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ANALYSING KNOWLEDGE GENERATION AND ACQUISITION FROM INDIVIDUAL AND FACE-TO-FACE COLLABORATIVE CONCEPT MAPPING

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Abstract. *Collaborative learning* provides students the opportunity to externalise personal perspectives and compare their understanding of a subject matter area with their peers. *Concept mapping* is a tool that permits students to build visual representations of the relationships among concepts to form a meaningful artefact that models a domain of knowledge or gives an answer to a posed question. *Emerging pervasive devices*, such as interactive tabletops, offer new possibilities to support collocated collaboration and analyse the collaborative process as never before. The synergy between these three fields: collaborative learning, concept mapping and the use of interactive tabletops, offers the possibility to both analyse and support the process of collaborative knowledge building. We report a study of 60 students who created concept maps in the stages: individual pre-concept maps, group concept mapping and individual post-concept maps. We analysed similarity between these and whether individual students were affected by the group collaboration measured through an automatic model. We found that students who contributed most to the group map maintain their understanding in the post-map; while those who contribute least to the group map tend to change their individual perspective. We also found that after students build a concept map at the tabletop their level of agreement is significative higher. The main contributions of this paper are the approach to study individual and collaborative concept mapping; and the analysis of knowledge acquisition and collaboration by tracking the flow of use of propositions.

1 Introduction

The goal of this paper is to present an approach to study the flow of knowledge, *created and acquired*, that occurs when students construct a concept map as a group, aided by a multi-touch interactive tabletop. The synergy between collaborative learning, concept mapping and the use of interactive tabletops offers the possibility to both support and analyse the process of collaborative knowledge building. *Collaboration* includes a series of activities such as discussions, explanations, disagreement, regulation and other group dynamics. These can trigger cognitive mechanisms that do not occur when students work individually and that may enhance learning (Dillenbourg, 1998). Group work provides students the opportunity to externalise their personal perspectives, compare their understanding of the subject matter with others, reach common ground about the concepts under discussion, and integrate individual with group ideas to generate new knowledge (Stahl, 2006). As a result, learning collaboration and argumentation skills is important for value generation in both educational and workplace scenarios (Scheuer et al., 2010). However, truly collaborative relationships do not necessarily occur when students work on a group activity even though computer-based learning systems have been created to facilitate such situations (Kreijns et al., 2003). The role played by teachers and facilitators in the classroom is crucial for helping students to be more aware about their group dynamics and learn collaboration skills (Dillenbourg et al., 2011b). Thus, teachers need resources to improve their awareness about collaboration and the flow of knowledge produced during small-group learning activities.

This paper links collaborative learning with a *concept mapping* activity. Concept mapping is a technique that can help students to create visual representations of the structure of their understanding about almost any knowledge domain, affording meaningful learning (Novak, 1990). Concept maps are directed graphs in which the nodes represent concepts of the learning domain and the relationships between them, called *propositions* or principles, represent a meaningful statement. Concept maps can be regarded as artefacts that model a domain of knowledge as perceived by the creator(s) and can serve as a vehicle for discussion and negotiation of meanings between students and facilitators (Novak, 1995). Thus, concept maps can effectively be used in facilitating collaborative learning and for enabling students to negotiate understanding in small group work (Novak, 1995; Stahl, 2006; Torres et al., 2010). The collaborative construction of a concept map for a given domain of knowledge can offer group members the opportunity to discuss and externalise ideas, represent knowledge from multiple angles, identify misunderstandings, reach agreement, or agree to disagree (Chaka, 2010).

The third element of our work involves the use of *emerging pervasive shared devices*, such as multi-touch interactive tabletops. These offer new possibilities to both support collocated collaboration and capture the *digital footprints* of students' interactions. These data can be exploited to analyse the collaborative process in radically new ways (Martinez et al., 2011a). Conventional tabletops are natural working spaces around which people discuss and work together in activities that require the expertise or consensus of all group members. Interactive tabletops offer an augmented shared space in which all students have equal opportunities of interaction with digital tools, content and communication artifacts, in addition to a natural space for face-to-face discussion, rich group awareness and instant communication (Dillenbourg et al., 2011a).

