DESIGNING PHYSICAL-DIGITAL WORKSPACES TO SUPPORT GLOBALLY COLLABORATIVE WORK

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ABSTRACT

This paper examines some aspects of physical-digital workspaces, focusing on multi-user, multi-touch technologies and how different workspaces impact collaboration. We introduce the concept of globally collaborative work. We chose to use case studies completed by groups of students in an engineering course to test different workspace modalities: the use of a large multi-touch table top in conjunction with a multi-touch board (vertical), the use of tablets with the multi-touch board, and finally the multi-touch board alone. The evaluation criteria are based on modes of interaction which emerge during globally collaborative work sessions: individual work, communication, coordination, cooperation and collaboration. We hypothesized that the workspaces would influence collaborative activity, expecting to see higher rates of collaboration in the table top environment than in the other two modalities studied. However, results showed less co-building and more cooperative work, as students divided their work and later attempted to negotiate a coherent product built on individual contributions. Lastly, we share a few design recommendations based on these results.

Keywords: Collaborative design, Workspaces for design, Human behaviour in design

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1 INTRODUCTION

The principal question for our research, which we propose to address only in part in this article, revolves around understanding how physical-digital workspaces can influence the emergence of collaboration and the development of collaboration skills in the classroom. Departing from the notion that competencies are developed and can be observed through action (Pastré, 2004; Samurçay & Rabardel, 2004; Tardif & Dubois, 2010), this paper classifies various physical-digital workspaces and proposes an evolutive model for understanding and analysing what we propose to call *globally collaborative work*. We explore how variations in workspaces influence collaborative processes, whether people tend to divide the work amongst the group members, work together on tasks or some combination of the two. To this end, we review research on the use of tactile, especially multi-touch, technologies for collaborative activities and go on to describe experiments in which we compare different workspace modalities, analysing results based on the emergence of 5 modes of interaction: individual work, communication, coordination, cooperation and collaboration. Our research found that the characteristics of the workspace available to a group has a greater influence on the form of the collaboration than does the activity itself.

2 TACTILE AND TABLETOP TECHNOLOGIES: PHYSICAL-DIGITAL WORKSPACES

Increased interest in collaboration skills and work styles for engineers/designers has led to increased interest in CSCWD (Computer Supported Collaborative Work in Design) tools. Multi-user interactive tables represent one such example, with researchers across various domains attempting to understand how these table top environments influence user behaviour.

Topics investigated by researchers include table size, Human-Computer Interfacing, device orientation, etc. (Buisine, Besacier, Aoussat, & Vernier, 2012; Homaeian, Goyal, Wallace, & Scott, 2018; Mercier, Higgins, & Joyce-Gibbons, 2014; Ryall, Forlines, Shen, & Ringel Morris, 2004; Zagermann *et al*., 2016) Some researchers have also begun integrating vertical surfaces. For example, Rogers and Lindley (2004) conducted experiments to examine how the physical orientation of different work surfaces impact collaboration. They identified several differences in work between vertical and horizontal displays during coordination and collaboration activities, finding that having a horizontal display encouraged group members to "work around it in a socially cohesive and conducive way" (Rogers et Lindley, 2004)." Contrariwise, working with a vertical display rendered the interactions more "socially awkward," often decoupling individuals working at the board from the rest of the group (Rogers & Lindley, 2004). Meanwhile, another study using both horizontal and vertical surfaces at the University of Technology of Compiegne found that the different surfaces facilitated different types of activity: tables were most useful for divergence and the generation of ideas, while vertical surfaces helped in decision making processes (Jones, Kendira, Lenne, Gidel, & Moulin, 2011). These studies have concluded that size and orientation of work surfaces impact behaviour in specific ways (especially socially), however the impact of work surfaces on collaborative processes merits further investigation.

