Paper-based Concept Map: the Effects of Tabletop on an Expressive Collaborative Learning Task

Son Do-Lenh, Frédéric Kaplan, Pierre Dillenbourg
CRAFT, Ecole Polytechnique Fédérale de Lausanne (EPFL)
Switzerland
{son.dolenh, frederic.kaplan, pierre.dillenbourg}@epfl.ch

ABSTRACT

Augmented tabletops have recently attracted considerable attention in the literature. However, little has been known about the effects that these interfaces have on learning tasks. In this paper, we report on the results of an empirical study that explores the usage of tabletop systems in an expressive collaborative learning task. In particular, we focus on measuring the difference in learning outcomes at individual and group levels between students using two interfaces: traditional computer and augmented tabletop with tangible input.

No significant effects of the interface on individual learning gain were found. However, groups using traditional computer learned significantly more from their partners than those using tabletop interface. Further analysis showed an interaction effect of the condition and the group heterogeneity on learning outcomes. We also present our qualitative findings in terms of how group interactions and strategy differ in the two conditions.

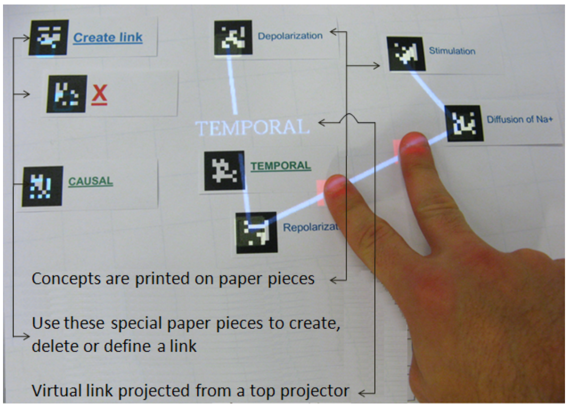

Figure 1: **Participants used the tabletop interface with physical papers and fingertips in our experiment.**

1. INTRODUCTION

An augmented tabletop is a table surface that works both as an input device and a visual feedback display to users; hence, it provides natural and direct mechanisms for interactions. Augmented tabletops offer potential to facilitate collaborative scenarios, in which multiple users work concurrently on the same task or data set.

Various tabletop systems have been proposed with different input modalities. Among other things, users can interact with the virtual objects on the table using mouse or multi-mice [16], their bare hands [33, 4, 21, 9], as well as stylus [17]. In this paper, we focus on tabletop systems that use tangible objects as an interaction input, e.g.[30].

Learning is one area that can greatly benefit from the use of tabletop systems with tangible input. However, there has been a gap between tangible interface designers, engineers and educational scientists who are trying to adopt this technology into learning environments [14]. Although a few studies were previously conducted, e.g. [8, 34, 13], experimental studies have generally failed to keep up with the pace of the developments in tabletop and tangible interfaces.

Moreover, most of the prior empirical research measured participants' performance through tasks that required mainly physical manipulations (home or office layout design) or low-level of information processing (memory retention, basic negotiation)[19, 16, 22, 15]. Thus a general lack of awareness of the effects of the tabletop on learning tasks of a higher level of abstraction, such as comprehension or synthesis, exists.

The goal of this research is to further the understanding of augmented tabletop environments' impact on students' outcomes in an expressive learning task, compared to those using a traditional single mouse interface as a baseline condition. We used a tabletop system [6] that enables students to interact with the system via paper pieces as well as their bare hands (Figure 1) and compared its ability to support students' performance to the traditional computer system. Throughout this paper, we use the term "tabletop" to refer to this augmented tabletop setting with paper-based input as a tangible interaction means.

While paper-based input is not really a tangible user interface, we refer to it as such since they share the main properties: they are graspable and easy to manipulate. We used paper in our task since it is an appropriate material to represent abstract concepts at an iconic level [2] and seemed to be suitable for expressive learning tasks in which students have to externalize their knowledge models to physical artifacts.

The main research question of this paper is the following: "To what extent does tabletop interface affect the collaboration between students and their learning outcomes." More specifically, we explore the relative educational values of tabletop setting compared to single-mouse configurations. The main hypothesis is that groups will benefit from using tabletop interface, having more positive learning outcomes than groups that use traditional single-user interface due to its support for concurrent interactions. Note that we were interested in how the interfaces (tangible tabletop and single-mouse) work as ecologically complete units, and hence the differences may be associated to more than a single factor. That led us to also observe qualitatively the group process, the artifacts created and the collaboration strategy adopted by groups in the two conditions.

