Collaborative Concept Mapping at the Tabletop

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ABSTRACT
Concept mapping is a technique where users externalise their conceptual and propositional knowledge of a domain in a way that can be readily understood by others. It is widely used in education, so that a learner's understanding is made available to their peers and to teachers. There is considerable potential educational benefit in collaborative concept mapping, and the tabletop is an ideal tool for this. This paper describes Cmate, a tabletop collaborative concept mapping system. We describe its design process and how this draws upon both the principles of concept mapping and on those for creating educational applications on tabletops.

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General terms: Design, Human Factors

Keywords: Information interfaces and presentation, Interaction styles.

INTRODUCTION

Concept mapping is an important educational technique that provides an excellent means for a learner to externalise knowledge of a particular domain and to get meaningful understanding of new information [12]. Moreover, concept maps are metacognitive tools that foster the development of strategies for organising knowledge and facilitating communication of understanding [2]. They basically include: the concepts of the domain; propositions, indicated by a labelled line linking two concepts; and use of layout, with the most general concepts at the top, more specialised ones lower and similar concepts at the same level and close to each other. Propositions are the key elements of concept maps because each one shows the learner's conception of the relationship between a pair of concepts.

An example is shown in Figure 1, where the most general concept is *Plants* and this is in three propositions, *Plants have Roots, Plants have Leaves*, *Plants have Stems,* and the concepts *Roots, Leaves* and *Stems* are less general than *Plants* and at a similar generality level to each other. Strong results indicate that concept mapping, used as a tool for guiding education, combined with cooperative learning, helps students to integrate new information with previous theoretical knowledge [14] and to make tacit and private knowledge public [2]. Novak's research also indicates that building concept maps in a collaborative environment leads to greater learning and superior maps. Multi-touch tabletops appear to have the potential to encourage collaboration, affording fluid interaction and improved access to information [7], important characteristics in educational contexts.

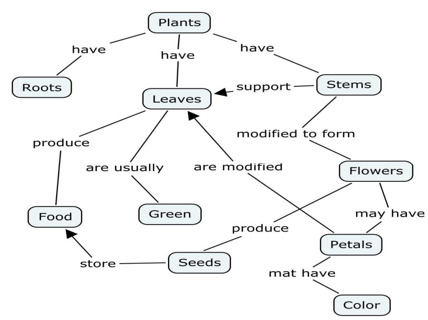

Figure 1: Example of concept map built with Cmap-Tools from [12]

We are exploring learner support for collaboratively building concept maps on a tabletop.
Concept mapping is a cognitively demanding task. This means that one valuable approach for making use of the tabletop for concept mapping involves two stages. In the first stage, students use an existing, validated desktop concept mapping tool, so they can focus exclusively on the construction of their individual maps. The students then come to the table to discuss these and build a common map, identifying the similarities and discussing the differences. This might mean that one person changes their mind, altering their own map. At other times, learners may not be able to agree. For example, in a biology task, one student's map may have the proposition "a whale is a mammal" while another student may have the proposition "a whale is a fish". One might convince the other to change or they may agree to disagree. We aim to create a tabletop interface that can support this process.

We present Cmate (*Concept Mapping at an Adaptive Tabletop for Education*), an interface designed to support learners in a form of discussion based on comparing personal understanding as captured in personal concept maps. Our design and its evaluation draws on principles of concept mapping, rethinking the usual interfaces to address the limitations and affordances of tabletops, to design an interface that allows users to focus on their core task of concept mapping. The design also was guided by user interface design heuristics: Nielsen's general usability heuristics [11], heuristics for interactive tabletop software proposed in [1] and specific guidelines for collaborative interactions at a tabletop given in [15]. We aim to encourage learners to reflect on their own knowledge representations and to support learners in building a common, shared and accurate concept map.

RELATED WORK

Multi-touch tabletop applications have been developed to enable groups of learners to work together on learning tasks. For example, Oppl & Starty [13] developed a hybrid tool for concept mapping using labeled physical tokens as concepts and digital unlabeled relationships between them. Do-Lenh et al. [7] found that collaborative concept mapping at an augmented tabletop shows insignificant learning effects compared with concept mapping on a single desktop computer. Members of groups who used the multi-touch tabletop tended to work in parallel and had difficulties bringing all the pieces together at the end of the trial. Therefore, mechanisms for encouraging collaboration should be considered in the design of such tools [6]. Additionally, Frisch et al. [8] explored and analysed a range of multitouch gestures specifically suited to edit node link diagrams. Some work has explored ways to help learners improve their concept maps. One is the Verified Concept Mapper, VCM [4], which gives feedback on the maps, inviting learners to reflect on parts that may be incorrect as well as omissions. Another such approach is Betty's Brain [10], where the learner creates a form of executable concept map, so teaching Betty and enabling her to pass tests. This was shown to promote metacognition as learners reflect on their own externalised knowledge model.