Based on these studies and observations from preliminary research phases, we identify four types of work spaces, along two axes: individual/collective and public/private. The individual/collective axis refers to the number of individuals who can interact within the space. For example, smartphones, tablets and computers represent an individual activity space, where tables can allow for a collective usage when equipped with multiuser software. The public/private axis refers to the number of users who can see the activity: visibility & readability vs. the possibility for interaction. Private spaces are limited to a single person, where public spaces are visible to all present actors.

While the other spaces can be achieved with a single instrument, the collective private space requires a specific juxtaposition of an individual private space with collective public space inside of the same tool. Few examples exist. It can, however, be observed when an individual searches his or her own personal documents while using a shared surface. Lissermann, Huber, Schmitz, Steimle, & Mühlhäuser (2014) demonstrate another example of such a workspace by pairing a multi-user (collective public) table top over which a private space is projected using glasses (individual private).

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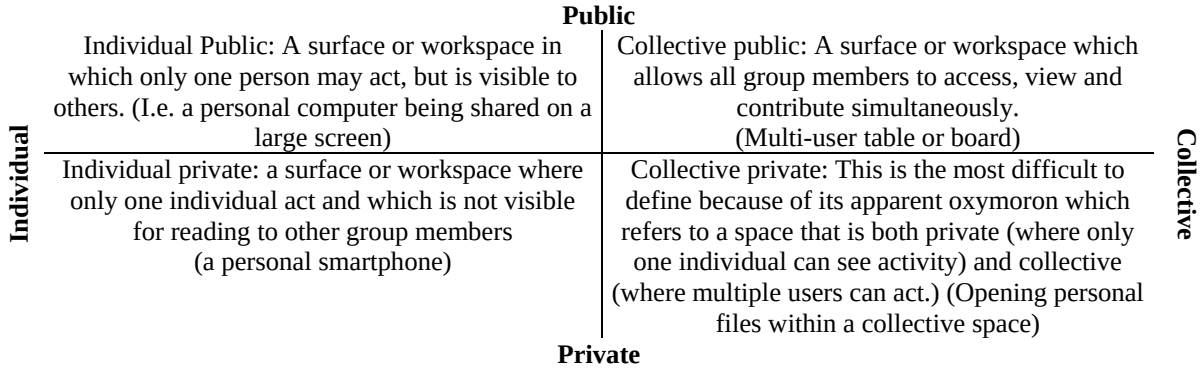

Figure 1: Physical digital workspaces

We can imagine these spaces as being dynamic, their identification being based on a variety of factors, such as, sharing settings (such as a folder in a Google Drive shared with a sub-group, but not the entire group), a juxtaposition between a designer's intended use and the actual use of the workspace, or social dynamics which may influence that use.

3 AN EVOLUTIVE MODEL OF COLLABORATION

In order to better understand collaboration during group work, we chose to examine its expression through various behaviours, including language acts (Soller, 2001), gestures and movements (Zumbach, Schönemann, & Reimann, 2005). During our initial research phases, we observed students during group activities, both with and without technology supports. We found that while researchers in CSCL/CSCW, and other fields, have sought to differentiate between collaborative and cooperative work/learning (Stahl, Koschmann, & Suthers, 2006), these delineations only seem to make sense on the scale of a short, well defined activity. Student behaviour does not necessarily fall into the neat lines that have been drawn. Nor, when looking at the work performed, do the definitions necessarily fit. Rather, we have observed that work can be *globally collaborative*. That is to say that the end result may be collaboration, but the behaviours that can be observed during *globally collaborative work* include cooperation, individual work, presentation of that work etc. As such, we propose five modes of interaction which attempt to break down *globally collaborative work* into its finer details: individual work, communication, coordination, cooperation & collaboration. In the section below, we define each of these and then go on to present the targeted production of the different modes as well as some elements regarding and the complexity of the interactions that make them up. See Figure 2.

Individual work can be understood as those moments when an individual retreats from the group in order to reflect and construct their ideas (Teasley & Roschelle, 1995), as well as work performed on tasks with which he/she was entrusted by the group.