2. RELATED WORK

There have been several studies about the impact of tabletop usage on group process and performance. In [24], the authors reported on the effects of group size and table size on the task performance and how the work was distributed. Rogers and Lindley [23] showed that small groups were more comfortable working around an interactive tabletop than in front of a PC or a vertical display. They proposed that tabletops invite people to reach out, and interact with it without feeling embarrassed of the consequences.

As proposed in [22], group process and performance may depend to a large extent on the availability of entry points and on the interaction modes. Concerning the former, according to [19], multiple mice led to individual learning outcomes comparable to single mouse condition in a memory retention task. It is shown that multiple mice solutions are preferred by children over a single mouse [27], encouraging their discussion [11], positively impacting their engagement with less off-task behaviours, more on-screen gestures and leading to more enjoyment of the activity [25]. The authors from [1] present that groups using multi-mice did more parallel work but ended up with a lower perceived quality of discussion than in one-mouse condition (note that these findings are resulted from a study with large vertical display). A recent work from [15] shows that the number of input devices alone does not affect the equity of physical and verbal participation of group members.

The latter - interaction modes - refers to the interaction means that one uses to interact with tabletops. For example, multi-touch, physical object or mouse are different interaction input modes. Ha et al. [8] investigated the effects of different input devices on users' behaviours and concluded that direct input methods (stylus, touch) support a greater awareness of intention and action than the indirect method (mouse). This is confirmed by a study comparing groups of three people using three mice against using a multi-touch table [10] in which the affordances of touch input and body movements resulted in a better awareness about (but also more interferences with) other group members. In terms of task performance, a single user may benefit from using a mouse in unimanual tasks and from fingers for bimanual input [7]. Direct drag-and-drop is considered the best all-around technique in a puzzle completion game, compared to indirect interaction methods on tabletop [17].

However, to date, there has been a lack of evidence about the effects of tabletop on learning tasks with a realistic setup. Most tasks used in previous research were layout design or physical performance tasks and required mainly physical manipulations (e.g. pointing, moving): puzzle-like games [16, 17], home, office, or garden layout [29, 22, 15]. Only a few of them involved a higher abstract level task, such as tasks of scheduling [28], cognitive conflict, basic negotiation [26, 22] or memory retention [19].

Although it is clear that to evaluate educational outcomes is complex and still open to debate, knowing the effects of tabletop on a higher level learning task such as comprehension or synthesis is beneficial for the community. Marshall [14] listed two types of tangible interfaces. The first is exploratory, where the learners interact with a simulation world, trying to understand the underlying principles [31]. The second is expressive, where learners expressing their own ideas and knowledge into physical representations and artifacts [20].

In this paper, we aim to contribute to the literature by exploring the effects of tabletop systems with tangible input in an expressive collaborative learning task where comprehension skill, interactions, physical manipulations and all representational systems (i.e., linguistic, symbolic, numeric, and diagrammatic) of learners are required. We conducted a study with students working side-by-side in groups, first reading individually, and later collaborating together to externalize their knowledge into a concept map with physical papers as nodes and virtual lines as links. The students would have access to different but complementary parts of information about the learning topic. This collaboration mode is known as knowledge interdependence which supports sharing learning resources among partners, and is believed to encourage students to have productive interaction activities such as explanation, or conflict resolution [3, 5].

In addition, we argue that the hardware setup also plays a role in group behaviour. For example, in studies [15, 16, 10], participants had to stand up and hence can move freely during the experiment. This may affect the group dynamics and how participants interact with other members. In our study, we adopted a tabletop system with the projection and camera on top, allowing subjects to be seated comfortably as in usual situations.

3. METHOD

3.1 Task description

We adopted an expressive collaborative learning task in which groups of three people studied a three-page document and built a concept map about a neurophysiologic phenomenon of "neural transmission".

Prior to collaboration, the document was divided into three parts of one page with equal length. Each member of a group was handed a different part, reading and understanding it individually. Then, the group was asked to collaborate in order to comprehend the document as a whole and externalize their common knowledge into a concept map (a map that represents relations among 23 important concepts, 7 or 8 concepts for each part). The relations are of five types: causal, temporal, whole/part, place and property.

The content of the document consisted of information that requires numeric comparisons in order to understand the logical order of neurons' processes. It also describes chemical interactions inside neurons, and hence, asked for translation from linguistic information into symbolic information. The group would also need to externalize their knowledge into a final diagram-like concept map. In short, we hope that this chosen task involved all four representational systems (linguistic, symbolic, numeric, and diagrammatic) that can be present in other typical collaborative learning situations.