Figure 1. Concept mapping at the multi-touch tabletop. *Left*: Three students starting to add some concepts to build a group concept map. *Right*: An example concept map mainly built oriented towards one of the students. The colours of lines and concepts indicate who created each concept or proposition

This paper focuses on defining a method to track and analyse the flow of knowledge that is created, shared and acquired as a result of group concept maps construction at tabletops. To achieve this goal our work aims to exploit the activity logs that can be obtained during both the individual as well as from collaborative concept mapping activities that were performed, first, in private, using a desktop application, and then, using an interactive tabletop (Figure 1). The information about the flow of knowledge that is shared, in the form of propositions, and its relationship with groups' collaboration can help teachers or students to be more aware about their learning performance, the knowledge domain and their collaborative processes. The main contributions of this paper are the approach to study individual and collaborative concept mapping and the analysis of knowledge acquisition and collaboration by tracking the flow of use of propositions.

The remainder of the paper is organised as follows. The next section describes other studies that have explored the study of collocated concept mapping at the tabletop. Section 3 describes the design and implementation of our study and the learning environments. Section 4 presents the results of the analysis and the discussions. We conclude with a description of ways in which this approach can be adapted to a real classroom scenario and the future work for this project.

2 Related Work

A number of researchers have explored the suitability of concept mapping for interactive tabletop environments (Do-Lenh et al., 2009; Martinez et al., 2011d; Oppl et al., 2011). One of the first of these corresponds to the work done by Baraldi et al. (2006) who built a system that uses concept maps to navigate through wiki's content. Tanenbaum et al. (2009) presented a tabletop system that provided support to students to create a concept map through the use of tangible objects on the interactive tabletop. This system was limited to one user so the opportunity to use the interactive tabletop for discussion and collaboration was restricted. Do-Lenh et al. (2009) performed the first study to explore the benefits of using an interactive tabletop to help collaborative concept mapping, compared with the use of a personal computer. Results were negative for the interactive tabletop as authors did not find significant differences between concept mapping at the tabletop or sharing via conventional desktop computers. Indeed, they found that a group sharing a desktop computer showed healthier aspects of collaboration such as discussion and negotiation. However, the comparison was not entirely fair because sharing one desktop computer means that one mouse and one keyboard must be shared. Therefore, there is a restriction that does not exist at an interactive tabletop, in which all students have the same opportunities for interaction. Later, Oppl and Stary (2011) designed a study to look for advantages of concept mapping aided by an interactive tabletop. They found that concept mapping at the tabletop offers students equal opportunities of participation to share their individual understandings and build a collaborative concept map when compared with other mediums (e.g. a networked system). The work reported in this paper presents research that goes beyond the previous work as our approach provides valuable insights about the *process* to create a combined concept map as they come together after working individually on personal concept maps.

3 Description of the Study

Next, we describe the methodology that was followed and the concept mapping collaborative learning system. One approach that has proven successful, both as a teaching technique and a research approach, is to follow the construction of individual concept maps in private with the construction of a collaborative concept map (Engelmann et al., 2010; Novak, 1995). This provides the opportunity for students to reflect in private and define a personal perspective about the knowledge domain at their own pace. After this, they then focus on the demanding task of collaboration to establish common ground with other students, negotiate their personal perspectives and appropriate the knowledge generated by the group. This strategy is supported by the theory of *Group Cognition* in which the process of knowledge building is modelled as a continuous loop of individual and collaborative moments of learning (Stahl, 2006). Our approach grounds on this theory by providing both an individual and a shared space for group members to build a number of concept maps about a chosen domain. The goal of our study was to analyse the flow of the use of propositions by group members, from individual to collaborative learning, linked with the level of collaboration. We aimed to investigate the following hypotheses:

- *Hypothesis 1. There exists a positive correlation between the quantity of propositions included by one student to the tabletop group map and the extent of permanence of their individual perspective.* In other words, students that contribute more to the *group* concept map at the tabletop demonstrate less change in their perspectives after the group concept map building task, whilst the less contributing group members modify their perspectives more, appropriating new information from the group.

- *Hypothesis* 2. *There is more agreement among group members after building a group concept map at the tabletop.* Building a group concept map at the tabletop makes an observable impact on the shared knowledge and persists after the activity.