Communication refers to the transmission of a message from one point to another via a given channel (Shannon, 1948). This mode of interaction allows individuals to introduce new information into the group, creating the point of departure for a shared vision (Teasley & Roschelle, 1995). Communication can take the form of providing information orally, via messaging (email, chats), longer presentations or adding written notes into shared spaces.

Coordination denotes the organization of activities (events, behaviours, tasks and actions) in such a way that they balance and synchronize (Baker, 2015). As such, coordination is seen in different actions of structuration, organization and division of tasks in order to facilitate cooperative work. According to Baker, coordination can also extend to the point of "coordinating representations," (individual representations of tasks), approaching the definition of collaboration used by a number of researchers in CSCL (Baker, 2015). However, we propose a different vision of the work of "coordinating representations", placing it within the area of cooperative work.

Cooperative work is produced following individual work, often preceded by the division of tasks amongst group members (Baudrit, 2007; Bruffee, 1995; Panitz, 1999). Once the work on these tasks is put into place, cooperative activity appears as the pieces are put back together. This pooling of individual work necessitates negotiation and new efforts to synchronize each actor's representations; it is in these efforts of reconciliation that cooperation can be observed.

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Finally, **collaborative work** designates the co-elaboration, co-evolution, or co-construction of tasks and ideas by participants in order to reach a common goal (Baker, 2015; Dillenbourg, 1999; Henri, 2015; Teasley & Roschelle, 1995). The most fundamental difference between collaboration and cooperation relates to how the production is constructed: together (in the case of collaboration), to the point that it is difficult to determine who contributed what; separately (as in cooperation), followed by integration. In order to identify and differentiate these modes of interaction, the context and sequence must be taken into account (i.e. idea > elaboration > modification > elaboration, etc...)
All or some of these modes of interactions are mobilized, in non-linear a manner, by participants during work sessions and over the course of long-term projects. Some groups divide into sub-groups, which then follow similar patterns within themselves. The project, environment, individual competencies, methods and tools used, intervention or instructions given by a teacher or animator, etc. influence the behaviour of participants and as such, the emergence of these modes of interaction.

	Targeted production	**Complexity of interdependency**
Individual work	The individual works through reflection, aiming at the construction of ideas and meaning with the goal of eventually re-introducing the elements he judges useful for the group.	Factors such as individual personalities and group cohesion (such as psychological safety (Edmonson, 1999)) can influence how individual work is completed. For example, in terms of personality, an introvert (C. G. Jung, 1946) may produce written notes, where an extrovert may narrate his activity and readjust based on the reactions of peers, using them as a sort of mirror (J. H. Jung, Lee, & Karsten, 2012).
Communication	Each member of the group has different information or skills. It is necessary to present them in order to resolve problems. As such, the objective of this mode of interaction is to introduce new information into the group.	Since no member has all of the necessary information to complete a task, it is necessary to work with others to achieve results. The capacity of each individual to present his work, ideas and arguments is essential. It is also vital that this information is received.
Coordination	The group must choose how it will work together or divide work between individuals in order to progress. In collective sessions, coordination discussions allow for the definition of tasks and identification of responsibilities.	Each person (or sub-group) has a specific objective. The division of work risks putting these objectives in tension with those of other members. Success depends upon the clear definition of tasks and planning for their completion.
Cooperation	The division of tasks (such as the decision to have individuals writing their ideas separately for a brainstorming activity) necessitates a pooling of work that was completed individually (or in sub-groups). This combining requires the establishment of consensus after having considered the information, opinions and arguments of each member.	In order to be successful, it is necessary to include all group members in the negotiation. There is a risk that the conversation may be dominated by some participants, while the others are withdrawn, which may compromise the consensus.
Collaboration	The group works together to co-produce: a shared vision of concepts, of a problem, solutions, strategies, a new product which is concretized through writing, models, reports or presentations, etc.	The success depends upon the capacity of the group to co-construct problems, objectives, solutions and results in a way that includes all participants. The risk being that one individual could take over, compromising the collaboration.

