I Learn. You Learn. We Learn? An Experiment in Collaborative Concept Mapping

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Abstract: In this paper we present an experiment on digitally-supported collaborative Concept Maps focused on asynchronous and remote collaboration. We investigated the integration of multiple perspectives on the same topic, providing users with a tool allowing an individual perspective for each user plus a shared one for the group. Several user actions were made available, affecting one or both perspectives, depending on the context. Results show that integrating different perspectives in a way that everyone can relate to is indeed a complex task: users need to be supported not only in the production of a shared Concept Map, but also in the process of adapting their mental representations, in order to understand, compare and possibly integrate others' points of view. Our experiment shows that both collaboration *in* concept mapping (emphasis on the process) and collaboration *on* a Concept Map (emphasis on the result) are needed, whereas most tools, including the one we experimented with, focus on the latter. The main challenge is allowing people to understand, compare and assess each other's map, recognizing commonalities and differences through different representation styles and spatial organizations.

1 INTRODUCTION

Small-group collaboration among peers is a well recognized way to promote the acquisition of new concepts in many different learning environments (Hertz-Lazarowitz et al., 2013; Johnson and Johnson, 2013; Johnson et al., 2000; Luff and Heath, 1998). The mechanisms that underlie positive learning outcomes have been investigated in depth (Roscoe and Chi, 2007; Webb and Mastergeorge, 2003), and all of them involve different forms of "Information Processing", where new knowledge is generated by connecting together old and new pieces of information, and by building new or different relationships between information already owned (Webb, 2013). In a collaborative setting, learning implies that part of the information and of the relationships among pieces of information comes from different individuals. Everyone involved in the learning process is therefore called to contribute to build up a shared view of the overall knowledge, while at the same time retaining a personal view of the learned concepts. This in turn contributes to the development of collective and social intelligence (Brackett et al., 2011; Meza et al., 2018).

As a consequence, personal views can differ even substantially from the shared one, and, apart from the new knowledge acquired on the studied subject, everyone involved in the process can learn that: i) there may be different perspectives from one's own, and even conflicting with it; ii) each perspective may provide different insights on the subject under study; iii) one can learn something from others' perspective.

Concept Maps are one of the most known and widespread tools to represent, communicate, share and acquire new knowledge, in a variety of branches of education (Cañas et al., 2015; Khine et al., 2019; Novak, 2010; Romero García et al., 2017). In a traditional setting, Concept Maps are used by either individual students or small groups of learners gathering together, often under the supervision of a teacher. The benefits of team work based on Concept Maps, as a part of problem solving approaches, have been investigated by several authors (Haugwitz et al., 2010; Kandiko et al., 2013).

Nowadays computer and network technologies allow Concept Maps to be represented digitally, and promote remote and asynchronous collaboration. Personal Learning Environments (PLE) (Attwell, 2007;

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Wilson et al., 2007) are emerging, allowing learners to build their own learning workspaces. PLEs often enable users to integrate shared and personal workspaces, although the definition of models supporting these features, while offering a high level of free-decision making, is still an open issue (Häkkinen and Hämäläinen, 2012).

Several digital tools for concept mapping exist that also allow for some type of cooperation among multiple authors. Many collaborative web applications for graph design include Concept Maps among their templates and stencils (see e.g. Lucidchart, Creately or Draw.io, to name a few), and CmapTools (Cañas et al., 2004), arguably the most complete tool for Concept Maps, also provides teamwork support.

Collaboration support in these applications ranges from merely enabling the concurrent editing of a same map by multiple authors, to more refined mechanisms for proposal, discussion, and acceptance or rebuttal of changes and additions to the collaborative map. Collaboration thus revolves around reaching a common understanding or presentation of a topic.

However, the effectiveness of collaboration in learning relies also on the participants gaining awareness of their different perspectives. Participants are encouraged to compare their points of view, to recognize both common ground and differences; from this process they can acquire not only a wider and deeper knowledge of the study subject, but also meta-knowledge on what is peculiar of their own understanding, as is common in competency-based pedagogical approaches, especially learn-by-teaching (see e.g. work by Grzega and Schöner (2008) and by Sedelmaier and Landes (2015))

The aim of our research is thus to further refine collaborative mechanisms by incorporating the notion of perspective within the Concept Map model, so that several personal perspectives (one for each author) can coexist with a shared perspective (common to the whole team of learners). As we will see in the next section, the fact that they are *perspectives*, and not just different "versions" of the same Concept Map, means that the personal perspective of each author is related to the shared team perspective. Actions performed on one of the two perspectives may affect the other as well.