- *Hypothesis 3. There exists a positive correlation between the extent of collaboration of a group and the new knowledge represented in the group concept map.* The theory of group cognition and a wide range of studies on collaboration indicate that one of the main outcomes of healthy collaborative interactions is the generation of "new knowledge". This takes the form of ideas that were not present in the individual perspectives (concept maps) but are discovered by the group cognition (Stahl, 2006).

- *Hypothesis 4. There is a negative correlation between the similarity of perspectives among group members and new knowledge represented in the group concept map.* In other words, those groups in which the group members have divergent points of view about the topic will come up with more conflicting ideas that will drive the generation of completely new ideas in the form of propositions that were never considered by any of the group members before the group session.

Hypothesis	**Formulation**
Students who have more of their propositions in the group map well reproduce most of their initial concept map after the group session.	ρ (d(m$_i$,m$_g$)),(d(m$_i$,m'$_i$))> 0
There is more agreement in the maps of group members after they build a group concept map at the tabletop.	Avg (d'$_{1,2,3}$) < Avg(d$_{1,2,3}$)
Groups that are more collaborative generate more new knowledge represented in the group concept map.	ρ ((m$_g$ - {m$_{1,2,3}$}) ,(collaboration) > 0
Groups of where students have more different individual maps generate more new knowledge represented in the group concept map.	ρ ((m$_g$ - {m$_{1,2,3}$}), Avg(d$_{1,2,3}$)) < 0

Table 1: Hypotheses overview. The formulation of each hypothesis refers to elements of Figure 2

3.1 Participants and Approach

A total of 60 students enrolled mostly in engineering and science courses participated in the study. An initial focus question was posed to the students: *What types of food should we eat to have a balanced diet?* The goal for students was to create concept maps after studying the Australian Dietary Guidelines (2011) published by the National Health and Medical Research Council of Australia in the form of concept maps. Participants were organised in teams of three students mainly grouped so group members knew each other. Before the activity, students received basic instruction about concept mapping and were requested to draw an example concept map not related with the Australian Dietary domain. Then, they were asked to read a one-page article based on these guidelines and draw a concept map individually at a personal computer using the well-known CmapTools (Novak et al., 2008) (Figure 2, 1). Then, each group of three students was asked to build a concept map collaboratively at the multi-touch interactive tabletop using an application called Cmate (Martinez, et al., 2011d) (Figure 2, 2). This application was loaded with the individual concept maps previously built, using the Concept-mapping extensible language for describing the content of concept maps (CXL). This allows group members to have access to the concepts, linking words and an image of the concept map that they created individually. This gave opportunity to students to compare their perspectives, a key aspect to enhance the collaborative learning process (Tifi et al., 2008). Afterwards, each group member was asked to draw an individual concept map again, from scratch, without looking at their initial individual or the group concept maps (Figure 2, 3).

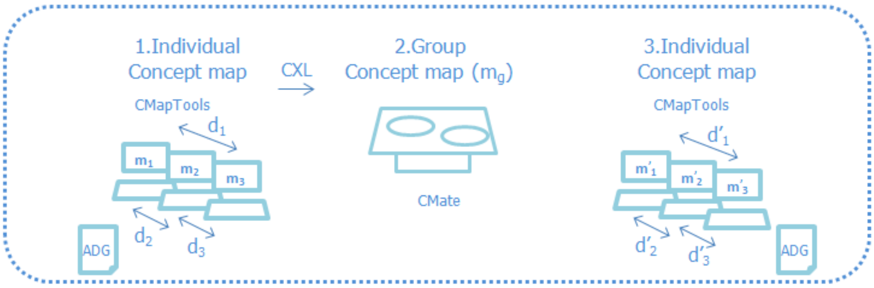

Figure 2. Approach. 1) Pre-individual concept mapping (creating m_1, m_2, m_3), 2) Group concept map (m_g) and, 3) Post- individual concept mapping (creating m'_1, m'_2, m'_3). Where = $d(m_i,m_g)$= similarity of pre-individual maps and the group map; $d(m'_i,m_g)$= similarity of post-individual maps and the group map; d_1, d_2, d_3 = similarity among pre-individual maps of a group. d'_1, d'_2, d'_3 = similarity among post-individual maps of a group. $d(m_i,m'_i)$ = similarity between each pre- and post individual map per student. ADG = One-page Australian Dietary Guidelines.