Figure 2: Complexity and interdependencies of modes of collaborative interaction (Tucker, Gidel, & Villemonteix, 2018)

4 EXPERIMENT OVERVIEW

4.1 Participants

The population studied consisted of 3 groups of engineering students, which varied in size from 4 to 6 participants, this is due to absences or substitutions which occurred over the normal course of the participating class. Participant ages ranged from 18 to 34, with an average age of 21 years old. These groups were part of a course using the platform to study functional analysis tools using a case study method. Students were chosen as the primary participants because of the project's overall goal, to understand and facilitate the development of collaborative competencies in the classroom.

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4.2 Materials

In this section, we present the technology that was used during the research, which allowed examination of various combinations of physical-digital workspaces and analysis of their influence on the emergence of collaboration. The tool used is called the TATIN system (Table Tactile INteractive) (UTC, 2018). Developed over a series of research projects at the University of Technology at Compiegne, the hardware and software systems were designed to facilitate collaboration during design. Today, UTC has 5 sets of the system, consisting of a large tactile table (horizontal) and board (vertical); each is equipped with a software suite that allows for a simultaneous interaction of multiple people on the same surface.

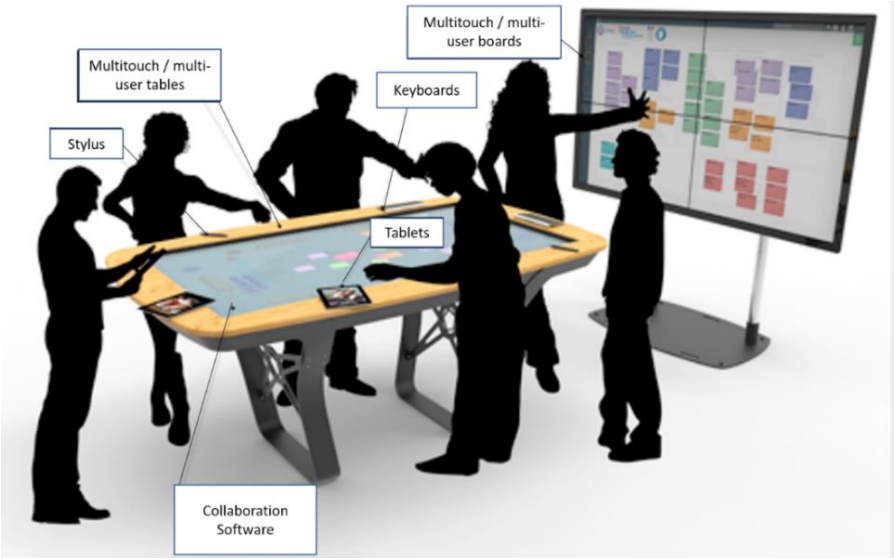

Figure 3: The Tatin system

The tables have an UHD screen (3840x2160 pixels) at 84" (1860x1046 mm), allowing a space for each individual user at the table, making reflection, research and note taking with a virtual keyboard possible within a common space. The board also has an UHD screen (3840x2160 pixels) at 86" (2042x1151mm). This space is designed for the sharing and organization of information produced by participants. In addition, any device with an internet connection and browser (smartphones, tablets, laptops) can connect to the session and be used for individual production of written notes, drawings, images, etc.

Research was conducted on three different modalities (Figure 4), each using the Tatin system, but with varied work surfaces. The first, consists of the multi-user, multi-touch table (individual public space) and board system as described above (collective public space). The second consists of single-user tablets (individual private space) and the multi-user, multi-touch board. The third modality is the multi-user, multi-touch board alone. The digital tables for modalities 2 and 3 were deactivated and covered to allow participants access to a standard table. Prior to the three sessions, students completed a similar task without the use of technology. Students had access to a whiteboard with markers, pens and paper. Participants were asked not to use technology apart from those provided during any of the work sessions.