The goal of our experiment is to study a learning process where each author can develop both perspectives together, contributing to the shared perspective with the insights and understanding gained from her/his personal work, while at the same time enriching her/his individual perspective thanks to what emerges during the collaboration. Within this context we can envisage two teamwork learning scenarios (actually, two extremes of a broad spectrum of learning activities that can be proposed):

1. collaboratively build a shared perspective of a given topic and, thanks to such collaborative process, develop an individual perspective, or
2. first represent one's own personal perspective, and subsequently use it as a contribution to a collaborative activity, where a shared perspective is developed starting from individual work.

In a previous work (Goy et al., 2017) we focused on the first scenario mentioned above, and report an in-lab evaluation of the first version of our prototype, Perspec-Map. In the experimental setting small groups of learners were asked to collaborate in order to build a Concept Map expressing knowledge shared by all the people belonging to the same group. Nonetheless, each volunteer was allowed to build a private map, i.e., a personal perspective, which essentially grew out of the shared one whenever there was a disagreement with respect to the shared map. To perform our experiments we developed a proof-of-concept prototype which enabled users to see and interact both with the shared and with the personal perspective, that were presented in separate panels on the screen. All participants were allowed to update the shared perspective, while a personal perspective could only be updated by her owner.

In a subsequent work (Nuninger et al., 2018) we report the evaluation of a second version of the prototype in a real world setting, namely, the Automatic Control class at Polytech'Lille, in a Continuous Vocational Training for Chartered Engineers. Thanks to this experience, we realized that the role of multiple-perspective Concept Maps could be much broader than the one devised initially. As we then stated (Nuninger et al., 2018), "the goal in collaboration is not to reach exactly the same perspective for all participants, but rather to help each other reaching a personal understanding of the topic under consideration".

Outcomes of our both experiments on scenario 1 can be summarized as follows. As instructed, participants tended to concentrate on building the shared perspective, while the personal one was mainly perceived as a repository of elements and/or as a place to sketch concepts to be later shared with the others. The personal perspective was seldom perceived as an alternative point of view w.r.t. the shared map, but rather used to compare it to the work done together to see if personal work had been kept or removed by other participants. Broadly speaking, participants found it difficult to fill the gap between the shared and the personal perspective. For most users it turned out hard to read and understand the map fragments provided by others: in most cases, they just added their map fragment to what already present, in some cases restating with different wording what already expressed by others.

All in all this is consistent with what found by Smit (1989) and Shea (1995): learners do not tend spontaneously to aggregate and collaborate with the aim of learning something new: new knowledge, new points of view, new perspectives. Working collaboratively to build new pieces of shared knowledge is perceived as difficult because of many reasons, including different understanding of the concepts, different focus on what is important and what can be overlooked, different terminology used. A plausible, more in depth explanation for such difficulties is that, actually, people often delve into the cooperative learning process without having in advance a clear personal understanding of the knowledge they are trying to develop cooperatively. If a piece of knowledge is only partially or confusedly comprehended, trying to integrate it with others' point of view of the same issue will definitely turn out a messy and tiresome process.

Because of the above reasons, one may wonder whether a collaborative learning process that starts from a well understood and clearly stated personal knowledge and moves toward a shared view can be more successful and user friendly. In fact, this scenario corresponds to the second type of collaborative learning process described above.

In this paper we illustrate and discuss the outcome of a series of experiments conducted on a novel prototype (Perspec-Map 2.0) where learners first tackle their individual perspectives, and only subsequently engage in team work. In our presentation we follow the guidelines of the Design Science Research Methodology as introduced by Peffers et al. (2007).

The rest of this paper is thus organized as follows. Section 2 introduces the approach we devised and experimented with. Section 3 presents the experimental setting and reports on the results, that is, qualitative observations and questionnaire answers. Section 4 discusses such results, and draw some lessons for future work. Section 5 concludes the paper.

2 MULTI-PERSPECTIVE CONCEPT MAPS

As our research focuses on collaboration in learning, it is important to recall that in any type of collaborative work there are two major distinctions, concerning the place and time of the collaboration (Skaf-Molli et al., 2007): co-located vs. remote and synchronous vs. asynchronous collaboration. We can therefore distinguish four different types of collaborative activity; each poses different challenges with respect to interaction.