3.1.1 Individual concept mapping

In this paper, we consider individual concept maps as graphical knowledge representations of a student's understanding of the domain. Moreover, following recomendations for the concept mapping practice (Cañas et al., 2004), students were free to use their own words to label the concepts, links and to follow the arrangement and structure that they wanted to use. We suggested an initial list of concepts extracted from the text to increase the chances of having *comparable* maps. However, students were free to use them, ignore them or create their own concepts and linking words at any time. Figure 3 shows two individual concept maps created by 2 students from the same group. In this example we can notice how different the students' perspectives can be even when all students had access to the same material and started with the same list of suggested concepts.

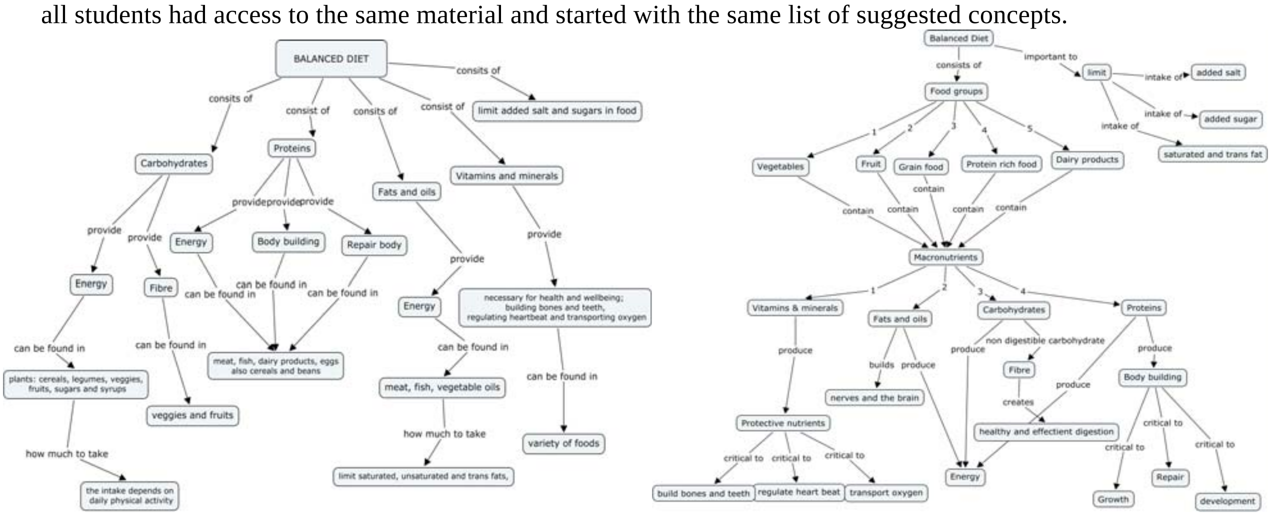

Figure 3. Example pre-individual concept maps built by two students from the same group that ended up building the group concept map shown in Figure 1 (right). The individual concept map at the left predominated in the group final map. Only, some propositions of the map at the right were included in the group map. The third individual map of the group (not shown) was very different and it was barely considered by other group members during group map building.

3.1.2 Collaborative concept mapping

The system used to capture the learners' face-to-face interactions consists of an augmented interactive tabletop that permits students to discuss and work on building a joint solution in the form of a concept map (Martinez et al., 2011b) (Figure 1). The tabletop hardware can detect multiple simultaneous touches. To distinguish between users' touches, an overhead depth sensor (*www.xbox.com/kinect)* recognises which users provided each input by tracking the position of each student around the table. Each single touch performed on the interactive surface is associated with a student. Verbal communication of group members is captured by a microphone array located at one side of the tabletop (www.dev-audio.com). This recognises when each learner is speaking.

The tabletop application Cmate (Martinezet al., 2010) permits learners to draw a concept map that represents their collective understanding about a topic. Students can build a totally new group concept map, but the application also provides each student with a personal menu to add the concepts from their individual concept mapping task at the personal computer (Figure 4.2). When students create new links, a menu appears around the new link to ease the selection of any of the top 6 linking words they used before (Figure 4.3). They can decide to type a new linking word (Figure 4.4). Students have also access to an image of the individual concept map they created to recall or share with others their initial perspective.