3.2 Technical setup

The computers used for the two conditions (Figure 2) were identical: Intel CoreDuo, 2.4Ghz, 2Gb RAM. Seats were positioned in a side-by-side setup with three chairs next to each other across a long side of a table whose size is 1.6m x 1m. This position setting was used to prevent any bias against the computer condition as this is the only setting that can allow participants to perceive all visual cues from the monitor (Figure 2). Visual display sizes remain similar across two conditions: the projection (tabletop condition) is 45cm by 35cm and the monitor real estate (computer condition) is 40cm x 35cm, both in a resolution of 1024 x 768.

3.2.1 Specific setup for the tabletop condition

In this condition participants manipulated (moved, rotated) concepts printed on small pieces of papers which were tracked by a camera on top of the table. The system recognized simultaneous manipulations of tangible paper pieces and superimposed visual feedback directly on the table.

There were special pieces of "paper tools," each of which represented a specific command to the system. For example, one can use a "create-link" paper tool by putting it close to a concept and then moving it close to another. This action is detected by the camera on top, and a virtual link would be projected down the table. Besides using a "delete-link" paper tool, another way to delete links was to use bare hands. Participants simply tapped two fingers on a link, kept them still for two seconds, and the link deleted.

Due to the limitation of our camera, the application was run at 7 frames per second (fps) although the algorithms can run up to 15fps. All subjects stated that they were not bothered by the speed of the program during our pilot studies. The experiments were conducted under controlled lighting condition (indoor, no direct sunlight, illumination varying from 600 to 800 lux). Prior to this study, a series of usability tests had been conducted and major problems had been corrected to the degree that there was no usability problem reported over all three pilot studies.

3.2.2 Specific setup for the computer condition

Besides an LCD monitor, a wireless standard keyboard and 3-button mouse were used to allow participants to pass them on to another without any obtrusive limitation.

(a)

(b)

Figure 2: **The Paper Concept Map experiment: Three subjects using a) Computer b) Tabletop interface**

The computer program used to build a concept map in this condition is IHMC CmapTools version 4.18. It had also been previously used by about 100 students during our other experiments without any usability problem.

3.3 Procedures

Forty-eight university students were solicited and renumerated to participate in the study. They may or may not have had some knowledge about the topic. 23% of the volunteers were female (11 people) and 77% male. 16 groups of three students were randomly formed based on their convenience time. The groups consisted of a female and two male participants in each of the 11 groups; three male participants in each of five other groups. The two experimental conditions were: (1) the tabletop condition, in which the participants used the interface described in section 3.2.1 (hereafter called tabletop groups); (2) the computer condition, in which they built concept map using traditional computer with a single mouse and keyboard (computer groups). Eight of the groups were assigned to one condition and the other eight to the other condition.

After a brief introduction of the purpose of the study, each of the experiments lasted 90 minutes, consisting of seven phases as follows.

Pre-test. Each participant completed individually a 30-item test: six multiple-choice items and 24 inference verification items. A multiple-choice item included four possibilities with one or more possible correct answers. The inference verification items included true or false assertions of a statement. The pre-test consisted of three parts, each part with two multiple-choice and eight inference verification items, related accordingly to the three parts of the document. All questions were validated by domain experts (a neurobiology researcher and a biology teacher) and tested with students in another experiment.

Hands-on practice. Five types of concept relationships were explained to participants. They were then given instructions on how the system worked and allowed to practice until they were familiar with it.

Individual reading. 7 mins. Each member of the group was handed a different page of the document and asked to read it individually. They were allowed to take notes on these pages or in other separate notebooks.

Main task: Collaborative concept-mapping. 28 mins. The group was given 23 important concepts in the document. In the computer condition, those concepts had already been created in the CmapTools program. In the tabletop condition, those were printed on paper pieces. The group was asked to collaborate with any strategy that they wanted, given the ultimate goal is to understand all the concepts and their relationships and be able to externalize their knowledge into a tangible paper-based concept map. There was no reward for finishing early and hence they could take their time in trying to comprehend the content of the document.

Post-test. 7 mins. The participants did an identical test to the pre-test individually.

Extra-task. 12 mins. The group used the other interface (computer interface in case they had used tabletop during the concept-mapping phase and vice versa) to re-build the concept map that they had created in the main task.

Satisfaction questionnaire. Each participant filled out a 7-point Likert-style questionnaire customized from the IBM's CUSQ questionnaire [12], with 1 representing strong disagreement and 7 representing strong agreement, about the interface they used for the main task.

3.4 Dependent measures

We gathered three sources of data: (1) direct observations of group interactions, (2) recorded logs of concept maps created by the groups, (3) pre- and post-study scores (learning performance and satisfaction questionnaires). We used five dependent measures, three at individual level and two at group level.