In the context we have been concentrating on – loosely-structured, possibly lifelong, ubiquitous and generally community-based learning – the collaboration is mostly *remote* and *asynchronous*. Therefore, our research is focused on this type of collaboration, and our experiments were similarly designed within this hypothetical scenario.

The interaction model we designed and tested enables users to work in a group with the goal of building a multi-faceted Concept Map, where multiple perspectives are maintained (a *personal* perspective for each group member, and a *shared* one for the group), focused on a given topic, maintaining conceptual relationships between the two. The goal is in fact to enhance meta-knowledge, by increasing awareness of the existence and value of different perspectives, as well as enabling reasoning on similarities and differences. A key step is therefore being able to relate one's own personal perspective with the shared one, and compare the two.

As already mentioned, in the proposed approach the personal and the shared perspective are represented as two super-imposed layers, with the layer on top being the "active" one, and the layer on the bottom being visible but not editable. Users can select which perspective is active by bringing it to front: elements of the upper, active perspective will appear with full opacity, in color, while those belonging to the lower, inactive perspective will be in grayscale and shaded, as if underneath a partially transparent white sheet. By changing perspective, users not only choose what to see on top, but they also choose a work mode, which will affect the set of available operations, and the consequences they have on the artifact.

In both cases, standard operations on the Concept Map elements (i.e., nodes and arcs) are enabled, namely: *add* (corresponding to the creation of a new element), *remove* (corresponding to the elimination of an existing element), *edit* (corresponding to the modification of an element label or a relation connections), *move and resize* (corresponding to the adjustment of visual aspects of the map, like the dimension of nodes or their position on the canvas).

When performed from the personal perspective, such operations do not affect the shared one. This implies that from their personal perspective users cannot actually edit, move or resize those elements that have been shared, and thus belong to the shared perspective.

When these operations are performed from the shared perspective, their effect cascades on the personal ones; in particular:

- when a user adds an element to the shared perspective, it is also added to her personal view;
- when a user deletes an element from the shared perspective, if it belonged also to her personal view then it is also deleted from it (while a copy of the element remains in each personal view that contained it); it is worth mentioning that, if a user removes an element belonging to both views from her personal perspective, the element is not removed from the shared one;
- when a user modifies an element in the shared perspective, it is also modified in each personal view that contains it;
- when a user moves or resizes an element in the shared perspective, it is also moved/resized in each personal view that contains it.

Moreover users can *share* elements from their personal perspective to the shared one: the effect is that the element is added to the shared perspective; if the element is a relation, and the connected nodes do not belong to the shared view, they are added to it as well.

Finally, a user can *import* elements from the shared perspective into her personal one: the effect is that the element is added to her personal perspective (if the element is a relation, the import is extended to the connected nodes).

The Perspec-Map 2.0 tool implementing this interaction model is an Angular-based application, that makes significant use of the HTML5 Canvas technology to represent the multi-perspective map, and is backed by a lightweight PHP server coupled with a MySQL database. Its users are grouped in "projects", each of them containing a number of maps (called "map works"). Inside a project, users can participate to map works, i.e. they can collaborate together to build shared maps.

A user can edit a map work either in individual or in collaborative mode. In individual mode, she or he will be shown her or his personal perspective in the foreground, with the shared one seen in transparency. Her or his actions will be understood as being performed from the personal perspective. Conversely, in collaborative mode the shared perspective will be in the foreground, and the user's actions will be interpreted accordingly.

Figure 1 shows the map work user interface: for each user, her personal perspective and the shared one overlay; while using it, users can switch anytime from the personal perspective to the shared one, by bringing to front the perspective they are interested in. The elements' color provides a chromatic clue about the perspective in focus, that is anyway made explicit on the upper bar.

In the current prototype, the green color scheme corresponds to the shared perspective: in it, light gray elements are not interactive, as they belong solely to the personal layer. Elements that are in both the personal and the shared view are shown with a dotted pattern. Furthermore, the personal perspective is associated to a purple color scheme: like before, light gray elements are "behind the glass", while in this case objects that belong to both perspectives are light gray, purple edged and uneditable – although they can still be used as relationship handles.

The mapwork user interface offers all the actions that are required by the Concept Map paradigm: concept or relationship creation, editing and deletion; single and multiple element share or import (depending on the actual perspective). Moreover, convenience features, such as map recentering and zooming, are available.

Finally, for each mapwork the tool provides a messages board, to allow users to make notes to each other.

