications in the teacher user interface: detailed information shown to the teacher when touching on a notification.

4.3 User Interface

The notifications generated by the MTFEEDBACK can be delivered to the teachers in different ways. In previous years, the MTCClassroom environment already provided teachers with a dashboard (the MTDashboard) that could show live-visualisations and allow the control of the technology according to a class script [33]. For our study, we added the functionality to the dashboard to additionally display the notifications generated by the MTFEEDBACK. Fig. 3 shows the teacher dashboard as displayed on a hand-held tablet. The interface has a set of buttons for the teacher to control the classroom technology. It also features up to five visualisations, each associated with one active tabletop. Inspired by work reported in [32], we selected one of a number of possible visualisations to be displayed on the MTDashboard for our studies. These are the visualisations in Fig. 3; they show the size of each group's solution and the proportion that matches the expert knowledge (the outer and inner circle respectively). Each visualisation is coloured according to the colour of each interactive tabletop so the teacher can identify whose group the visualisation refers to. The arrangement of the visualisations also matches the physical layout of the tabletops in the classroom.

Notifications provided to teachers on the dashboard appear as a square (red for negative and green for positive) around the visualisation that corresponds to the group that triggered the notification. For example, Fig. 3 shows two active notifications: a negative notification for the group with the most misconceptions (red square around the blue table's visualisation), and a positive one for a group that has included half of the expert knowledge and had no misconceptions (green square around the red table's visualisation). Teachers were instructed they could get additional information about the notification by tapping inside of the square. Fig. 4 shows an example of the type of information displayed as a result of tapping on the visualisation corresponding to the blue table in Fig. 3; the message about this negative notification indicates that the blue group has three misconceptions and shows the details of up to two of them. To dismiss the message the teacher taps the button indicating whether the notification was useful or not. After dismissing a

notification, that group would not trigger the same notification for s seconds ($s = 60$ in this study). For the Misconception Notification, this allows the teacher to see if other groups also have a high number of misconceptions.

4.4 Study Design

As the tutorials were conducted in-the-wild, our work focused on capturing as much evidence as possible without compromising the authenticity of the classroom activities. This poses both challenges and opportunities. Whilst the conditions of the learning environment and the activities are close to those in a regular classroom, there are constraints on what data can be automatically captured for analysis and evaluation of the tools provided to teachers. As a result, besides the data automatically logged by the tablets and sensors, an external observer assessed each group's quality of collaboration based on an adapted rating scheme [37]. This has four dimensions quantified from -2 to 2 , for each of:

- mutual understanding and dialogue (which assesses grounding processes and coordination of the communication process);
- consensus (which assesses discussion to reach a joint decision);
- task division and technical coordination (which assesses how well students manage task dependencies and deal with technical interdependencies); and
- reciprocity (which assesses social interactions and equality in contribution). For further details about the assessment see Meier et al.'s [37] rating handbook.

A second observer registered all teacher actions, including times when s/he attended to (A), intervened in (I) or answered questions (Q) for each group; when s/he looked at or interacted with the dashboard; and when s/he walked around or gave instructions to the whole class. Additional evidence was obtained from semi-structured interviews conducted after the tutorials with the class teachers regarding the use of the system.

5 ANALYSIS AND RESULTS

5.1 Data Exploration

Before addressing our research questions, we explored the data captured to see whether any simple statistics could distinguish the tutorials where MTFeedback was used (Week 13) in relation to the rest of the tutorials. We particularly compared those tutorials with Week 7, when a similar concept mapping activity was conducted without using MTFeedback (visualisations only).

First, we evaluated the impact of the knowledge the teachers had built up about the groups in their classes, e.g. if by Week 13 they had identified groups that commonly struggled in each weekly tutorial. For this, we checked whether the teachers had expectations beforehand about which group would need more attention by Week 13 compared with Week 7. The graph shown in Fig. 5 presents the *teacher attention* in terms of the proportion of the total time of the activity (%) dedicated to attending to groups, as logged by the external observer. The graph shows that