3.4.1 Individual measures

Individual Learning Gain Total (denoted as IGT). This variable is computed for each participant by taking the difference between the post-test score and the pre-test score. The students having a certain amount of knowledge about the topic would normally score high in the pre-test and hereafter are called the high-expertise students.

Individual Learning Gain from Partners (IGP). This variable reflects the number of questions for which students provided correct answers despite the fact the corresponding information was not included in their partial text. This variable shows how much knowledge from the two partners was shared to this individual.

Self-Reported Interface Preferences. We report here the analysis of participants' agreements on two items in the satisfaction questionnaire: "I like using the interface of this system" and "Overall, I am satisfied with this system".

3.4.2 Group measures

Group Learning Gain Total (GGT). The sum of all three IGT in the group.

Group Learning Gain from Partners (GGP). The sum of all three IGP in the group.

4. HYPOTHESES

We expect that the support of tangibility and simultaneous actions and the nature of tabletop interface will facilitate collaboration among group members and hence lead to more positive learning outcomes. Specifically, we state the following hypotheses.

(H1)(Group). The Group Learning Gain Total (GGT) will be affected by the interfaces. In particular, we expect that GGTs of groups using tabletop interface will be higher than those of groups using computer.

(H2)(Group). Same as H1, but with GGP.

(H3)(Individual). The interface used by groups will affect the Individual Learning Gain Total (IGT) that each individual achieves after the concept-mapping phase. We expect that IGTs in tabletop interface condition will be higher than in computer one.

(H4)(Individual). Same as H3, but with IGP.

(H5,H6)(Individual). The interface used by the group will affect the satisfaction level of each participant. We expect that participants will prefer to use the tabletop interface (H5) but will be more satisfied of the computer interface due to their familiarity with it (H6).

5. RESULTS

(H1). The interface had no significant effect on the Group Learning Gain Total. A t-test found no difference between GGT in two conditions, $t(14) = 1.24, p > .05$ two-tailed, though computer groups gained higher on average ($M = 25.63$ vs $M = 21.88$ for computer and tabletop groups respectively).

To look for an explanation of the rejection of H1, we used a post-hoc factor called "group discrepancy" that is the standard deviation of the pre-test scores from all three group

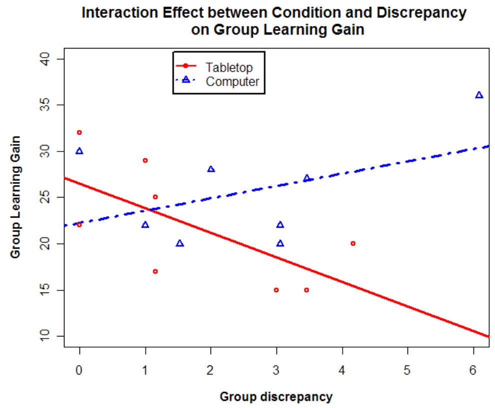

Figure 3: **High-discrepancy groups scored less in Group Learning Gain Total in the tabletop condition compared to those in the computer condition.**

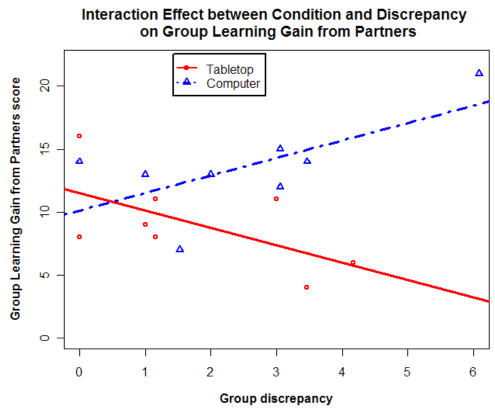

Figure 4: **High-discrepancy groups learnt less from their partners in the tabletop condition compared to those in the computer condition.**

members. We formulated a multiple linear regression of the Group Learning Gain Total GGT as the response variable on the condition factor x group discrepancy. There is strong evidence that GGT is related to the interaction between condition and group discrepancy (and not to any of them), $F(1, 12) = 5.74, p = .03$.

Figure 3 shows that when group discrepancy stretches, the group learning gain increases for groups using computer (dashed blue line), and decreases for groups using tabletop interface (solid red line). It indicates that the condition impacted the group learning gain differently according to their variance in pre-test scores.

(H2). Computer interface groups had significantly greater score in Group Learning Gain from Partners (GGP) than tabletop interface groups. This surprising finding suggests the rejection of H2. In the computer condition, the GGP averaged 13.63 points, compared to 9.13 points in the tabletop condition, a significant difference confirmed by t-test, $t(14) = 2.40, p < .03$ two-tailed.