3 EXPERIMENTATION

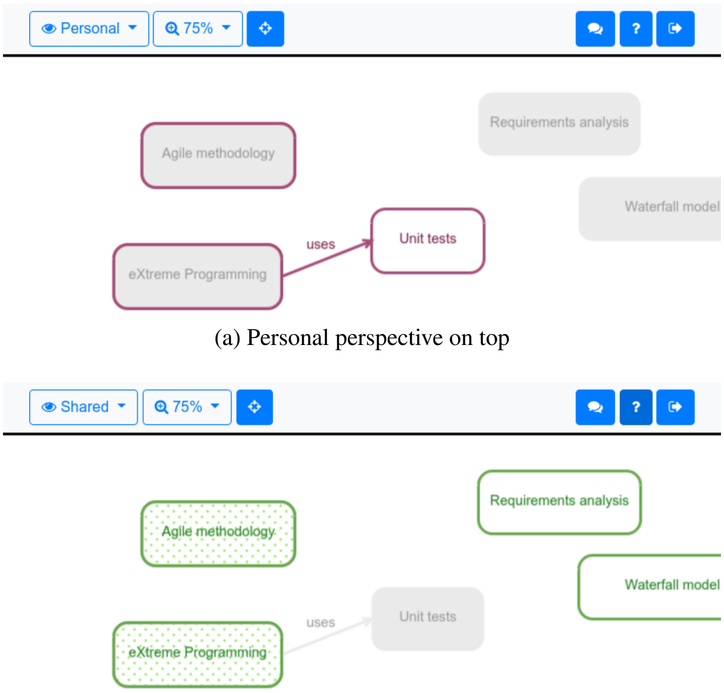
3.1 Setting

The experiments involved fifteen volunteers recruited among colleagues, PhD, graduate and undergraduate students. Ten participants had a background in computer science, two in biology, two in human sciences and one in economics. Three participants had a PhD, three a master's degree, two a master's degree and the remaining seven were undergraduate students.

Our experiments were conducted in three steps, as described below.

Step 1: People were asked to read a six pages introduction to Software Engineering, describing basic concepts and a few more in depth details about the discipline. If needed, a two-page introduction to Concept Maps was also available. Volunteers had a few days to read these two documents at their ease.

Step 2: Every individual scheduled a working session with a member of the supervising team (composed by the authors of this paper). In this session, using the prototype described in the previous section, the volunteer built her personal map of what read in the document on Software Engineering. The working session was supervised by one of us, but without any intervention on the choices made be the individual while developing her personal map. While supervising this work, we discovered that some of them



(a) Personal perspective on top

(b) Shared perspective on top

Figure 1: The map work user interface in Perspec-Map 2.0. Both screenshot show the same map work. The upper screenshot (a) shows the map work in individual mode, with the personal perspective on top, highlighted by solid lines, and the shared perspective grayed out in the background. In the bottom screenshot (b) the situation is reversed: we are in collaborative mode, thus the shared perspective is on top, highlighted by solid lines, while the personal one is grayed out in the background. Thus for example the concept "Unit tests" exists only in the personal perspective of this user, while "Agile methodology" and "eXtreme Programming" exist in both. "Requirements analysis" and "Waterfall model" on the other hand exist only in the shared perspective. The top bar shows which perspective is active, and the visibility (75%) of the inactive perspective, which can be brought down to 0 if one only wants to see the active one. Buttons on the right allow users to open the chat, to see the help page, and to exit from this map work.

had decided to jolt down on paper a first sketch of the Concept Map they were asked to build in this step.

Step 3: After a few days, experimenters were grouped in five groups, and the three individuals in each group were asked to meet in order to build a shared map of what read in step 1, starting from their personal maps built in step 2. People in each group worked together at the same time, but they could communicate between each other only through real time written messages. Even in this step, one of us was present in each session to provide support, again avoiding any intervention in the development of the shared map. During this step, each volunteer was allowed to update her personal map on the basis of what was going on in the development of the shared map.

Every action taken and every message exchanged in both step 2 and 3 was logged in order to be later analyzed so as to understand how people interacted with the prototype and between each other while building their map. Moreover, after the completion of step 3, volunteers were asked to fill a questionnaire regarding their experience during the experiments. The questionnaire was focused on the following:

- the perceived usefulness (toward the learning goal) of the collaboration tasks we asked them to perform;
- the perceived ease with which these tasks were performed in the tool we provided them with;
- their general attitude toward collaboration in concept maps.

Our goal was for the questionnaire to help us understand their subjective point of view, and to distinguish as much as possible whether the obstacles they encountered were due to the tasks themselves or to the tool they were using.