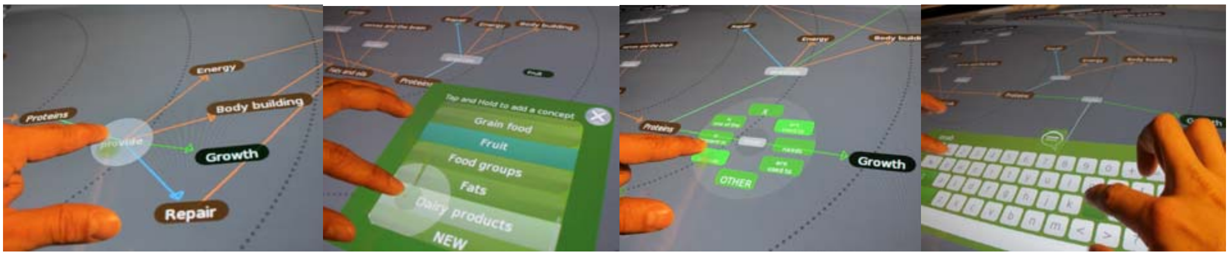

Figure 4. Interactive tabletop application for concept mapping. 1) Partial view of a concept map being built at the tabletop 2) Personal list of concepts used in the individual stage loaded to the tabletop. 3) List of suggested linking words available when a student creates a new link at the tabletop (e.g. Proteins – provide – growth). 4) Students can add new concepts and linking words at any time or edit the links (e.g. for the same link change the word "provide" to "enable").

3.2 Data Description and Measures of Similarity and Collaboration

The data used in this study includes all the seven final concept maps built by each group. These are the three maps built by each student initially (m_1, m_2, m_3), the group map built at the tabletop (m_g), and the three post-individual maps (m'_1, m'_2, m'_3) (see Figure 2). In order to test the hypotheses, a basic measure of similarity between concept maps was implemented. We used a modified technique inspired by the method for scoring open-ended concept maps developed by Taricani et.al. (2006). 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. This automatic technique proved successful and very close to ratings performed manually by a human. In our study, this technique is used to automatically measure the similarity or "distance" between the propositions contained in any 2 concept maps. In this way, we calculate the similarity between each student's pre- and post-concept map (s_1, s_2, s_3), the distances among the individual concept maps of each group that were built before (d_1, d_2, d_3) and after (d'_1, d'_2, d'_3) the group map, the distances between each pre- and post- individual concept map and the group map (dg_1, dg_2, dg_3 and dg'_1, dg'_2, dg'_3; using the grouped average Dg and Dg' respectively). We do not use any referent map and we do not consider *correctness* of the propositions.

Another important indicator needed for Hypotheses 2 and 3 is the measure of the extent of groups' collaboration. For this study, we automatically measured the "level of collaboration" detected by the system as a summary of group communication and equality. It is based on a model developed by Martinez *et al.* (2011c) using the data mining prediction Best-First tree algorithm. This model classifies each block of half a minute of activity according to a set of features that can be captured from collocated settings such at an interactive tabletop. These features are: the number of active participants in verbal discussions, amount of speech, number of touches and symmetry of activity measured with an indicator of dispersion (Gini coefficient). The system labels each 30 second episode as one of three possible values: Collaborative, Non-collaborative, or Average. This means that, for example, for 30 minutes of a collaborative concept mapping session, the algorithm obtains 60 blocks with 60 individual labels. We take the average of the labels to define whether each group was collaborative or not.

4 Evaluation and Discussion

Next, we describe the evaluation of the hypotheses listed above.