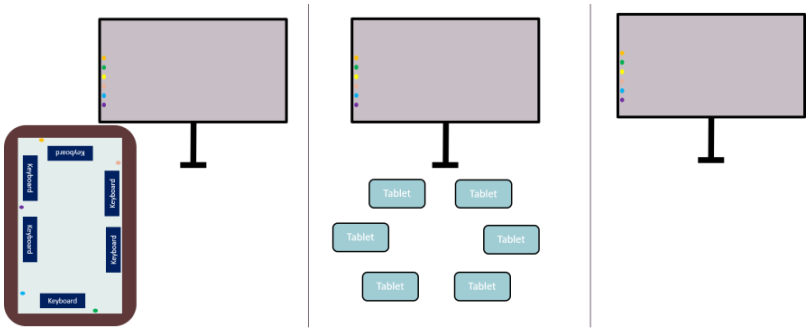

Figure 4: Physical-digital work surface, (Table & board; Tablets & board; Board)

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4.3 Procedures & data collection

The data comes from 4 separate class sessions, where each lasted approximately 1.5 hours. Groups did not change modalities between sessions B, C and D. The data presented comes from the analysis of the following activities:

A: Revisiting the sack of flour –Identify and analyse two situations from the lifecycle of sack of flour and propose alternative solutions to its current functions.

B: Causal analysis of an ice scrapper - Analyse a situation in which an ice scrapper is used, from causes to results and propose potential alternative solutions based on these.

C: The case of the school bag – Analyse a client request to reduce the weight of student school bags or alleviate the need to carry them, without using digital solutions. For this activity, they needed to determine what functional analysis tool to use to best respond to the brief.

D: Recruitment resumé and cover letter – Examine a request from a recruiter who is unsatisfied with the traditional resumé–cover letter pairing. They were given a list of questions, sometimes providing a specific analysis tool while other questions required students to choose which tool to use as a group. This activity was designed to use multiple tools to help students prepare for an exam.

At the end of each case, students were required to share their final production with their professor for evaluation and feedback. The work was recorded (video and audio). The data was analysed for movement, gestures and speech acts to determine modes of interaction throughout the session. Videos was broken up into 30 second segments and annotated based on the modes of interaction which appeared.

4.4 Results

Results will be presented on a modality by modality basis, after which we will compare and discuss limitations. We have classified results as being collaboration-heavy, cooperation-heavy, balanced, and failed collaboration. Results that are identified as collaboration-heavy demonstrate significantly higher levels of collaboration as opposed to cooperation, cooperation-heavy demonstrates high levels of cooperation over collaboration, balanced refers to the appearance of both collaboration and cooperation in equal measure and failed collaboration designates those work sessions which do not make significant progress beyond the modes of interaction used to regulate activity (individual work, communication and coordination).

4.4.1 Technology-free session

The technology-free session analysed 3 groups of students working on the same activity (A). Primary modes of interaction varied greatly in the non-instrumented sessions. Some groups leaned heavily on cooperation (group 1 & 3), while others were balanced (group 2). In each group, 2-3 students were responsible for the majority of ideas produced, with shared talk time being significantly lower when compared with all experimental modalities. This supports previous findings from Jones *et al*. (2011). In groups scoring high on cooperation, ideas were produced and challenged with high frequency. Groups with higher collaboration tended to produce ideas and then build upon them, rather than debate them. How to best use the board space became a concern quickly, with students worrying about lost work. As such, they were highly focused on note-taking tasks.

The primary mode of interaction did not always carry over from this activity. The majority of members of group 1 moved to the table/board modality, which did stay the same. The majority of group 2 moved to the board modality and group 3 to the tablet/board modality, neither of which kept the same mode of interaction pattern.