3.2 Results

3.2.1 Subjects Profiling

All fifteen volunteers declared to frequently use computers for studying. Eleven out of fifteen already knew Concept Maps (possibly with another name) and used them; however, only four had an experience with digitally-supported Concept Maps, whereas the others had only used paper-based maps.

3.2.2 Usability Assessment

We administered a standard usability questionnaire[1] in order to check the overall usability of the tool, and to highlight possible usability problems that could affect the results of the Perspec-Map 2.0 functionality evaluation.

In short, this questionnaire confirmed that the Perspec-Map 2.0 application was usable enough; interaction difficulties highlighted in our evaluation results (reported in sections 3.2.3 and 3.2.4) are therefore not directly ascribable to standard usability issues. We report here the answers to the most relevant questions in the following.

Users found the application quite easy to use: On a 5-point scale, *tool usability* scored a mean of 3.71 and a median of 4 (1=low usability, 5=high usability); *tool awkwardness* scored a mean of 1.71 and a median of 1 (1=low awkwardness, 5=high awkwardness). Users also judged the tool simple (without unnecessarily complex features) and quite intuitive (they would not need special assistance to be able to use it). Users also found the application usage easy to learn: *tool easiness to learn* scored a mean of 3.57 and a median of 4 (1=difficult to learn, 5=easy to learn); *learning overload* scored a mean of 1.36 and a median of 1 (1=light overload, 5=heavy overload). Users also found a sufficient degree of functions integration, evaluated with a mean of 2.93 and a median of 3.

3.2.3 Questionnaire Results

The first question (Figure 2) was aimed at assessing, on a 5 points scale, the usefulness of Concept Maps *per-* , in relation to study, regardless of the specific tool or application. **Drawing solo maps** and **comparing solo maps** are both deemed reasonably useful (average 3.71, median 4), with a slightly higher variability in answer on the latter (one user deems comparing maps totally useless, while 4 found it highly useful). Participants were instead divided on the usefulness of **drawing collaborative maps**: although the median is again 4, as for the other two activities, 4 people deem this activity very little or not at all useful.

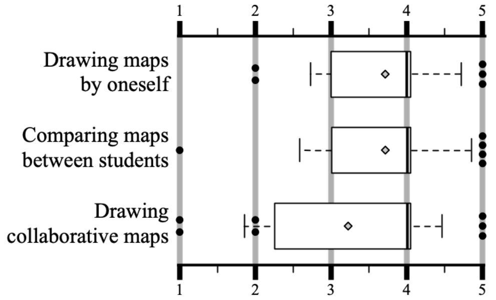


Figure 2: In your experience, how fruitful are the following activities when learning a subject?

The next set of questions (Figure 3) concerned more specifically computer-supported map building and investigated four aspects of the activity the users had to carry out in our experiment: *(a)* building a Personal map, *(b)* building a Shared map, *(c)* the existence and management of common concepts in the two (Personal and Shared) maps, and *(d)* the "differential" representation of the two maps in overlay in order to highlight commonalities and differences.

It is worth noting that, in this experiment, we were not interested in evaluating the quality of the shared map *per se* (Nuninger, 2015; Nuninger et al., 2018), but rather the quality and usefulness of different aspects of the learning process.

In particular, for each aspect *(a)* to *(d)*, we asked our participants to rate both its potential usefulness when learning a subject, and the effectiveness of its implementation in our application.

Concerning *(a)*, i.e. building a Personal Map, the potential usefulness and the effectiveness of the implementation were perceived as good (average 3.71 for the former and 3.86 for the latter, median 4 for both). This result is also consistent with the perceived efficacy of building solo maps shown in our first question (see Figure 2).

The potential usefulness of aspect *(b)*, i.e. building a Shared Map, left the participants quite divided. They however were slightly more positive in this answer, which concerned specifically a computer-aided activity, than they were on the general task of building collaborative maps with fellow students in the previous question (see again Figure 2). On the overall the implementation of this aspect was however seen as only partially effective (average 2.64, median 3).

Concerning aspects (c) and (d), they were both deemed moderately useful to the learning process (av-

[1]The questionnaire is based on the System Usability Scale (SUS) developed by John Brooke at Digital Equipment Corporation. (c) Digital Equipment Corporation, 1986.