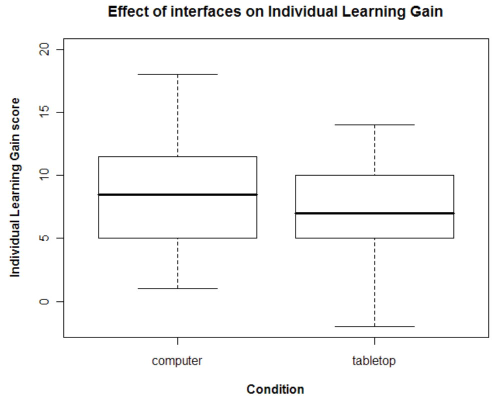

Figure 5: **There is no significant effect of the interface on Individual Learning Gain Total.**

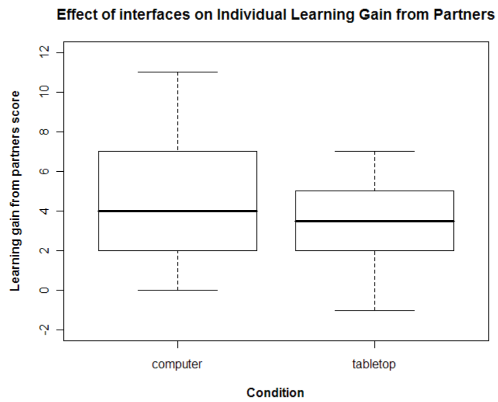

Figure 6: **There is no significant effect of the interface on Individual Learning Gain from Partners.**

An interesting explanation for this difference is found when we fitted a multiple linear regression model with GGP being the response variable; the condition factor and group discrepancy being two predictor terms. The fitted regression model indicated that when factors are controlled, it is the group discrepancy and the interaction between group discrepancy and condition that correlated with the GGP, not the condition itself.

Further analysis showed that the interaction between group discrepancy and condition is a significant predictor of GGP, explaining 57% of total variance in GGP ($R^2 = .57, F(2, 13) = 8.59, p < .004$). Group discrepancy alone had no correlation with GGP ($R^2 = .04, p > .05$). The condition factor had a significant correlation with GGP, but could explain only 29% of its total variance ($R^2 = .29, p < .03$) and should not be considered as the only correct predictor. As shown in visualization of the interaction effect (Figure 4), when the variance in pre-test scores among three group members increases, groups in the computer condition learned more from their partners (dashed blue line), whereas this outcome decreases for groups in the tabletop condition (solid red line).

(H3). The interface used by groups had no significant effect on the Individual Learning Gain Total IGT that each participant achieved. When using computer and tabletop interface, each individual scored in the IGT respectively on average 8.54 points and 7.29 points (Figure 5); not a significant difference: $F(1, 45) = 1.12, p > .05$.

(H4). The interface had no significant effect on the Individual Learning Gain from Partners IGP that each participant achieved. Participants who used the computer interface achieve a IGP score of 4.54 on average, which is higher than those who used tabletop interface averaged 3.04 points (Figure 6). However, this divergence in IGP was only marginally significant, $F(1, 45) = 3.29, p < .07$.

(H5,H6). The interface affected participants' agreement about the preferred interface, but not the overall satisfaction level.

Participants agreed significantly more strongly with the statement "I like using the interface of this system" for tabletop interface (5.78 in average) than for computer interface (4.96 in average). Hypothesis H5 was accepted and confirmed by a Wilcoxon sign-ranked test, $W = 372.5, p = .036$.

There was no statistical difference in the agreement level for two conditions with the statement "Overall, I am satisfied with this system" ($W = 219, p > .05$), thus H6 was rejected.

6. OTHER FINDINGS

6.1 Performance-preference paradox

When exploring the data in the tabletop condition, we found an interesting issue (shown in Figure 7). It indicates that participants who scored low in the pre-test agreed more with the statement "I like using the interface of this system" than those who scored high (mixed linear regression, $df = 14, F = 22.34, p = .0001$).

This finding was replicated when we checked the pre-test score against the agreement level on the statement "Overall, I am satisfied with this system". The fewer correct answers the subjects made during the pre-test, the more they were satisfied by the tabletop interface ($df = 15, F = 9.18, p < .009$). This result is coherent with the so-called Performance-preference paradox in [18]. We did not find the same effect with computer interface.