4.4.2 Table & board

Across all activities, the table and board modality demonstrated higher levels of cooperative activity and is identified as cooperation heavy. The majority of the production was done individually, followed by a phase of communication, in which group members explained the ideas they had produced. During these phases of communication, team members would pose questions, give feedback or challenge the idea. These interventions led to cooperative work, the negotiation, defence and modification of individual work in an effort to form a coherent product. Individual activity was high during all work sessions, as students spent time generating written notes to share, sometimes using drawing features to illustrate their ideas or finding images or information online. Some students also took personal notes

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for prolonged periods of time, increasing the individual work count substantially. This did not occur to the same extent in other groups, but is likely not related to the tool but to individual study and work habits.

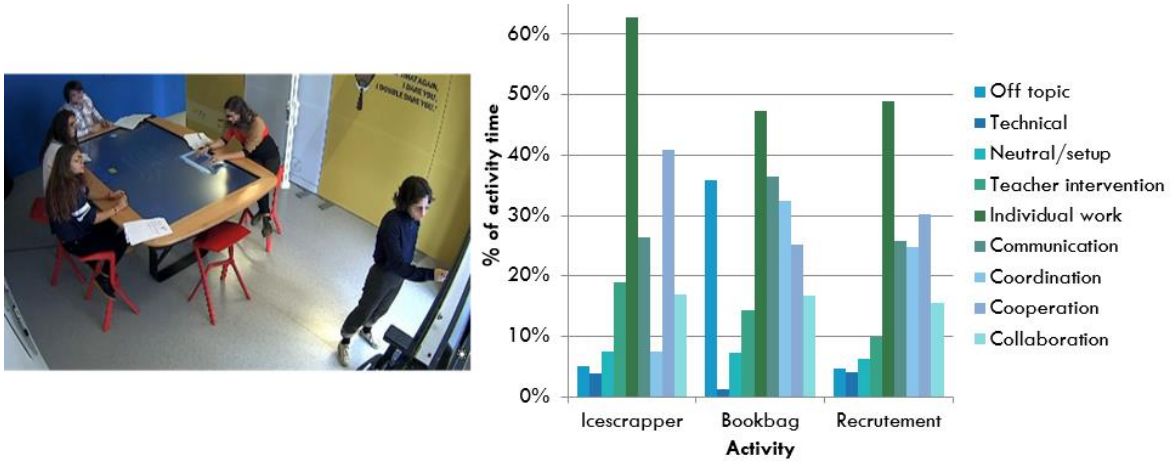

Figure 5: Table & board cooperation/individual work (l); Modes of interaction by activity (r)

When coordination activities were high (above 20%), the group was more likely to be judged as unsuccessful by the teacher. This is likely due to the fact that groups which remained in a coordination mode for long periods found it difficult to reach decisions and therefor struggled to move the work forward.

4.4.3 Tablets & board

The tablets & board modality demonstrated balance between collaborative and cooperative work, with variations in individual work. When levels of individual work were high, this group paired it with increased instances of communication. Activity itself resembled that seen with the table & board modality, but this group coordinated their work in such a way as to allow for more collaborative activity. They wrote down ideas on their tablets, sent them to the board where they were then discussed and put into a coherent framework (cooperation), but then instead of returning to their seats, students stayed gathered around the board to further develop new ideas. Tablets were used to write down these new ideas, typically from a standing position. Tablets seemed to provide a greater ease of movement, while still allowing individuals to have a private workspace in which to produce ideas or record those made by the group efficiently. Each activity was evaluated as highly successful by the professor.