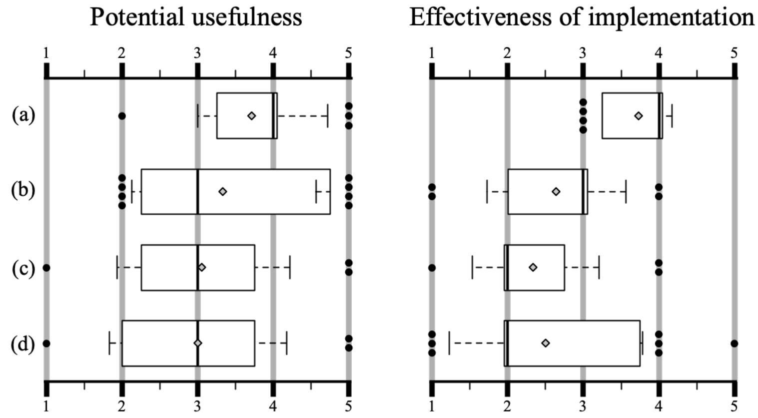


Figure 3: Potential usefulness and effectiveness of current implementation for *(a)* building a Personal map, *(b)* building a Shared map, *(c)* existence and management of common concepts in the two maps, *(d)* "differential" representation of the two maps in overlay.

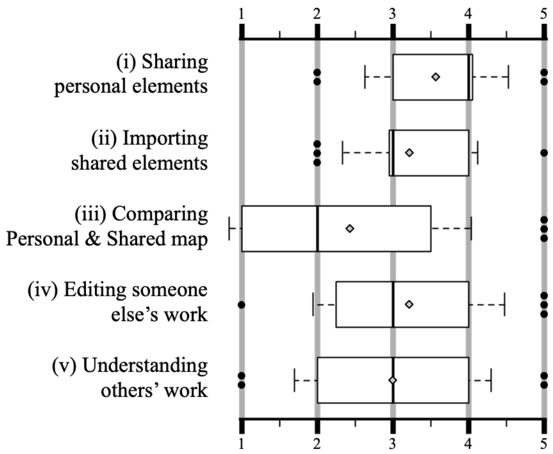


Figure 4: How easy was each of these tasks on a 5-points scale?

erage 3, median 3) for both, with a moderately high variability in answers. The implementation of (c) was perceived as not very effective (average 2.36, median 2) quite consistently by most participants. The implementation of (d) presents similar aggregated results (average 2.5, median 2) but more variable answers, with 9 answers in the "low" range (scores 1 and 2), 4 in the "high" range (scores 4 and 5), and 2 with the intermediate score of 3.

Next we asked our participants to evaluate the ease of the different collaboration tasks. Figure 4 shows the results: tasks *(i)*, *(ii)* and *(iv)* were rated moderately to very easy by at least two thirds of the participants (average 3.57 and median 4 for *(i)*, average and median 3 for *(ii)* and *(iv)*).

Since our experiment revolved around collaboration, we also inquired about how and if the Personal map turned out to be useful during the collaboration. All participants said that the Personal map was useful to some degree. 12 people found it useful to compare their perspective, expressed by the Personal map, with the one expressed by the group in the Shared map. 9 people found it useful to be able to safe keep things that others wanted to delete from the Shared map. Only 2 people used the Personal map to keep some things private, but most did not see privacy as an issue in this context.

3.2.4 Qualitative Observations

In the following we summarize the qualitative observations we collected while users performed the experiments, including explicit comments they voiced aloud. We organize them in three categories:

- **Spatial Organization:** comments and observations concerning the changes in the position of map elements due to the concurrent editing of the two overlaid perspectives (personal and shared);
- **Seeing and Comparing:** comments concerning the impossibility of seeing others' personal perspectives;
- **Verbal Interaction:** comments concerning the availability of tools for verbally explaining one's own actions;

Spatial Organization

- "The position of nodes is important in order to represent concepts";
- "I am uncomfortable with having my personal perspective modified when other users change nodes (their position) in the shared perspective";
- "It is important to me to keep my own alignment of nodes" ;
- "The spatial changes in the shared perspective make my personal one ureadable";

- "Building a shared perspective was disruptive for my personal one, conceptually and spatially";
- "I would like to be able to have nodes in different positions in the shared and personal perspectives";
- "When a shared perspective is very different from the personal one, the overlay may generate confusion";
- "It would be better to be able to choose whether to apply the overlay mode or not";
- "I like the overlay but I would also like to be able to compare the two perspectives side by side";
- (Our observation) some users worked only in the shared perspective: they seemed to be too confused with the personal perspective due to the overlay;
- (Our observation) some users did not work because of many changes by others in the shared perspective made them feel intimidated;
- (Our observation) for some users even small changes brought about by others' work seem to easily generate confusion.