6.2 Collaboration strategy and group process

6.2.1 *Collaboration strategy*

At the beginning of the experiment, five of the eight groups (called cluster A) in the computer condition started the concept-mapping phase by explaining their own texts to their partners. This was explicitly suggested by a group member, as in this excerpt.

```
S1:  Can we talk just fast to summarize a little?
S2+S3:  Yeah.
S1:  So we can.  Do you want to start S3?
S3:  I think there is an order in the texts.
S1:  I don't know.
```

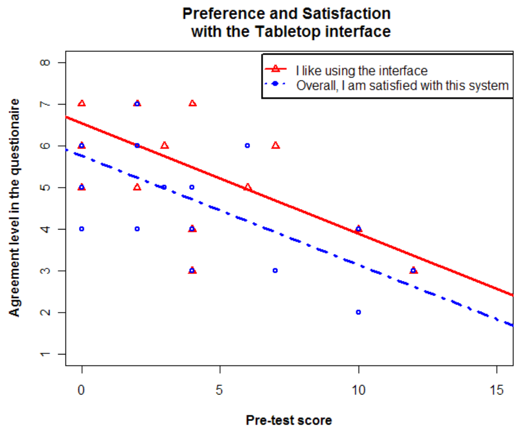

Figure 7: **The low-performing students were more satisfied and preferred using the tabletop interface than the high-performing ones.**

```
S3:  I don't know what 'resting potential' is...
S1:  Maybe I start.
S2+S3:  OK
(S1 starts explaining his part)
```

After that, they would go on to build the concept map collaboratively. The other three groups (cluster B) started by working together right away with on-screen manipulations intertwined with explanation along the way.

In the tabletop condition, the strategies involved a mix of explanation, individual work and group work. Three out of eight groups (cluster C) started off by taking turns to explain their texts, then working collaboratively with some periods of individual work. Five groups (cluster D) started without explanation: two of which (D1) followed a strategy similar to cluster B but intertwined with many periods of individual work; the other three groups (D2) doing parallel physical manipulations individually right from the beginning.

Out of the three groups in cluster D2, one group kept on working individually without talking much with each other until the end of the experiment and the two other groups stopped after a few minutes of doing this individual work to explain the texts. The excerpt below demonstrates this latter situation when they realized after 4 minutes of parallel manipulations they should collaborate more.

```
(after doing individual work without much progress)
S2:  It's not going to be easy...
S2:  We should start by an explanation.
S1:  Yes.
S3:  It's difficult.
(S2 made a gesture to tell S1 to start explaining)
```

6.2.2 *Roles assignment*

While participants were assigned to specific contents, explicit roles for executing the task were not assigned. Video analysis showed that people assigned roles either implicitly or explicitly. In the computer condition, this was clearly the case. Very often, the person who sat next to the keyboard or mouse would be the one to use it. Generally, the subjects who sat to the right of the monitor often were the ones who used the mouse; the subjects who sat in front of the monitor were the ones who used the keyboard. Any group member who wanted to do something would propose it out loud and then wait for the "responsible" members to carry out the real action. We observed that in four out of the eight groups the participants who were responsible for handed the mouse over to another, and no group changed the keyboard.

In six out of eight groups, there was a "leader" who emerged. They were both high-expertise students who suggested to the two others what to do and dominated the whole conversation. Quantitative analysis showed that there is a strong correlation between expertise and speaking time (Pearson's $r = .28, df = 46, p = .048$).

In the tabletop condition, there was less evidence of role assignments. However, in cases where there was a high-expertise student in the group, that person would dominate the conversation at the beginning of the experiment when the group members were explaining the texts to each other and would fade out gradually towards the end. This was likely because all members had something in front of them to do and the "leaders" failed to impact the others' behaviours like in the computer condition.

6.2.3 Group process

We observed that groups in the tabletop condition shifted back and forth between parallel mode, i.e. people working individually simultaneously, and collaborative mode, i.e. people working in collaboration. On the other hand, groups in the computer condition worked closely together from the beginning to the end of the experiments.

Because tabletop interface allows simultaneous manipulations, we found that there was an appearance of parallel working periods of some sort in all the groups in the tabletop condition. These periods could involve each group member creating, defining or deleting links separately, or two members collaborating with one another to perform a task while the other doing another action.

However, this process may not necessarily be considered productive: sometimes they spent too much time working individually with it rather than really communicating with their partners, like in the following extract:

```
S3:  'Channels' opening'.  Is that what you have?
S1:  (building her own links) What?
S3:  'Channels' opening'.  I think there is a way to
create a link.
S2:  (more concentrated on building his links, ask-
ing without looking up) With the channels' opening?
S3 stops asking in frustration.
```

In the computer condition, these concurrent actions happened occasionally, but since there were only a mouse and a keyboard, participants generally worked together. For example, the group that scored the highest scores in both measurements (GGT and GGP) started the main task by taking turn to explain their own texts, and then collaborate to build the concept map. In the course of collaborating, all questions were addressed to the group as a whole. They also asked their partners to confirm every time a link between two concepts was created.