Hypothesis 1: There exists a positive correlation between the quantity of propositions included by one student to the tabletop group map and the extent of permanence of their individual perspective. A Pearson correlation coefficient was computed to assess the relationship between: the similarity of the pre-individual and the group map; and the similarity of the pre- and post- individual maps (ρ $(d(m_i,m_g)),(d(m_i,m'_i))$). There was a positive correlation between the two variables, r = 0.503, n = 60, p <= 0.0002. Students that contribute more to the group concept map, measured by the similarity between the pre-concept maps and the group map, present less change in their perspectives after the group concept map building task. This is indicated by higher similarities between the pre- and post- individual maps for each student. At the other end of the spectrum, those students who did not include much of their perspectives into the shared concept map presented significantly more change on their perspectives indicated by less similarity between their pre- and post- maps. This suggests that those students that tended to dominate the collaborative activity had more chances to influence others to modify their perspective accordingly. This situation might be desirable in the case in which the high participants built a coherent concept map about the knowledge domain, but this might not be not necessarily the case.

Hypothesis 2: There is more agreement among group members after building a group concept map at the tabletop. This indicates that the similarities among post-individual maps are higher than the similarities among pre-individual maps, as a result of the construction of the group map at the tabletop. This was calculated by comparing the averages of these distances per group as $Avg(d'_{1,2,3}) < Avg(d_{1,2,3})$. We found a very statistically significant difference for group map construction of these two conditions, $t(19) = 6.73, p < .0001$. Overall, groups increased their levels of agreement as a result of concept mapping at the tabletop. We further wanted to know if this increase in the level of agreement was favoured by high collaborative groups or the less collaborative ones. In fact, we found that the less collaborative groups presented higher levels of agreement after the tabletop session ($t(8) = 7.86, p < .0001$). For the less collaborative groups, the average similarities jumped from 0.29, for the pre-concept maps, to 0.50 for the post-concept maps. For the collaborative groups the agreement came from 0.30 to 0.43 ($t(10) = 3.67, p < .0043$). These findings could suggest a contradiction with theories on collaboration that affirms that one outcome of collaborative work is the establishment of common ground and possible agreement on the same group perspective (Stahl, 2006). Nevertheless, this is not necessary true, at least for concept mapping, since one or two group members can convince others to change their perspectives or dominate the activity in such a way that collaboration is less effective. In our study, students who belonged to less collaborative groups tended to appropriate more of the group propositions than collaborative groups.

Hypothesis 3: There exists a positive correlation between the extent of collaboration of a group and the new knowledge represented in the group concept map. The relationship between the quantity of new propositions created during the group task (m_g - $\{m_{1,2,3}\}$) and the level of collaboration as indicated by the automated model was computed using Pearson correlation (ρ $(m_g - \{m_{1,2,3}\}),(collaboration)$). We found a positive correlation between the two variables (collaboration and new knowledge created), r = 0.33, n = 20, p <= 0.06. This correlation is not strong enough for fully accepting the hypothesis (p>0.05). A deeper analysis on the way collaboration is assessed should be carried out (e.g. by using video analysis in order to judge whether each group was indeed collaborating). However, there was not a strong tendency of collaborative groups to create more new propositions that were not considered individually.

Hypothesis 4: There is a negative correlation between the similarity of perspectives among group members and new knowledge represented in the group concept map. This hypothesis aims to set a relationship between the average of the similarity among pre-individual concept maps of a group ($Avg(d_{1,2,3})$); and quantity of new propositions that were created during the group concept mapping task (m_g - $\{ m_{1,2,3}\}$). In this case, we found some negative correlation between the two variables, r = -0.36, n = 20, p <= 0.059. This correlation is at the borderline to accept the hypothesis (p>0.05). Groups in which students presented more agreement tended to create sensibly less new knowledge, focusing more on the integration of the propositions that each of them already created. On the other hand, groups in which their individual perspectives were more different from each other tended to create a new group map with more new content.