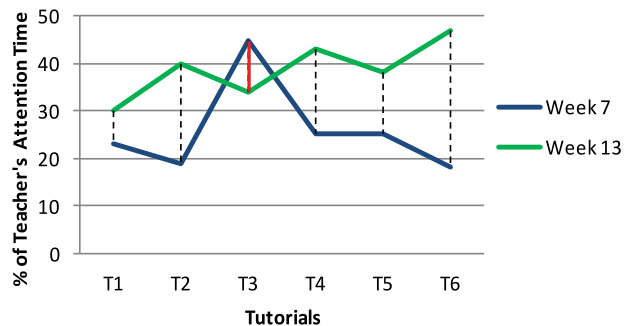


Fig. 5. Proportions of the time teachers spent attending to groups in each tutorial in weeks 7 and 13.

teachers dedicated an average of 26 percent (± 9) of their time in Week 7 and 38 percent (± 6) of their time in Week 13 attending to or intervening in groups. This is a significant increase in the amount of time devoted by the three teachers to attend to groups in Week 13 ($t(10) = 2.58$, $p = 0.027$). As shown in the graph, only one of the teachers (the one who conducted T3 in both weeks) dedicated more time to attend to groups in Week 7.

Additionally, in only one of the six tutorials (T2), did one of the teachers dedicate most of his/her attention to the same group across weeks 7 and 13. This means that previous knowledge that a teacher may have had about each group was not a major driver for providing attention in the classroom. One teacher described this during the post-tutorial interviews as follows: *“Based on the dashboard and how students were talking, I would decide which group to attend next. It didn’t matter how they performed the previous week, because it was not easy to remember and also the activity was on a different topic”*. This suggests that teachers did not necessarily know beforehand which group would need more attention so they had to make decisions regarding how to distribute their attention time and the provision of feedback on-the-fly for each new tutorial.

Second, we examined whether there was a variation in group *collaboration* itself. This is important, because if groups tend to present the same ‘levels’ of collaboration each week, then it may be straightforward for the teacher to provide special attention to the same groups each week. Whilst this is true in some real classrooms, we had to evaluate if this was the case in our multi-tabletop environment. As mentioned above, the teachers indicated that the groups commonly behaved differently in each tutorial. For example, one of the teachers said that *“some groups were very good but in some sessions they might be doing other things and not concentrating”*. We analysed if this was also valid according to our adapted rating scheme [37] as noted by the external observer who assessed each group's quality of collaboration. Comparing ratings of each group in weeks 7 and 13, 10 groups improved; four remained at the same level; and 10 worsened in terms of collaboration (see Table 1—first row—Collaboration). Therefore, while the teachers had broad awareness about which groups may have needed closer attention, the classroom was essentially quite dynamic and students tended to present different challenges for orchestration in each session. This is aligned with the notion of classroom orchestration that proposes that the classroom is a multi-constrained

TABLE 1

Variation of Group's 1) Collaboration and 2) Achievement in the Concept Mapping activities from Week 7 (without MTFeedback) to Week 13 (using MTFeedback)

	Improved	Remained the same	Worsened
1) Collaboration	10	4	10
2) Achievement	16	6	2

environment so teachers may need to deal with unpredictable events [10].

Third, similar to the previous exploration, we examined the variation in *groups' achievement* between weeks. We measured this in terms of how closely the solution matched the source of expert knowledge generated by the teacher. In this case, 16 groups increased the amount of expert knowledge included in their artefacts from Weeks 7 to 13, while six had the same proportion, and only two decreased (see Table 1—second row—Achievement).

At this point, it is not possible to establish the cause of this observed difference in teacher's attention and students' collaboration between weeks 7 and 13. Additionally, since the topics were different, we cannot conclude that there was a direct effect of using MTFeedback in Week 13. However, overall, these pieces of evidence helped us understand the context and interpret the results of our research questions that we describe next.

5.2 Analysis of the Research Questions

- i) *What is the impact of teacher attention on group achievement as a result of providing a) only visualisations, or b) visualisations and notifications, on the dashboard?* Through this question we analyse the impact of visualisations and notifications, together, on the interplay between teacher attention and to what extent this resulted in groups incorporating part of the expert knowledge into their solutions.

To investigate this, we analysed students' final artefacts at the end of the tutorials by comparing them with the source of expert knowledge. As a result, we found that in five of the six tutorials (83 percent) when MTFeedback was used (in Week 13), the groups that received most of teacher attention also had the most expert knowledge in their solutions. Similarly, groups that had minimal teacher attention also ended up having the least expert knowledge in their solutions (83 percent of those).