6.3 Amount of speech

Since each group member read a different part of the document, it was crucial that they explain their text to the partners in order to build the whole concept map. Hence, we hypothesized that the amount of speech would have a good contribution to the learning outcomes. We coded all the videos to count the time spent speaking about the contents of the texts and concept map-related issues.

Contrary to our predictions, there is no correlation between the amount of speech about the concept map with the learning gain and learning gain from partners in both individual and group level (Pearson's and Spearman's correlation coefficient calculations with $p > .05$).

However, video recordings of the three groups that scored best and worst and second worst in learning gain showed that the amount of speech in these groups did differ. In the best group (computer condition), the total amount of speech contributed by each member respectively was 208 seconds (11% total time of the main task), 488 seconds (24.8%) and 308 seconds (15.7%). Interestingly, the member who talked the most (who also scored high in the pre-test) got the lowest learning gain (8 points), and the one who talked the least got the highest learning gain (15 points).

As predicted, we found that the worst group (tabletop condition) did not talk much. Nevertheless, the amount of speech from the group was so low that we decided not to analyze their data, rather choosing the second worst group for more useful information. The members of the second worst group spoke less than the best group, for a total time of 240 seconds (14.1%), 151 seconds(8.9%) and 105 seconds (6.2%), respectively.

In fact, individually, participants spoke slightly more about concept map in the computer condition than in tabletop, $t(46) = 1.78, p = .08$. However, at group level, there is no difference according to a Wilcoxon test, $W = 43, p > .05$.

6.4 Concept maps

We analyzed the impact of interfaces on the concept maps that participants created during the task. In the computer condition, participants created concept maps with an average of 23.88 links, while in the tabletop condition, concept maps had 24.88 links on average, not a significant difference by t-test, $t(14) = -.52, p > .05$.

When checking the number of concepts that are connected to four or more other concepts, we found that groups using computer created significantly more high-degree nodes than groups using tabletop interface (Wilcoxon test, $W = 56, p = .01$). This implies that the number of links in concept maps created by groups using tabletop interface were more equally distributed to each concept, rather than concentrated on a few highly connected nodes like in the computer condition.

The numbers of "interlinks", i.e. links connecting a concept of a group member to that of another one, do not differ statistically across conditions ($t(14) = .7, p > .05$), although groups using computer created more interlinks ($M = 8.12$), compared to 7.00 in the tabletop condition.

7. DISCUSSION

The nature of collaboration with different tabletop configurations and with different task types may vary very much. In this study, we explore the effects of tabletop interface with tangible input on an expressive learning task of high level of abstraction that requires comprehension and explanation from students. Although the number of participants is limited, we believe that the findings are still useful to inform some implications for practice.

At group level, there was no significant benefit of using tabletop interface compared to using traditional computer in the measurement of "Learning Gain Total". In the other measurement, "Learning Gain from Partners", there was a significant effect in favor of the computer condition. Groups using computer interface had statistically greater scores in this measure than groups using tabletop interface.

We also observed a significant correlation between both GGT and GGP with the interaction of condition and group discrepancy. Groups with more variance in initial knowledge among members learned more in the computer condition but struggled in the tabletop condition. In other words, tabletop interface is considered harmful to some extent for groups whose members do not have equivalent knowledge about the topic. One might suggest that this effect might be because with tabletop setting, the high-expertise students failed to dominate the conversation as much as with computer, and suffered from learning incorrect information from their partners while busy doing individual manipulations.

Contrary to our predictions, there is no significant correlation of the amount of speech about the concept map with the Learning Gain Total and Learning Gain from Partners at both individual and group level. Nonetheless, participants in our study spoke slightly more in the computer condition and the qualitative analysis shows that it might still have some effect on learning outcomes. This is somewhat in line with the studies [22, 1] in which the authors found that the single point of access with mouse and keyboard in some way enforces more verbal interaction among group members. It can be argued that the best group's members who were in the computer condition scored higher in the learning gain measure since they had a higher amount of speech, questioning and confirming the new knowledge from their partners.

Another possible explanation for the higher scores in the computer condition is that tabletop interface provides a twofold effect. On one hand, as also suggested in [15], it allows more freedom and equity in interaction: simultaneous manipulations with the system from multiple users. On the other hand, it contributes to the lack of verbal collaboration which is considered beneficial for learning activities [32, 5] or even decreases the quality of discussion [1]: each one focused on one's own actions, and looking down to the table, instead of discussing with the group. Group members may have misunderstood or learned incorrect information without having a chance to confirm with their partners since they were busy doing their own manipulations on the tabletop.