USER VIEW AND DESIGN OF CMATE

Our system, Cmate, aims to provide a new form of learning environment that helps learners and their teachers to gain a clearer understanding of each learner's knowledge and misconceptions. To do this, we use the tabletop to combine the privately constructed individual users' concept maps. As part of this process, learners need to identify where there is consensus and disagreement. We support this by providing a user interface which maintains the collaboratively created group map as well as one layer per user showing their individual map contributions. We illustrate the user view of Cmate with a scenario. Alice and Bob (Learner 1 and Learner 2 respectively in Figure 2) have just read a text, "Introduction to Living Things". They first each use a desktop concept mapping editor, CmapTools [12], to create a personal concept map capturing their own understanding of the key ideas in the text. These personal concept maps are exported in the CXL (*Concept Mapping Extensible Language*) format and loaded onto Cmate. This will serve two purposes: (i) to extract the vocabulary of concepts and links used in individual maps and make it available to the users, and (ii) to be able to highlight in the group map which concepts and links were present in each individual map. Alice and Bob then start using Cmate to create the collaborative concept map shown in Figure 2. For the collaborative process of creating a combined concept map, Cmate starts with an empty map. It presents just blue concentric circles, which will help the learners lay out concepts at the levels, reflecting the generality of the concepts. This design differs from the classic layout of concept maps, as in Figure 1, to account for the different orientation of users around the table. In Cmate, the most general concept is placed in the centre, with more specific concepts placed around it. Each user is allocated a colour (e.g. orange for Alice and yellow for Bob), a *user menu* and a blue destructor, called the *black hole*. The user menu has two kinds of buttons: *colour-coded* buttons and corresponding *text-coded* buttons. The *colour-coded* buttons are for drawing gestures on the tabletop to add concepts and links related to a particular user's pre-built concept map. The *text-coded* buttons highlight the parts of the group map that were present in the relevant individual concept map. Alice and Bob have discussed their individual maps; Alice begins placing concepts onto the combined map.

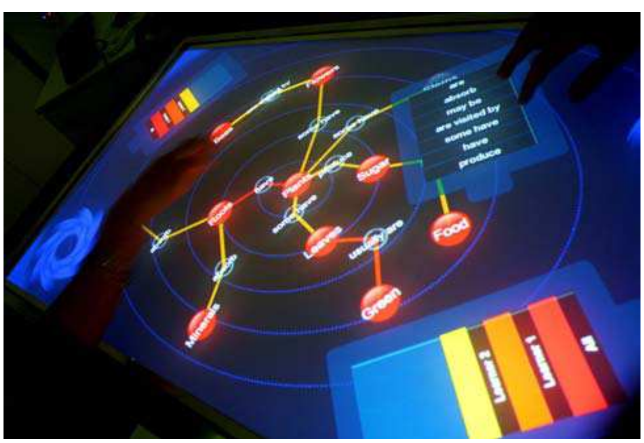

Figure 2: Two people using Cmate

She selects her colour (orange), and then brings up a menu with a gesture *similar to a number 6*. Cmate presents a menu with the list of concepts from her individual map. Alice and Bob discuss which concept is the most general and they agree it is *Plants*. So she selects this concept and places it at the centre of the table. After some discussion, they agree on a proposition (two concepts and their associated link). Bob takes over, selecting his colour (yellow), places those concepts and links them by *drawing a line between them*. This gesture invokes the links menu. Bob selects one of the link terms he used in his individual concept map, or creates a new one. If Bob wants to delete a concept or a link, he touches it and drags it into any of the *black holes*. He can also edit the text of any node by double tapping it. Then, a virtual keyboard appears next to it allowing him to change the link term or concept phrase.

Alice selects the *text-coded* button with the title *Learner 1*, from the *user menu*, to highlight the links and propositions she added (see Figure 3). The common parts between Alice's and Bob's concept maps are shown in red lines. Then, Alice picks the button with the label *all* to see the general layer for having a broad idea of the whole topic by visualizing all the elements added by either Alice or Bob. As a result, both learners built a new single group concept map using some parts of the individual maps built before the tabletop session or by adding new ones. The different layers are useful for reflecting on the similarities and differences between the individual concept maps as well as on whose ideas are more predominant. The general layer depicts all parts of the concept map showing the links added by each user with a different colour. The individual layers highlight only the elements that are also present in the individual concept maps. Cmate's design enables small groups, of up to four learners (e.g. see Learner 3 added in Figure 3), to externalise their knowledge, then to identify shared understanding in the form of common propositions. They also consider the differences and discuss these. We have taken care to allow users to define their own concepts and link names, following the approach advocated by the concept mapping community [3].