Overall, there was a significant correlation between the proportion of teacher attention and the expert knowledge included in final artefacts ($\text{corr} = 0.6$, $p < 0.05$ —see Table 2).

A possible causal relationship between the time dedicated by the teacher attending to a group and the resulting expert knowledge made explicit into students' solutions may appear empirically evident. However, for the tutorials held in Week 7 (classes without notifications); teacher attention did not have any significant effect on the inclusion of expert knowledge in students' solutions. None of the groups given the most attention presented high levels of expert knowledge ($\text{corr} = -0.05$). This does not mean that groups did not include expert knowledge into their solutions; but that we could not find evidence of these two variables being correlated. This indicates that MTFeedback may have played a key factor in helping teachers focus on giving immediate feedback to students according to the expert knowledge in Week 13.

To explore possible causality, we looked at whether teachers indeed attended to the lower achieving groups after looking at the dashboard during the class. The observer recorded a total of 179 times when the dashboard was viewed by the teacher (Week 13). In 128 of these (72 percent), the group given attention was either the least or second lowest achieving group. As a reference, in Week 7, teachers attended to the weaker groups only 50 percent of the time after looking at the dashboard. This suggests that there may have been some effect of using the dashboard and/or the notifications on the attention teachers provided. The next research question tackles this.

We also gained insights that the attention provided to students was translated into more expert knowledge included by students in their solutions when MTFeedback was used. Also, in most cases in Week 13, teachers attended to the lowest achieving groups after looking at the dashboard. A teacher said that they commonly "*went to the groups that had less propositions*" or to "*help them [a group] fix a misconception*". In the next section we specifically isolate and investigate the effect of the notifications on teacher attention.

- ii) *What did teachers do after receiving a notification and what is the impact of teachers' interventions on students' achievement?* In this case, we investigate what happened after

TABLE 2

Analysis of the Impact of the MTDashboard on the Interplay between Teacher Attention and the Extent to which Groups Incorporated part of the Expert Knowledge into their Solutions

Tutorial's week	Groups that garnered <i>most</i> of teacher attention that had the <i>most</i> expert knowledge in their solutions	Groups that garnered <i>least</i> of teacher attention that had the <i>least</i> expert knowledge in their solutions	Correlation
7—Visualisations only	0%	0%	-0.05
13—Visualisations and MTFeedback	83%	83%	0.6, $p < 0.05$

TABLE 3

Effect of Immediate Teacher Feedback on Students' Performance after the Teacher Attended a Notification (Week 13) or Looking at the Dashboard (Week 7), in Terms of i-Students' Gain of Expert Knowledge (A and B) and ii- Proportion of Groups that Addressed Their Misconceptions (C)

Analysis of students' performance	After 2 min	After 3 min	After 4 min
Gain of expert knowledge—Week 13	0.8 (± 0.8) propositions	1.5 (± 0.9) propositions	1.6 (± 1) propositions
Gain of expert knowledge—Week 7	0.6 (± 0.7) propositions	0.7 (± 1) propositions	0.7 (± 1) propositions
Addressed misconceptions—Week 13	70%	80%	80%

the notifications were displayed on the dashboard including the teacher reaction and the impact their feedback on students' achievement. A total of 83 notifications were reported to the teachers in Week 13 (avg = 14 per tutorial). The logs indicated that, out of these, teachers rated 48 as useful and 14 not useful (the remaining 21 were not explicitly tapped by the teachers to get more information). One of the teachers explained that "sometimes [she would] ignore some notifications if [she] already talked to that group previously, so after visiting other groups, [she] would go and see what happened with that group".

According to the observations triangulated with the logs, an average of 88 percent (± 19) of the times that teachers read the message of the notification, they also immediately attended to the group that triggered the notification to either provide feedback or have a closer look. The process commonly followed by teachers, immediately after a notification appeared on the dashboard, was described by one of them as follows: "I would tap on the notification and read about the problem. Then I would move to the table, see their concept map and have a conversation to understand what they did and help them if needed". According to the logs, teachers reacted to the notifications at varying rates, taking up to four minutes (avg = 2, ± 2 minutes).