Seeing and Comparing

- "It could be useful to see others' personal perspective and to import parts of them in my own";
- "It could be useful to see everybody personal perspective to decide how to proceed with the joint work; it would also help to understand the others' point of view and learn from them";
- "The app looks more useful to build personal perspectives rather than the shared one".

Verbal Interaction

- "It would be useful to be able to explain to others my own perspective and receive explanations on theirs";
- "Longer visible explanations would be useful";
- "I would like to be able to add notes to nodes in the shared perspective to better define concepts";
- "Longer descriptions would allow to use Concept Maps as effective summaries";
- "Vocal or written chats might be useful to explain concepts";
- "Preliminary discussion could be useful to clarify different approaches";
- "It would be easier to understand (and accept) changes if who is making them could explain what s/he is doing".

4 DISCUSSION

Participants undertook the experiment with an initial positive bias on Concept Maps: according to questionnaire answers (see Figure 2) they believed Concept Maps to be an effective support when learning a subject, and that comparing map with fellow students could contribute positively. As to the fruitfulness of collaborative work on a Concept Map, people started out with mixed feelings, probably due to a difference in learning styles.

Knowing the participants' opinion on the experimental tasks *per-se*, independently from our tool or interaction approach, together with the mostly positive evaluation on the Standard Usability Questionnaire, gives us a baseline to analyze their observed behavior and their remarks, as well as their questionnaire answers.

If we look at the box-plot on the left in Figure 3, we see that all the answers concerning the shared perspective (*(b)*, *(c)* and *(d)*) reflect the same "dividedness" that participants originally had on the idea of collaborating on a map. Comparing the two box-plots in the figure (left and right) we however see that the actual implementation of the shared perspective (on the right) was perceived as less effective than its potential (on the left) would suggest.

In order to better understand this feedback we need to rely on our qualitative observation of the learners' process (Section 3.2.4). Almost all the participants complained about how the overlay of the two perspectives – and the constraint that the common elements should have the same position in both – made their personal perspective "unreadable", as its spatial arrangement was disrupted by the attempt at organizing the shared one. When they tried to rearrange their personal perspective to restore their "meaning", the other group members complained that the shared one had become unreadable in turn. For some people even a minor change was enough to generate confusion.

This showed us that the spatial organization of the concepts in a Concept Map is more significant than we originally thought, sometimes and for some people even more significant than the actual existence of named relationships between the concepts. While spatial organization, i.e. the map topology, is sometimes used to convey a specific meaning (e.g. hierarchical structure, or order of importance), and at least in part reflects the depth of learning, it seems that – at least for our experiment subjects – it also expressed additional, sometimes implicit, sometimes intuitively understood, relationships between the represented concepts. And, since the "shape" of a Concept Map is captured with more immediacy at a glance than the writings on it, it is the shape, i.e. the spatial organization, that turns the graph made of nodes and edges into a *map*, a tool one can actively use to navigate the territory of her or his knowledge.

When the spatial organization was altered by another participant, her/his team members found it difficult to recognize the knowledge under the changed map, and lamented "disruption", "meaninglessness", and "unreadability". The difference among two learners's perspective – and, for the sake of this argument, we can regard the *group* as another learner, different from all its members – seems to lie not so much in the choice of concepts to represent, which were often similar among people dealing with the same learning materials, but in the relationship, both explicit (the graph edges) and implicit (spatial organization).

Of course, a Concept Map can communicate meaning even to readers without knowledge of its implicit relationships. However, if we rearrange another person's map we are tampering with implicit relationships which we are not aware of. In fact, our participants did not complain about the shared perspective being rearranged when they were away, even if they did not always understand what had been done and why. They rather complained about their own personal perspective getting rearranged in the process, due to the overlay restriction that the shared position always "won" over the personal one.

Disrupting a previous perspective in order to accommodate for new knowledge and points of view may well be a formative act, but in order to do so the person has to participate in the break or change reflecting the evolution of her/his understanding. Due to the mostly asynchronous nature of the collaboration we proposed, this was not always possible: participants found the map rearranged, without being able to participate in the process. The textual comments left by the other team members did not appear to help their understanding; some even remarked that they could have related to the "disruption" of the map if it had been rearranged "in real time", with the person making the changes explaining at the same time what s/he was doing and why.