Another finding is that low-performing students in the pretest were more satisfied of the tabletop interface and preferred it to computer, in comparison with high-performing ones. This finding is similar to the research presented in [18] in which the authors found low-performing students were less aware of the tools they needed to perform well. They may also have been more attracted to the belief that technology would compensate for their performance deficits, or perhaps make their work easier.

Our observations reveal that there were certain differences in concept maps created with two interfaces. The number of total links and interlinks did not vary significantly, but using tabletop interface resulted in concept maps with a higher distribution of links across the map while participants using computer created a map with more highly connected nodes. It remains unclear how this affects the learning outcomes and how this happened. For the latter, it could be because the better distribution of concepts and physical actions across the table among group members in the tabletop condition. It was also likely in part due to the presence of a leader who dominated the conversation in most of the computer groups. This finding is somewhat consistent with a large display study [1] where the authors suggested that parallel streams of activity with multiple inputs make it more difficult for a group member to influence group outcomes.

The collaboration strategies followed by the groups differed depending on the conditions. Collaboration in the tabletop condition involved a mix between explanation, group work and individual work with group members shifting back and forth between these modes. Collaboration with computer is much more coordinated with the group having an implicit work division, e.g. a person "using mouse to create link" and a person "typing on the keyboard". This can be explained by the proposition that people are usually comfortable working at arm's length [24]. There are implicit "private" spaces that their partners were reluctant to reach into.

8. LIMITATIONS AND FUTURE WORK

It is clear that there are many tabletop interfaces, from a single-user tablet PC used with a single stylus to a multitouch table. Our study only took into account a specific multi-user technology, and used it to compare with the traditional computer as a complete unit. We were interested in how the high-level tasks are performed with the traditional computer as a whole and with the multi-user tangible interface as a whole. While some of the factors such as the display orientation, the input methods and the input entry points have been controlled in other experiments [23, 22, 15, 8], it is difficult to separate them in our study which is more of an observational study.

It turned out surprisingly from our study that a combination of these factors involved in the study had a negative effect on learning outcomes. However, the collaboration in the tangible condition seemed to be qualitatively better, providing a wide range of collaboration styles and group process. Our future work will be to separate out those factors and observe their respective contribution to the outcomes and the interactions. Further verbal interaction analyses in this study may also give us more insights into how the group members collaborated and exchanged information with one another.

Table 1: Differences in process variable observations

Process variables	Tabletop condition	Computer condition	Note
`Amount of speech about concept map`	Individually, participants spoke slightly more about concept map in computer condition than in tabletop		t-test, $t = 1.78, p = .08$.
`Nodes' density`	Groups using computer created significantly more high degree nodes than groups using tabletop interface		Wilcoxon test, $W = 56, p = .01$.
`Collaboration strategy`	Mix of explanation, individual work and group work	a) Explanation then group work or b) Intertwined explanation and group work	
`Roles assignment`	More equity in physical manipulation. Leaders did not dominate that much	High division of labors with mouse and keyboard. Leaders dominated the conversation throughout	
`Group process`	Often shifting back and forth between parallel work and collaboration work	Close collaboration with occasional periods of individual work	
`Satisfaction`	Low-performing students were more satisfied and preferred to use tabletop interface over traditional computer		

9. CONCLUSION

On the one hand, our findings showed that if the learning goal is to have knowledge transferred effectively among group members in a high level task requiring comprehension skills, especially in groups with high discrepancy, the traditional computer's single mouse interfaces still have their benefit. According to our results, in this condition, participants may not have many individual manipulations and may be dominated in conversation by an emerged leader, but still gain knowledge from their partners productively.

On the other hand, it is worth remembering that knowledge construction cannot be determined only by such a sample size and pre- and post-tests like those used in our study. As we stated at the beginning of the paper, to evaluate educational outcomes is a complex and still open issue. Hence the results of our study should be interpreted with the particular focus of the study in mind: expressive task type, tangible input, short-term knowledge comprehension testing. Other factors include the specific knowledge domain, projection size, group size. It is clear that not only a single factor, but a combination of them affected the learning outcomes in our study. We list some observed contrasts between two conditions in Table 1 that might have played a role in the difference.

Knowledge transfer from their partners is not always the only desired outcome. In general, we believe that media has no intrinsic effects, rather how they are used for a specific task is crucial. We have shown qualitative findings that describe the dominance of the more knowledgeable peer in the computer condition, and the richness of interaction styles and strategies in the tangible condition. Similar to some other researchers [15, 22], we argue that if it is a task where more concurrent physical manipulations are important, tabletop should be adopted since it brings about the speed, the variety in styles, and more equity in interaction.

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