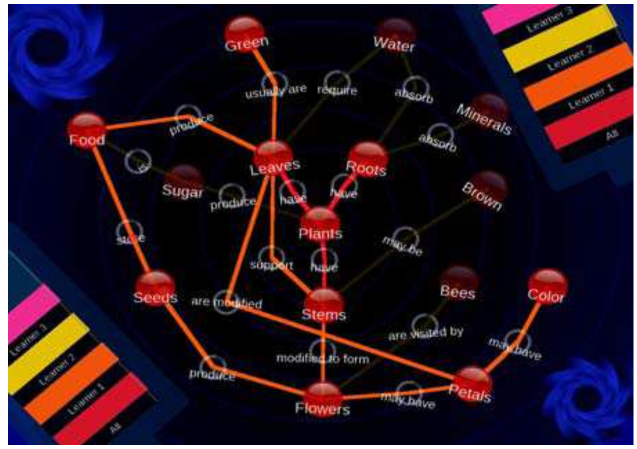

Figure 3: Visualisation of two concept maps merged using Cmate. In this case, the concept map from Figure 1 is highlighted and enriched by the combination of a second concept map.

IMPLEMENTATION

Cmate is written in Python and OpenGL using PyMT [9]. It is hardware independent and we have tested it on multi-touch tabletops. Cmate natively supports multi-touch interaction (given the adequate hardware).

Next, we describe the ways that the design was influenced by available design guidelines: those specifically for tabletop design, from Scott et al. [15] and Apted et al. [1] and adapted versions of general heuristics of Nielsen [11]. We now explain how these were used.

Consideration for arrangement of users

Cmate users are able to view and interact with the application at any position around the table. This poses a design problem in relation to the layout of the concept map. To address this, we introduced a new paradigm for the hierarchical structure layout. We chose a concentric hierarchy in which the most central concept is the best representative of the topic of the map. Then we provide circular lines as a map level reference, helping users arrange the concepts to reflect the levels of generality and to help place similar concepts. Following the design guidelines given in [1, 15] every component of the interface can easily be oriented as the user wishes, by holding down on a blank space of the screen to reorient the whole map or by manually rotating particular components.

Support transitions between tabletop collaboration and external work

As described in the scenario, Cmate supports the loading of the previously created individual concept maps and this also provides the initial set of concepts and the terms of the links for the group concept map. The design minimises the need for a keyboard, physical or emulated, to reduce clutter and make for simplicity.

Support transitions between activities

Cmate addresses this guideline by ensuring that users can move between all possible interface actions at any time. This includes creation of concepts and propositions, layer selection, drawing lines to link concepts, rearrangement of components and resizing/sliding menus.

Support transitions between individual and collaborative work

A key challenge for tabletop interface design is to support the right balance between private activity and collaboration. This issue was a problem in [7], as users tended to work in parallel, without being aware about their peers' actions. Cmate natively supports multi-touch interaction (given the adequate hardware). Importantly, its design provides a novel form of *personal space* in form of a personal layer. The current design of Cmate permits users to select just one of the *colour-coded* buttons at a time and therefore have just one active brush on the whole tabletop area. Consequently, the design encourages the users to take turns in adding their concepts or connection links. Alternatively, users can agree to work simultaneously while adding new ideas onto the general layer using the red-coloured brush. Through this approach the group could decide between both focusing on explaining the subject matter using new concepts and linking words or to solve the agreements and conflicts between the ideas contained in the preloaded maps.

Minimise human reach

To achieve this, the design ensures that the user can control the location of all concepts, linking words, menus and the *black hole.*

Use large selection points

We provide large targets on the menus for the concepts and link terms. All elements of the Cmate interface also have large edge area targets for the rotate and resize gesture.

Manage interface clutter

We took the idea of the *black hole* from [5], enabling users to delete unwanted concepts or propositions by letting them fall into the metaphoric *black hole*. In addition, our use of gestures to invoke menus avoids the need for an additional interface element and so reducing clutter.