Regardless of the different reaction times for each teacher, we analysed if there was any change in students' concept maps as a result of teacher feedback. We calculated the gain of expert knowledge for these groups after 2, 3 and 4 minutes of receiving teacher attention. Results showed that students added 1.6 (± 1) propositions from the teacher's list every time they received feedback counting up to 4 minutes after the event. Table 3 (first row) shows that groups tended to add at least 1 proposition from the expert knowledge set within 3 minutes of receiving teacher feedback. By contrast, in Week 7, the gain as a result of teacher feedback provided immediately after looking at the dashboard (displaying only visualisations) averaged 0.7 (± 0.8) propositions (Table 3, second row). This suggests that the notifications translated into a significant "gain" of expert knowledge as a result of teacher feedback to the groups in Week 13 ($t(154) = 3.98, p = 0.0001$).

For the case of students' misconception alerts, we analysed the cases when the students reduced their misconceptions, also after 2, 3 and 4 minutes

of receiving teacher feedback. Table 3 (last row) shows that, within two minutes of receiving teacher feedback, in 70 percent of the cases, the attended group addressed at least one of the misconceptions that triggered the notification. After 3 and 4 minutes there was not a large change in this trend. This suggests that MTFeedback effectively made teachers more aware about students' misconceptions and guided their attention to groups that required it, to immediately address raised concerns.

Overall, the results of the analysis motivated by our second question indicate that teachers generally took advantage of the notifications, even though they reacted to them at different speeds. In most cases, teacher attention driven by a notification resulted in an improvement in the students' perspective matching the expert knowledge. This did not occur when only the visualisations were shown to the teachers. This suggests that the information provided by the visualisations is not sufficient to drive teachers attention so they can provide relevant feedback. One of the teachers said that, in Week 13, she "didn't have time to look at the details of the visualisations" and that only if she "didn't have any notifications to attend then (she) could look at the details of the visualisations".

- iii) How differently did teachers use the notifications when groups had more misconceptions or when they were closer to expert knowledge? Finally, we explored the differences among the types of notifications generated by MTFeedback and how they were used by teachers. For this, we combined the evidence logged from teachers' interactions with the dashboard, indicating whether the notifications were useful or not, and teachers' responses in the post-hoc interviews. Table 4 shows the number of notifications generated for each type. It shows a larger number of Misconception Notifications (MN = 61 notifications) compared with the other two types (SN = 4 and PN = 18 notifications) because it is possible to detect misconceptions from the beginning of the activity. By contrast, the Slow-Group Notifications and the Positive Notifications require the class to cross a minimum threshold of propositions created by each group.

The three teachers considered the Misconception Notifications useful. As stated by one of the teachers, "the 'red notifications' [MN and SN] were useful because I can easily identify if there is a problem in a group and try to fix it, as soon as I see it". Another teacher stated that as a result of their

TABLE 4
MTFeedback Notifications in Week 13 Tutorials and
Teachers' Responses

Notification type	Misconceptions (MN)	Slow-Group (SN)	Positive (PN)
Notified	61	4	18
Useful	33	2	13
Not useful	9	2	3

immediate feedback, if there is some problem, *“students can immediately take action or [the teacher] can make some suggestions so they can figure out what is the problem and learn something”*.

The PN, even though there were fewer of them, proved to be useful to teachers (for 13 of the 18 PN notifications presented in the dashboard) in a different way: teachers used them to provide positive feedback to students *“to encourage groups to stay motivated”*. However, two teachers mentioned that these notifications *“had the lowest priority but [they] still used [them], to go to the group, [to] let that group know that they were progressing positively”* if no other group had unsolved misconceptions to attend to first. This evidence complements the previous two questions to help understand the different kinds of feedback that teachers provided as a result of the negative or positive notifications.