The four hypotheses posed in this paper sought to find out evidence contained in the concept maps that can provide information about acquisition of propositions, knowledge creation and extent of collaboration of the group members. Two out of four of the hypotheses were statistically supported. The last two hypotheses showed a less strong tendency but still provided some information about the usefulness of the approach that can be followed to analyse groups' collaboration and the flux of knowledge. The first finding (hypothesis 1) showed that students who actively contribute to the group work tend to convince others to adopt a similar point of view; therefore, these students are inclined to maintain their perspectives. A number of collaboration sub-processes can be involved in this effect for example elicitation, negotiation and conflict resolution. The scope of this hypothesis is limited to study whether is possible to inspect the similarities between concept maps to analyse the flux of knowledge before and after collaboratively concept map building at the tabletop. The second hypothesis tackles a different angle of the group outcomes: agreement after the group activity. Overall, the study proved that after building a concept map at the tabletop group members built common ground and could individually represent parts of their shared artifact after the group work. However, a deeper analysis of this hypothesis showed that less collaborative groups strongly agreed after the group session. Examples of less collaborative group behaviours includes the presence of a dominant student who performs most of the work without consulting others; independent work; having one student sub-participating or being just a free-rider (Martinez et al., 2012). Hypothesis 3 and 4 were not fully accepted but they showed some tendency that can be observed in some groups. Hypothesis 3 links the level of collaboration with the amount of new knowledge generated. Studies on collaboration support a positive correlation between these two indicators (Stahl, 2006). However, the purpose of this hypothesis was to investigate whether the concept maps contain enough evidence to confirm this positive effect of collaboration. Most of the high collaborative groups showed higher levels of communication but this is not necessarily always reflected in the final concept map. The range of possibilities is wide: some of the better ideas may not be have translated into propositions, partial solutions can have more quality than the final concept map or simply the way students draw their concept map as a group does not reflect their discussions. Regarding Hypothesis 4, studies on collaborative learning have provided evidence to support that that groups with more divergent points of view tend to generate more new ideas (Dillenbourg, 1998; Stahl, 2006). Similarly to Hypothesis 3, the goal was to analyse whether the concept maps can contain enough traces of information to confirm such relation. The negative correlation was not strong enough to generalise that divergent points of view in the individual concept maps generate an increment on the new knowledge under discussion but showed that the tendency is close to be significant (r= -0.36).

5 Conclusions and Future Work

Concept mapping is a tool that provides enormous learning advantages to represent knowledge and enhance meaningful learning. It has also been proven that it is effective as a collaborative activity to build knowledge, share perspectives and help understanding a knowledge domain from different angles (Torres, et al., 2010). This paper aims to motivate research in the field by combining the affordances of new shared devices to help analyse aspects of the process and outcomes of collocated collaborative concept mapping. Specifically, this paper responds questions about the flux of the knowledge contained in the propositions created in the individual and group stages of the concept mapping activity. Our goal is to highlight the value of investigating the interactions of the students and the final products of the collaborative concept mapping process to offer insights that can help students or their teachers improve collaboration, learning or their concept mapping skills. The study had some limitations: simple text analysis was used to compare concepts and the usage of synonyms, writing errors or slight changes in the words were not captured; the context of learning was not totally real, students did not have to learn the content to get marks or pass a subject; students might have been affected by fatigue, specially for drawing the second individual concept map thus affecting the quality of their work; and the student population was chosen from a number of disciplines of science. The contribution of this paper is the approach and the exploration of the possibilities behind the synergy of different technologies and theoretical principles to study collaborative learning from a different perspective. This approach needs to be complemented by other means of input such as teachers' observations, qualitative assessment of the concept maps and a deeper analysis on the application logs. Future work on this research includes the usage of other techniques such as data mining to keep track of the evolution of the concept map and the process of collaboration by inspecting the student-computer interaction logs from the tabletop and the Cmap Recorder feature of CmapTools.

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7 References

Baraldi, S., DelBimbo, A., & Valli, A. (2006). Bringing the Wiki Collaboration Model to the Tabletop World. (pp. 333-336)

Cañas, A. J., & Carvalho, M. (2004). Concept Maps and AI: an Unlikely Marriage. Paper presented at the Proceedings of SBIE 2004: Simpósio brasileiro de informática educativa, 2004.

Chaka, C. (2010). Collaborative Learning: Leveraging Concept Mapping and Cognitive Flexibility Theory Handbook of Research on Collaborative Learning Using Concept Mapping (pp. 152-170).

National Health and Medical Research Council (2011). Australian Dietary Guidelines.

Dillenbourg, P. (1998). What do you mean by 'collaborative learning'? Collaborative Learning: Cognitive and Computational Approaches. Advances in Learning and Instruction Series. (pp. 1-19): Elsevier Science.

Dillenbourg, P., & Evans, M. (2011a). Interactive tabletops in education. International Journal of Computer-Supported Collaborative Learning, 6(4).