EVALUATION

We conducted a qualitative, formative evaluation of usability. The collaborative nature of the task meant that this was a form of naturalised think-aloud but we also asked participants to comment on any problems as they used Cmate. We invited pairs of users to first create private concept maps using CmapTools for the topic *does recycling help the environment*? We then gave them a short demonstration of Cmate and asked them to create collaborative maps. Two pairs of users completed the task. All the users were also usability specialists. Our main goal was to see whether users could make sense of the different layer levels and, at the same time, build a common and accurate concept map. The study provided valuable formative results for refinement of the interface. The users explored all parts of Cmate. Importantly, all considered that the interface helped them to merge their ideas in form of propositions and easily distinguish their personal work from the collaborative map. At the same time they identified several areas for improvement. Users expressed that the *black hole* was tedious to use especially when they wanted to delete several elements. They also reported an issue with the *user menu* component. This includes the *colour-coded* buttons to select the brush for drawing gestures to add elements onto the concept map. However, just one brush can be active at a time for the whole tabletop, forcing them to make decisions on turn-taking. Users initially thought that the two copies of the *user menu* were not synchronised and allowed them to work with different brushes at the same time, therefore not requiring them to take turns. Users also pointed out the need for better feedback when pressing buttons and an easier way to reorient all elements of the concept map.

CONCLUSIONS

The main contribution of this paper is the description of a new way to support collaborative learning. Taking account of problems observed in previous work [7] we designed Cmate with a novel approach to manage private and shared elements: users create a multi-layer concept map, with a separate layer for each individual and one for the collaborative map that represents the propositions that all the users agree on. Our design aims to encourage people to collaborate more effectively by taking turns in their use of the interface. The approach is a foundation for improving learning as users discuss differences between the individual's understanding, and the associated different propositions in their initial personal maps, trying to resolve them. There are many directions we want to explore: use of hardware/software that automatically identifies users; refinements of the interface or gaining understanding on the ways Cmate can be useful in a classroom for providing useful information to teachers about the process of the collaborative mapping. We are also exploring mechanisms for supporting negotiation between users by highlighting disagreement. We intend to do this through the layered interface which could show users the parts of the map on which they have discrepancy or different points of view. We also propose to explore other contexts that may benefit from our approach of using layers to capture and present private and collaborative information spaces.

REFERENCES

1. Apted, T., Collins, A. and Kay, J. Heuristics to support design of new software for interaction at tabletops. *In Proc. CHI '09*, 2009.
2. Cañas, A. J. and Novak, J. D. Next step: consolidating the cmappers community. *In Proc. CMC 2008*, OÜ Vali Press, 2008, pp. 532-539.
3. Cañas, A. and Carvalho, M. Concept Maps and AI: an Unlikely Marriage. *In Proc. SBIE 2004*, 2004
4. Cimolino, L., J Kay and A Miller, Concept Mapping for Eliciting Verified Personal Ontologies, *IJCEELL, 14 (3), 2004*, pp. 212-228.
5. Collins, A. and Kay, J. Collaborative Personal Information Management with Shared, Interactive Tabletops. *Proc. PIM 2008 CHI Workshop*, 2008.
6. Dillenbourg, P. and Self, J. A. Designing Human-Computer Collaborative Learning. *In Proc. COOP'96*, Springer-Verlag, 1996, pp. 245-264.
7. Do-Lenh, S., Kaplan, F. and Dillenbourg, P. Paperbased concept map: the effects of tabletop on an expressive collaborative learning task. *In Proc. BCSHCI'09*, ACM Press, 2009, pp. 149-158.
8. Frisch, M., Heydekorn, J. and Dachselt, R. investigating multi-touch and pen gestures for diagram editing on interactive surfaces. *In Proc. ITS 2009*, ACM Press, 2009, pp. 149-156.
9. Hansen, T. E., Hourcade, J. P., Virbel, M., Patali, S. and Serra, T. PyMT: a post-WIMP multi-touch user interface toolkit. *In Proc. ITS 2009*, ACM Press, 2009, pp. 17-24.
10. Leelawong, K. and Biswas, G. Designing Learning by Teaching Agents: The Betty's Brain System. *IJAIED, 18(3)*, 2008, pp. 181-208.
11. Nielsen, J. Enhancing the explanatory power of usability heuristics. *In Proc. SIGCHI, 1994*, pp.152-158
12. Novak, J. and Cañas, A. The Theory Underlying Con cept Maps and How to Construct and Use Them, IHMC, 2008, *DOI=10.1.1.137.2955*.
13. Oppl, S. and Stary, C. Tabletop concept mapping. In *Proc. TEI 2009*, ACM Press, 2009, pp. 275-282
14. Preszler, R. Cooperative Concept Mapping: improving performance in undergraduate biology. *Journal of College Science Teaching, 33(6)*, 2004, pp. 30-35.
15. Scott, S. D., Grant, K. D. and Mandryk, R. L. System guidelines for co-located, collaborative work on a tabletop display. *In Proc. CSCW 2003*. Kluwer Academic Publishers, 2003, pp. 159-178.