6 DISCUSSION AND CONCLUSIONS

Providing teachers access to automatically captured data can enhance their awareness [23]. However, effective ways to show this information in the classroom were still needed. We presented MTFeedback, an approach that exploits students' information captured at a multi-tabletop classroom to alert the teacher about aspects of students' solutions that cannot be easily analysed by the teacher on-the-fly. Whilst our approach can be generalised to other kinds of small group learning activities, this paper focused on the design of a collaborative concept mapping activity as an instance of the application of MTFeedback. The role of the system proved important in enabling class teachers to provide immediate and delayed feedback regarding the emerging misconceptions about the subject matter. In this way, the notifications help enhance teacher awareness of small group work in the classroom. In the words of one of the class teachers, the dashboard allowed her *“to even skip interventions during the activity and still be aware that some problems existed”*.

By analysing evidence captured from automated data logs, external observations and interviews with teachers, we addressed our three research questions. In this section, we finalise the paper with a discussion of the scope of our approach, potential research strands for future work and the limitations of the study described above.

6.1 Towards Making the Generation of Classroom Notifications an Orchestrable Technology

Our approach features a number of configurable elements that can be tuned by the teacher in design-time, including: i) the source of expert knowledge and ii) a list of identified

common misconceptions. These can be generated by the teacher from previous experience or class activities. In our study, the source of expert knowledge is actually the set of propositions the teacher expected students to produce, based on what had been taught, representing the level of knowledge for that stage of learning. By contrast, in our study, the list of misconceptions was created by the main teacher based on the misunderstandings that she had observed in previous examinations. The aim of the teacher in Week 13 in the multi-tabletop classroom, from a pedagogical perspective, was to identify whether students still had the same misunderstandings so they could be discussed in class and also addressed in the context of other theoretical elements.

From an orchestration perspective, the system aligns to the principle of *modest computing* [23] by offering minimal alerts and short messages to avoid disrupting the already heavy cognitive load of teachers while enacting classroom activities. From the perspective of 'orchestrable technology', our study was limited to demonstrating the applicability of our approach in offering a small set of configurable design elements for its use in an authentic classroom scenario. As mentioned earlier, the system offers at least two configurable elements that may affect the way the notifications are generated. These elements are: 1) the proportion of expert knowledge required to be in a students' map to trigger positive notifications (parameter P); and 2) the parameter that controlled the pace at which MN would be triggered, by defining the time interval that must elapse before triggering a MN notification again for a group that was already attended to. A further analysis of the different ways teachers can configure the system, and the addition of extra configurable parameters is beyond the scope of this paper. However, the rationale behind the provision of such configurable elements should be considered in the design of similar notifications systems in the future.

6.2 Interactive Tabletops for Classroom Orchestration and Collaboration

The work presented in this paper also aims to contribute to the *orchestration* approach [39], applied to a multi-tabletop classroom, by providing the teacher with the means to design the elements that influence the learning activity and monitor the enactment of this design [30]. This complements the approach presented in this paper which has the goal of enhancing teacher awareness of small group's progress and performance in the learning task (through the generation of visualisations and run-time positive and negative notifications) and also of the overall class progress according to the planned script.

6.3 Findings

- i) *The provision of notifications to the teacher can allow them to take their own decisions in-class time.* This is important, because it allows students to receive feedback and negotiate their misconceptions with the teacher. The dialogue between teachers and students can facilitate a richer experience that would be lost if, for example, the system automatically provided

feedback directly to the students. In such a case, the role of the teacher would be secondary and would not trigger important conversations.

