Mining the collaborative learning process at the tabletop to offer adapted support

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ABSTRACT
One of the main challenges in the design of collaborative learning tools is the provision of adequate support to the collaborative activities adapted to meet the needs of different groups. In group work, facilitators have to divide their attention between two or more groups and they typically only see the final product. As a result, the collaborative process may be hard to determine. Groupware devices, such as multi-touch interactive tabletops, are very promising to attend this issue in *collocated settings* since they provide not only enriched learning environments but also a medium to capture groups' social dynamics. We address this problem by exploring ways to capture the collaborative relationships of the group members and offer adapted support to collaboration at the tabletop. We exploit the audio and application log traces of activity to automatically infer the group behaviour through visualisations, group modelling and data mining techniques. The key contribution of this research is the creation of a framework that provides adapted support to face to face collaboration and helps groups and their facilitators to be aware about the group collaborative process.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces, Input devices and strategies, Interaction styles.

General terms: Design, Human Factors

Keywords: Collaborative learning, Tabletop, Visualisation, Data mining

INTRODUCTION AND MOTIVATION

The many benefits of collaboration on learning and sharing knowledge are well documented by the Computer-Supported Collaborative Learning community: collaboration promotes social interaction among learners and their facilitators, and also enhances the capacity of thinking by triggering particular learning mechanisms that cannot be activated by individual learning [2].

Important cognitive activities that may result into learning only occur when students give explanations of possible solutions to problems, maintain mutual understanding of the nature of the concepts being discussed, and integrate present learning with past knowledge. Collaboration skills are therefore rising as key conditions for value generation not just in educational environments but also at training and organisational levels. Thus, a group of people that aims to work collaboratively must know how to provide effective leadership, decision-making, discussion-building, communication and conflict management. Given the complexity of these skills, teachers ought to encourage enhanced performance by providing adequate feedback or implementing strategies within the groups to help students to be more aware about their collaboration dynamics.

However, in a regular classroom or training setting, it is challenging for teachers to meet the needs of each student. Teachers do their best to manage their limited time and divide their attention focusing on the students who need closer coaching. Ideally, in a *small-group classroom*, each group would have the attention of the teacher all the time during the session. In the real world, teachers try to identify which groups have healthier collaborative interactions to leave them work more independently in order to focus on groups that need more attention. As a result, some groups that needed support might be neglected. At the end of the class, the teacher may not be able to know what happened with certain groups and usually they have to assess their performance based only on the final product of the activity. Nevertheless, the final product tells nothing about the collaborative process, the individual contribution or previous states of the solution that could have had better quality than the final result.

It has also been posed that *interactive tabletops* are very promising to improve collaborative work in education and there are a number of applications that aim to improve learning [1, 3, 4, 9]. However, it is time to move towards the provision of tools that can adaptively attend students and their facilitators' needs so that they could find these technologies useful and worth to try.

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RESEARCH OBJECTIVES

Research questions. Specifically, we state the following research questions:

- (1) Can we automatically detect collaborative moments or potential issues from the groups working at an interactive tabletop?
- (2) Can we find patterns of interaction that can be mapped with collaborative group behaviour?
- (3) If this is possible, how can we provide adapted support to the collaborative activity to help learners and their facilitators?

Approach. Our infrastructure is integrated by two main parts. The first part includes pedagogical software that supports the creation of shared artefacts on a collaborative environment using desktop and tabletop devices. We focus on capturing a multi-modal set of data from this collaborative environment. Our datasets consist of the real time collection of the users' footprints produced while interacting with personal devices, the tabletop and with other learners. These include automatic speakers' identification, location of learners around the table, logs of physical interaction with the surface identifying who is touching the surface, video analyses, and snapshots of the status and progress of the task. We also take into consideration the *learner model*, this is the knowledge that the system can have about each group member, for example, outcomes of other related learning activities, individual perspectives or previous knowledge that students have about the topic to be learnt.

Then, the second part of our infrastructure includes the tools for analysing and providing support to learners and teachers. Among the techniques we use in the project to analyse the user interactions and the collected data, we chose to run *usability studies* to guide the design and validation of our tabletop user interfaces. In order to analyse the data we make use of *group modelling* and *data mining* techniques. These can help to identify patterns of interaction and moments of activity that can be used by the system to offer adapted support to both the learners and their facilitators. Finally, we also use *visualisations* of the collaborative process to mirror information back to the users and teachers.

