Int. J. Human-Computer Studies 83 (2015) 62–82

Contents lists available at ScienceDirect

Int. J. Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

TSCL: A conceptual model to inform understanding of collaborative learning processes at interactive tabletops ☆

Roberto Martinez-Maldonado *, Kalina Yacef, Judy Kay

School of Information Technologies, The University of Sydney, Sydney, NSW 2006, Australia

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form
27 November 2014
Accepted 2 May 2015
Communited by Andrew Howes
Available online 14 May 2015

Keywords:
Multitouch
Awareness
Collaborative learning
Student tracking
Visualisations

ABSTRACT

Emerging systems for tabletop interaction have the potential to support small groups of students in collaborative learning activities. We argue that these devices have the potential to support learning by exploiting the interaction data that they can capture. The *capture*, *analysis* and *presentation* of these data can provide new ways to gain understanding of the collaborative processes. This is particularly important for teachers at two levels. First, they can gain a deeper level of awareness of the progress of individual students and groups in their class and, based on this, make real-time informed decisions. Second, they can do post-hoc reflection and analyse aspects of the class. This paper presents Tabletop-Supported Collaborative Learning (TSCL), a conceptual model that provides foundations for building tabletop-based systems that can inform understanding of the collaborative learning process. The model provides guidance for building the infrastructure to: (i) capture traces of student activity; (ii) exploit these through data analytics techniques; and (iii) provide useful information about the collaborative processes. We illustrate the usefulness of TSCL in its use to create a learning environment that was evaluated in two studies conducted in tertiary education contexts. The first was a laboratory study, where 60 students in 20 groups worked on a concept mapping task, with data from their interaction used to create visualisations of the group processes. The second study was conducted in-the-wild, involving 140 students, working in 8 class sessions.

1. Introduction

The current proliferation of surface devices, such as tablets, smart phones and more expensive tabletops, is causing a shift in the ways people interact with computers (Hilliges et al., 2010). This is creating opportunities to make computers more ubiquitous and pervasive, rather than the centre of the activity as is often the case with most desktop/laptop computers. In particular, *interactive tabletops* can enrich a typical face-to-face setting in several ways: by supporting convenient, unconstrained orientation of people around a shared device; allowing the placement of physical items on the table; affording persistence of the interface status when working with virtual content, so that it can be retrieved for later reuse; and offering each group member equal opportunities for participation (Müller-Tomfelde and Fjeld, 2012; Piper and Hollan, 2009).

A particular focus of our work is to support group work in a learning context. Indeed, collaborative skills are important for students (Scheuer et al., 2010) and are not straightforward to learn (Dillenbourg, 1998). Students require close attention and timely feedback from their teachers. Unfortunately, in regular classrooms, the multiple responsibilities that teachers face can make it difficult for them to provide timely attention to the students who need it most (Dillenbourg and Jermann, 2010). Teachers often see only snapshots of student progress and have severely restricted insights into their collaboration. At tertiary education level, this issue can be exacerbated by even larger student numbers enrolled in the courses (Salmi, 2001). A particularly promising way that interactive tabletops have the potential to support collaborative learning is by exploiting the interaction data that they can capture whilst students work face-to-face, in small groups.

The introduction of new technologies in education needs to be thought through carefully to realise their potential benefits and take account of their limitations. Similarly to other learning technologies, tabletops by themselves do not necessarily provide a direct improvement in learning, collaboration or instruction (Dillenbourg and Evans, 2011). Rather they offer the potential for new ways for teachers and researchers to design and conduct activities (Dillenbourg and Jermann, 2010). Dillenbourg et al. (2011) described the tendency to *over-generalising* the possible benefits of tabletop devices to address a number of educational challenges, and the *over-expectation* of their affordances. These

☆This paper has been recommended for acceptance by Henrik Iskov Christensen.

* Correspondence to: School of Information Technologies, The University of Sydney, Level 3 West, Building J12, Sydney, NSW 2006, Australia. Tel.: +61 2 9351 5711.

E-mail addresses: roberto@it.usyd.edu.au (R. Martinez-Maldonado), kalian@it.usyd.edu.au (K. Yacef), judy@it.usyd.edu.au (J. Kay).

http://dx.doi.org/10.1016/j.ijhcs.2015.05.001
1071-5819/

acknowledged challenges point to the need to gain understanding of the ways that these devices can be used to enhance learning and teaching. They also suggest the need for a grounding, based on established educational theories, to build effective classroom tools using such devices. At the core of our work is a deep awareness of these risks and a commitment to build from solid theoretical foundations.