- ii) *The provision of teacher notifications can indirectly enhance students' achievement.* We found that teacher feedback, when MTFeedback was in use, produced a positive effect for groups including key expert knowledge into their own solutions and to address common misconceptions. Although the positive effect of feedback on students' learning strongly depends on multiple factors, including: teacher support; the collaborative interactions; and individual learning processes. Our study proved that the MTFeedback system helped teachers take informed decisions about the kind of feedback that students needed at certain times.
- iii) *Both negative and positive notifications can be helpful for the teacher.* Overall, the notifications provided in our study helped teachers to give timely attention to groups that needed help or to encourage them to keep working. Providing only negative notifications to teachers may be enough to help them keep the 'homeostasis' of the classroom. But the teacher can also provide positive feedback about the students' artefacts and encouragement if this information is available to them.
- iv) *The provision of notifications to the teacher can allow them to adjust the execution of the design.* In our study, even though students tended to reduce their misconceptions after receiving feedback, teachers reported that, in some cases, students were able to justify why the possible misconceptions were not necessarily wrong in the context of their concept map. In such cases, the system helped teachers dialogue with the students so they could externalise their arguments to defend their responses. Teachers can also decide later on whether a misconception is not necessarily important and "change" the design on-the fly, by deciding not to ask students to change their maps. The teacher can make adjustments and use the system as a support tool rather than an automated tool that performs direct actions on students' tables or a tool that prescribes exactly what the teacher should do next.
- v) *Through our approach the teacher can take the decision of providing immediate feedback or delayed feedback (at the end of the class).* Teachers reported other uses of the information provided by the notifications. For example, "if all the groups eventually had the same problem [the teacher] could stop the whole class and explain any misunderstanding". The notifications also helped teachers frame the reflection at the end of the class. A teacher mentioned that, based on the most frequent misconceptions, she could highlight alternative solutions at the end of the class or "give feedback to particular groups". Another teacher explained that "if the same misconception was recurrent in various groups, [the teacher would] skip the feedback for some groups and provide an explanation on that misconception to the whole class in the reflection at the end of the tutorial". This shows that the notifications can also

help teachers provide delayed feedback and have a better understanding of the common problems that the class is facing as a whole.

6.4 Limitations

Our approach was designed to contribute to improve our understanding of the possibilities generated in learning contexts where large shared devices, similar to interactive tabletops, are used in the classroom for a range of group activities. Our in-the-wild study illustrated an approach to assisting the teacher's regulation and orchestration in a multi-tabletop classroom environment.

Implementing our approach in an authentic classroom (with real teachers, tasks linked to the curriculum and a number of sessions with different students and group formations) brought both limitations and advantages. The main limitation is that it was unacceptable in our context to control all the conditions. The realities of the class imposed real constraints. For example, it was not possible to compare the use of the MTFeedback with a control group in the same week, since the teacher had to offer similar learning opportunities to all students. As a result, our methodological approach was to compare activities conducted in different weeks (7 and 13), even though this introduces the possibility that the observed effect of the use of the notifications was also influenced by the activities performed during the five intervening weeks. This may include teachers getting used to the dashboard and orchestration of the tabletop room, and students becoming more comfortably with the tabletops. There may also be an effect due to the topics studied in each week.

In spite of these limitations, our in-the-wild deployment is valuable as it demonstrates that our approach can be effectively realised in real classrooms, going beyond the lab. A future study is needed to explore the impact of these notifications on teacher's pedagogy.

6.5 Conclusions and Future Work

We demonstrated that notifying teachers in real time about key aspects of students' work using shared multi-touch devices to support collaborative activities is technically possible for up to five groups of students simultaneously. These notifications occur in class to support the provision of timely and salient feedback. Through our research questions we learnt that when the notifications were shown to the teachers, the attention provided to students translated into more expert knowledge included in students' solutions. Teachers took advantage of the notifications to make informed decisions about which group to attend to, based on their possible misconceptions, although each teacher reacted to the notifications at a different pace. In most cases, teacher attention, driven by a notification, resulted in an improvement in the students' learning artefacts matching the expert knowledge and a reduction in identified misconceptions.

Finally, both negative and positive notifications were important to help teachers provide feedback, clarify students' misunderstandings or encourage groups to stay motivated. Importantly, the approach has the potential to be used to explore the ways that the notifications can

enable a form of communication between the lead teacher and the other class teachers—since the latter saw notifications about misconceptions. The lead teacher may have access to the activity logged by MTFeedback or discuss with the class teachers about the common misconceptions among classes.

The research work presented in this paper can serve as a basis to motivate further exploration in a number of strands of research. Future work can focus on exploring the use of artificial intelligence techniques that can detect more complex patterns or potential problems in groups before they occur, so that teachers can become even more proactive. Future research can also explore alternative and less intrusive methods to notify teachers about students' problems in the classroom. For example, usability studies may be conducted to identify the best ways to enhance teacher awareness in the classroom. This may include consideration of visual alarms, auditory hints, vibrating devices or tiny displays that can convey similar information to what we currently show on a handheld dashboard. Finally, further research should focus on the pedagogical considerations so that teachers can use, configure and maintain not only the notification system, but the overall multi-surface classroom ecology.

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