Many participants expressed the wish to be able to see the others' personal perspectives, in order to understand their work on the shared one. Some even said that the most useful aspect of building a shared map was, in their opinion, being able to see other people's perspective to learn from them.

This may suggest that working on a collaborative concept map as a learning task, *in order to better understand a topic* by comparing and merging different points of view, may include two collaboration goals, that are, at least to a certain extent, independent from each other:

1. collaboration *in* concept mapping (emphasis on the process), where people support each other in finding their own understanding, and
2. collaboration *on* a Concept Map (emphasis on the result), where people contribute to a common artifact.

It has been argued by Hattie (2008) that a group-oriented learning activity pursuing only the second goal (i.e. a learning activity where a group is put together with the sole objective to produce an artifact, without being guided to reflect on the collaborative process) is scarcely effective. Then, process-oriented collaboration, where people collaborate in order to reach a personal goal (in this case knowledge acquisition), emerges as a key factor in collaborative learning.

As some of our participants remarked, comparing and importing other people's maps (or parts of) in one's own work can be useful without even needing to work on a shared version. And, even when a group is assigned the task to produce a common map, the process of building it can intertwine with the individual processes, highlighting how personal learning remains the ultimate goal.

Thus the lesson learned is that one of the main challenges is allowing people to compare their Concept Maps, recognizing commonalities and differences.

Our previous work (Goy et al., 2017) showed how juxtaposing two maps with the same concepts in different positions makes for a very difficult comparison. The present experiment, however, showed that the overlay feature did not seem to provide an optimal solution, at least in its present incarnation, as shown by the questionnaire answers in Figure 4.

An open discussion we had with our participants at the end of the experiment suggested that combining these two approaches (juxtaposition and overlay) may allow to gain the advantages of both, at the same time overcoming their limitations. In the combined version, two overlays would be juxtaposed side by side, each with a different perspective on top. Moreover, the spatial organization would follow the perspective on top.

These observations on the importance of comparison tools suggests the need for the design of features specifically supporting process-oriented collaboration. In particular, to name a few: the singling out of recurring concepts, the recognition of common clusters of concepts and relationships, the identification of similar subtopics within different maps, and in general the analysis of both graph structure and spatial organization characterizing the different maps.

5 CONCLUSION

In this paper we have discussed a set of experiments performed on a new prototype developed to investigate a cooperative learning scenario based on Concept Maps, where learners work on their individual perspectives, and are later engaged in team work to build together a shared perspective. In particular, our research focused on a collaboration type where people can work remotely and asynchronously with respect to each other. Learners were called to relate their own personal perspective with the shared one, and compare the two.

Our experiments highlighted some of the dynamics that emerge during the development of a shared perspective of knowledge. Of course, a learner will always have a preferred and most effective way of understanding and representing knowledge s/he is acquiring, but it is important that s/he recognizes that multiple representations are possible. Ideally, s/he should also be ready to reconsider, review, and adapt her/his understanding when others are involved, in the light of their contributions. In practice, our experiments showed that collaboration takes place in a way that is often perceived as messy and difficult to control, where people can be disoriented by actions taken by others. In particular, integrating different perspectives in a way that is understandable by everyone (even to those that do not agree with part of the outcome) has proven to be a complex task. Admittedly, our approach to multi-perspective maps did not take into account all the subtleties and and complexities of this process.

As discussed above, *process-oriented collaboration* emerged as a key element in collaboration when learning. By process-oriented collaboration we mean a collaboration whose goal is not necessarily the production of a shared artifact, but rather helping each other, by exchange and contamination, to build a better personal perspective. This phase of exchange and contamination can of course serve as a preliminary work toward the creation of a shared perspective.

In most collaborative applications this type of collaboration is not taken into account, because the purpose of the applications themselves is the production of artifacts. Interestingly enough, an example of a process-oriented collaborative environment can be found in the field of computer programming. The popular distributed version control system GIT (Chacon and Straub, 2014) supports various types of collaboration; among these, the possibility for different people to extend and expand a set of programs or libraries in various directions, comparing their code and picking interesting elements from each other's work. While GIT also supports the merge of different expansions in a single shared project, it does not enforce it nor focuses exclusively on this aspect. Unfortunately these advanced functionalities of GIT have a quite steep learning curve, and are sometimes difficult to manage even for computer scientists. Our current research direction focuses on designing how to translate the GIT collaboration model (or at least those parts of it that are pertinent to our goals) to the context of collaborative learning by means of concept maps.

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