This paper proposes an approach that consists of a *conceptual model* which we call Tabletop-Supported Collaborative Learning (*TSCL*), to echo the name of the established field, Computer-Supported Collaborative Learning (CSCL). TSCL exploits the particular affordances of interactive tabletops and guides the design aspects of the infrastructure that can effectively inform understanding of the collaborative learning process at tabletops. Our *vision for TSCL* is to facilitate the creation of systems that support collaborative learning processes at a quite new level. The core affordances of tabletop learning applications are to support student collaboration. However, that support has not previously made rich use of the learner's digital footprints of collaboration at the tabletop. TSCL changes this. It enables a new level of information to be made available to teachers, as in the work we report in this paper. Beyond that, insights can also be provided to students. It is also a foundation for adapting the interface or system behaviour, depending upon student progress and characteristics of collaboration. It can, further, drive the choice and timing of alerts to learners and teachers.

Fig. 1 illustrates the core elements in the tabletop-based learning contexts. These need to be understood in order to support the collaborative activity. These include the learners, who are central actors of the learning activity. According to teacher-centric approaches (e.g. Dillenbourg et al., 2011) teachers are also key actors because they commonly manage the resources available in the learning setting; they have an influence on the learnering, due to their roles during the design of the tasks and during the activity, particularly, in providing feedback. Learners, teachers and other stakeholders (such as learning designers, researchers, or academic directives) can beenfit from using the data-based support to be provided by an implementation of the TSCL. It is also required to understand the context of the learning situation; this includes the particular features of the learning tasks, the learning goals and the each learner's needs. The identification of the above elements can underpin the definition of a Conceptual Design that matches the many different learning contexts, each with their particular group dynamics, learning goals and tasks. Inspired by literature on interaction analysis (Harrer et al., 2009), the TSCL establishes the elements and mechanisms needed for *capturing* traces of students' interactions at one interactive tabletop, or a number of them in the classroom setting; *analysing* these data through analytics techniques; and accomplishing the Interface Design to *present* distilled key indicators to the teacher to improve their awareness, decision taking and management of students' collaborative learning processes. Finally, this approach proposes that learning theory should strongly influence the implementation of the Conceptual Design and all the elements of the model.

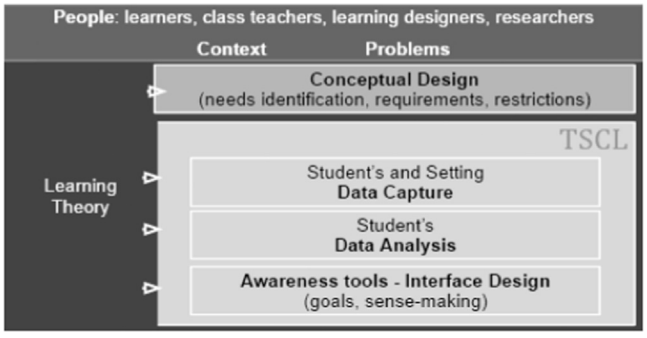

Fig. 1. Contextual diagram of the TSCL conceptual model, showing the conceptual design that each implementation should build upon and the strong influence of Learning Theory on the main elements of the TSCL.

We explored how to achieve our vision, with the TSCL emerging in parallel with our creation of systems that tackle challenges of enhancing a teacher's awareness. We demonstrate the utility of the model by showing how it can enable the creation of interfaces that help teachers see valuable information of students and the learning activity. We do this in two case studies, both conducted in tertiary education contexts. We created two new forms of information: visualisations for *post-hoc* analysis for a small group of learners at a single tabletop (Fig. 2, left); and *real time* visualisations of students' progress at a multi-tabletop classroom deployed in the wild (Fig. 2, right). The model builds on theoretical foundations from Computer-Supported Collaborative Learning (CSCL) research. It is also strongly influenced by research on tabletops for collaborative work, taking an HCI perspective and building upon the previous work on analysis of indicators of collaboration.

The key contribution of this paper is the TSCL conceptual model that can be used as a basis to build tabletop-based collaborative learning systems. Associated contributions come from two implementations of it, each demonstrating its use to capture and exploit tabletop learning data collected unobtrusively, to provide useful forms of information about collaboration. In both case studies, the learning activity was based on the collaborative concept mapping technique. This is a well-established learning technique that has proved effective in promoting meaningful learning among students (Novak, 1990), and it is specially valuable for learners when maps are built in group (Chaka, 2010). It provides an excellent means for a learner to externalise knowledge and build meaningful understanding about

Fig. 2. Two envisioned example tabletop-based scenarios of application of our approach. Left: a dedicated single-group activity. Right: multiple groups in the classroom.