Dillenbourg, P., Zufferey, G., Alavi, H., Jermann, P., Do-Lenh, S., & Bonnard, Q. (2011b). Classroom orchestration: The third circle of usability. Paper presented at the International Conference on Computer Supported Collaborative Learning 2011. (pp. 510-517).

Do-Lenh, S., Kaplan, F., & Dillenbourg, P. (2009). Paper-based concept map: the effects of tabletop on an expressive collaborative learning task. Paper presented at the Proceedings of the 2009 British Computer Society Conference on Human-Computer Interaction, (pp. 149-158).

Engelmann, T., & Hesse, F. (2010). How digital concept maps about the collaborators' knowledge and information influence computer-supported collaborative problem solving. International Journal of Computer-Supported Collaborative Learning, 5(3), 299-319.

Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: a review of the research. Computers in Human Behavior, 19(3), 335-353.

Martinez, R., Kay, J., & Yacef, K. (2010). Collaborative concept mapping at the tabletop. Paper presented at the ACM International Conference on Interactive Tabletops and Surfaces, ITS 2010. (pp. 172-181).

Martinez, R., Ackad, C., Yacef, K., & Kay, J. (2011a). Designing tabletop-based systems for user modelling of collaboration. Paper presented at the International Workshop on Adaptive Support for Team Collaboration held at UMAP 2011.

Martinez, R., Collins, A., Kay, J., & Yacef, K. (2011b). Who did what? who said that? Collaid: an environment for capturing traces of collaborative learning at the tabletop. Paper presented at the ACM International Conference on Interactive Tabletops and Surfaces, ITS 2011. (pp. 172-181).

Martinez, R., Kay, J., Wallace, J., & Yacef, K. (2011c). Modelling symmetry of activity as an indicator of collocated group collaboration. Paper presented at the International Conference on User Modeling, Adaptation and Personalization, UMAP 2011 (pp. 196-204).

Martinez, R., Kay, J., & Yacef, K. (2011d). Visualisations for longitudinal participation, contribution and progress of a collaborative task at the tabletop. Paper presented at the Computer supported collaborative learning, CSCL 2011. (pp. 25-32).

Martinez, R., Yacef, K., Kay, J., & Schwendimann, B. (2012). Unpacking traces of collaboration from multimodal data of collaborative concept mapping at a tabletop. Paper presented at the International Conference of the Learning Sciences ICLS 2012, (pp. 241-245).

Novak, J. (1990). Concept maps and Vee diagrams: two metacognitive tools to facilitate meaningful learning.. Instructional Science, 19(1), 29-52.

Novak, J. D. (1995). Concept mapping to facilitate teaching and learning. Prospects, 25(1), 79-86.

Novak, J. D., & Cañas, A. J. (2008). The Theory Underlying Concept Maps and How to Construct and Use Them In T. R. I. C. 2006-01 (Ed.): Florida Institute for Human and Machine Cognition.

Oppl, S., & Stary, C. (2011). Effects of a Tabletop Interface on the Co-construction of Concept Maps. Paper presented at the Human-Computer Interaction – INTERACT 2011. (pp. 443-460).

Scheuer, O., Loll, F., Pinkwart, N., & McLaren, B. (2010). Computer-supported argumentation: A review of the state of the art. International Journal of Computer-Supported Collaborative Learning, 5(1), 43-102.

Stahl, G. (2006). Group Cognition: Computer Support for Building Collaborative Knowledge: MIT Press.

Tanenbaum, K., & Antle, A. N. (2009). Using Physical Constraints to Augment Concept Mapping on a Tangible Tabletop. Paper presented at the International Conference on Education and Information Technology. (pp. 539-547).

Taricani, E., & Clariana, R. (2006). A Technique for Automatically Scoring Open-Ended Concept Maps. [10.1007/s11423-006-6497-z]. Educational Technology Research and Development, 54(1), 65-82.

Tifi, A., & Lombardi, A. (2008). Collaborative Concept Mapping Models. Proceedings of the Third Int. Conference on Concept Mapping, Tallinn, Estonia & Helsinki, Finland: University of Tallinn.

Torres, P., & Marriott, R. (2010). Handbook of research on collaborative learning using concept mapping: Information Science Reference.