Technical aims. This proposal has two main goals:

(i) Define and capture the user *model* of the different aspects of collocated groups working at the tabletop.

(ii) Create a framework that offers personalised and *adapted support*.

Research challenges. These two aspects are particularly challenging for the design and implementation of a tabletop interface because it requires the capture of live contextual information around the tabletop and exploiting it to look for interesting patterns. If we are to take advantage of the educational data mining techniques, it is also particularly important to focus on investigating how to apply such techniques on tabletop-based datasets. Therefore, the main goal of this project is to implement the mechanisms to offer *adapted support (ii).* As a secondary aim we *use and combine* readily available software and hardware technology to capture the *model of users (i).*

BACKGROUND

This project is interdisciplinary thus it requires a deep revision of literature in different areas of study. These include the involvement of specialists and the revision of studies on interactive surfaces, computer-supported collaborative learning, teaching and data mining applied to education. Next, we only describe the related works that are focused on aiding collaboration at the tabletop for reasons of space.

Morris et al. [12] reported on the importance of the role that interactive tabletops can play for mediating face-to-face discussions, their impact on the group dynamics and the significance of the user identification. Nacenta et al. [13] explored the influence of the design of the user interface interaction techniques and location of feedback on the way in which users collaborate at the tabletop. Their findings demonstrated that the interface input and output features have a great effect on the collaborative process. An example of research work more focused on the social affordances of tabletops is provided by Fleck et al. [3]. This work demonstrated the need to include the analysis of the verbal discussions of learners given while they solve a problem at the tabletop to have a clear view about the forms of personal interactions that are facilitated by these devices. Through this work authors also showed the significance of grounding on theories of psychology and learning to study collaboration at the tabletop. The study carried out by Kharrufa et al. [4] also shed light about how school kids can collaborate through the interactive tabletop. A remarkable feature introduced by these authors was the use of a scripted design of the activity at the tabletop to guide the learners to negotiate and take decisions about the thus favouring the inclusion of the group members in the discussions. AlAgha et al. [1] presented a possible vision of the near future in which a classroom features multiple tabletops used by the students, orchestrated by a teacher's monitoring tabletop.

This project goes beyond the given examples by taking principles of group work and educational data mining, in order to capture tabletop contextual data, process it and make information accessible in real time to services that mirror or give adapted support to the group and teachers.

METHODOLOGY AND CURRENT WORK

Next, we describe the methodology to be followed and the preliminary results of the project. Our methodology includes the next set of steps: 1) First, the exploration of existing groupware datasets to identify which data should

be captured and what data mining objectives and techniques should be considered. 2) Next, the construction of the software and hardware environment that fulfils the data mining requirements and the collaborative learning theories in which our approach is grounding. 3) The implementation of the framework that offers adapted support to users and visualisations to their teachers.

1) Exploration of the datasets. For the first part of the project we started by designing and building a tabletop prototype application. This application, Cmate [9], permits learners to externalise their knowledge about a given topic in the form of a concept map. It served to run initial experiments to collect a pilot dataset to explore the format in which the data need to be captured and to observe the behaviour of the learners around the tabletop. The participants were mostly university students and the chosen topics varied substantially. For example, participants were required to respond questions about biological processes, computer science and health.

Based on a number of pilot user studies using Cmate, we designed and evaluated an initial set of visualisations of group work. We grounded these visual aids on theories of group cognition [14], data exploration and observations. These visualisations depict the quantity of speech of the group members, their physical actions on the tabletop and the progress of the collaborative activity. These visualisations include a number of spider-web, pie and sparkline charts calculated every determined period of time of the group activity. They proved to be successful in aiding the *facilitator* to have an overview about the collaborative activity at the tabletop. More details about the design and evaluation of the visualisations can be found in [10].

Then, we ran a couple of studies to explore the extent in which the data mining algorithms can be applied to the two dimensions of data that can be captured from *the majority of the* tabletop system: physical touches and speaking detection. The aim of these was to investigate how the presence or absence of certain types of activity can be used to infer if a group is engaged in collaborative activities. The dataset analysed in this case was based on a multi-display collocated collaborative environment. The participants were first grade university students and they were asked to solve an optimisation problem. For the first study [11], we used a set of classification techniques to *learn* the human perception of collaboration based on quantitative data only. Our models were able to identify when a group was clearly behaving as collaborative or, at the other extreme, non collaborative. However, when group's behaviour is not visibly collaborative (e.g. one participant is providing key ideas to the group even when he is not saying much or interacting with the system quite often) our models cannot accurately detect the groups' interactions. In other words, if the groups are clearly non-collaborating, it is possible for the system to detect this kind of undesirable group condition. We ran a second study [8] involving a tabletop environment to explore the measure of symmetry as an indicator of collaboration. Symmetry of activity means that all group members participate in similar extents either in the conversation or in the physical interactions with the device. We proved that the inclusion of this indicator in the group model can give insights of the extent of collaboration of the group. As a result of these both studies we demonstrated that even when the quantitative information that can be automatically collected from a collocated environment does not tell the whole story about the group dynamics; it can give very important hints about groups' collaboration.

We ran another study with a different dataset [6]. This dataset was obtained from an educational tabletop application, Digital Mysteries [4], a system to aid children in the resolution of problems and decision taking. This dataset only included the physical interaction with the horizontal display. The activity consisted in solving an open-ended problem; therefore, the quality of the solution was very important in educational terms and it had to be evaluated by experts on that collaborative activity. We applied sequence mining techniques to find the patterns of activity that distinguish the successful from the unsuccessful groups. This study pioneered an interdisciplinary field in which data mining techniques are applied to find patterns from tabletop-based systems data. We could discover significant differences between the strategies followed by the high achieving groups. For example, these groups organised the information at the tabletop to avoid skipping elements that they needed to solve the problem, or linked the information in simple but effective formats. On the contrary, the less achieving groups did not follow a clear strategy to explore the content hence spending additional time cleaning the layout or building very complicated solutions.

2) Environment to capture contextual data. We worked on the design of the environment to capture our own dataset in the format and dimensionality we need to feed the data mining algorithms and learner models. We started by outlining a set of *theoretical principles* to be taken into account in the design of tabletop systems prepared to generate mineable data [7]. Among these, we included, for

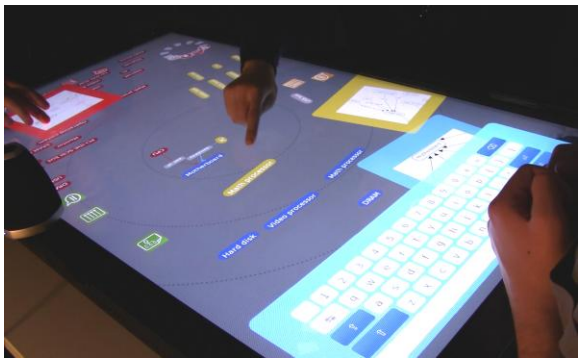

Figure 1: Current version of the system Collaid + Cmate

example, that it is important to detect what it is said around the tabletop along with knowing which person performs each action.

Grounding on these principles, we built a system called Collaid [5]. Figure 1 shows a current version of Collaid being used to collect a dataset using the Cmate application. The key features of Collaid are: the capture of multimodal data about collaboration (video, audio and application logs); the implementation of a microphone array to differentiate speakers and a depth sensor to identify position of the learners and authorship of each touch. The Collaid environment is integrated to other systems, such as, a third party desktop learning system, a database to gather the logs and allow real time data sharing, and a multi-touch dashboard that shows a visual overview of the information generated by the group of learners. In this work we showed that the data captured from our tabletop environment can feed visualisations depicting the processes that occurred during the collaboration at the table, and sequence mining techniques to highlight frequent patterns of interaction.

3) Visualisations of the collaborative process and adapted support. The next step of the project includes running a larger set of user studies to collect a second dataset using our controlled tabletop setting. We also will extract sequences of the collaboration process applying sequence pattern mining, Hidden Markov Models and process mining. Additionally, we will build and evaluate a second set of visualisations of collaboration that incorporates sequences of collaboration. We will put all the milestones reached so far together to integrate a Framework for supporting group activity at the tabletop based on the group model and develop a new version of our environment which will implement the framework.

SUMMARY AND FUTURE RESEARCH

The goal of this research is to capture the model of groups of learners working at the tabletop in order to afford adapted support to their collaborative activity by encouraging collaboration if needed, providing the resources they require to complete the task or distilling the generated information to ease the facilitator's judgement. Our approach fundamentally lays on the collaborative learning theory of group cognition [14] and the real-time automatic capture of the physical and verbal activity of the group members. Our main objective is to build a framework to empower learners' collaboration and teachers' ongoing class management effort. The next steps in this project include the collection and analysis of a larger dataset enabling us to perform a deeper examination of the logs using data mining techniques.

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