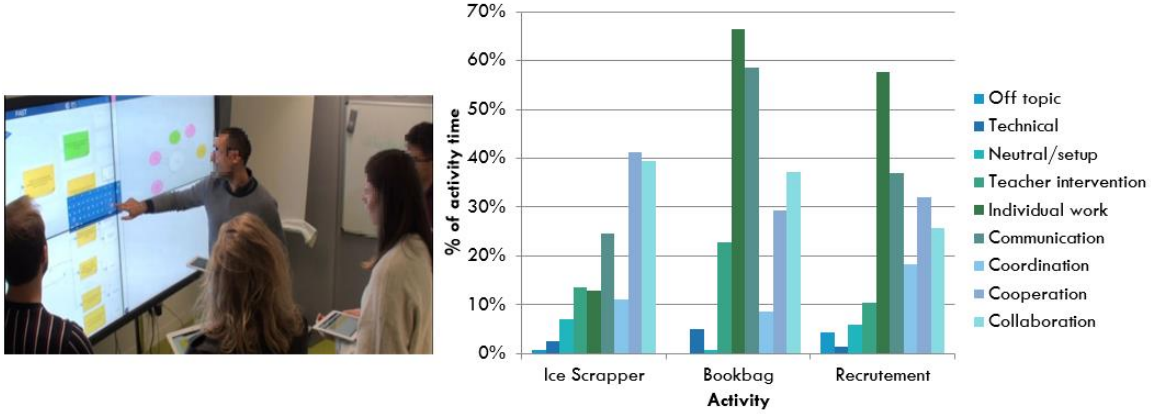

Figure 6: Tablets & board collaboration (l); Modes of interaction by activity (r)

4.4.4 Board

The board modality was collaboration heavy across all activities. This group relied primarily on dialogue to introduce new ideas into the group, where the other two modalities made use of individual space to produce written communications. As such, few items added to the collective public space

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were produced by an individual, but were the production of a dialogue with each group member invested in the final written result. The only session with a relatively high amount of cooperative activity was the recruitment case study. This activity lead to increased cooperation across all groups, due notably to the length vs. time limitations. For the board modality, to cope with this increase in work, the group split the board in two and worked in sub-groups of 3 students. After a short time, the sub groups explained their work, allowing an opportunity to negotiate and re-write some items to form a coherent whole.

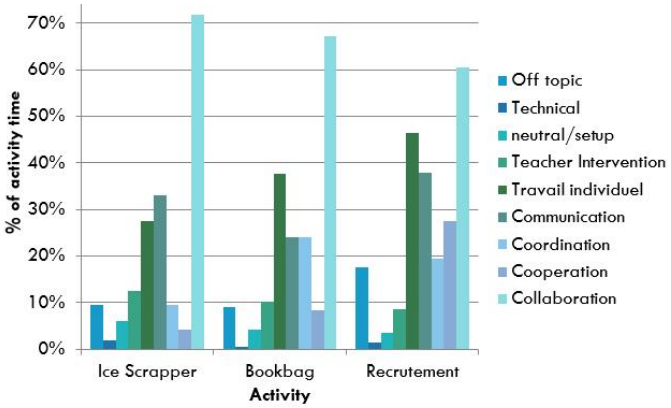

Figure 7: Board subgroup work (l); Modes of interaction by activity (r)

Despite the size of the board itself, it was difficult to fit the entire group around the board and almost impossible for all members to produce written text simultaneously. This limits the possibilities for some individuals to contribute, an option that other groups do have, which in turn raised the levels of collaboration. Additionally, the presence of several people at the board blocked the view of others, necessitating movement to see what was being written. The table/board and tablets/board modality tended to have one person at the board moving objects while others used their individual space to produce new written objects, either as a result of cooperation/collaboration or for communicating new ideas.

5 DISCUSSION

This study has a number of limitations which must be considered. First, the use of students to perform the research may be considered a limitation in that we can only hypothesize and use ethnography to suppose the application of globally collaborative work to diverse teams and work structures, but as our ultimate goal is to assess how workspace influences the development of collaborative competencies for the possible integration of such tools into classrooms, the population is a logical choice. Variations in group size from activity to activity meant that there were small behavior changes, especially around the board modality. With fewer people, more space was available for all members to contribute via writing. Second, the analysis method on a 30 second time frame was practical, but a finer analysis is possible. Some instances of communication, for example, may be lost as it can occur several times within a 30 second time-frame, but is currently only counted once. We do not feel that this changes the results shown above in a meaningful way. The size of the study is also limiting, as group makeup and individual personalities can significantly impact results. We attempted to control for this by observing other classes and activities which, due to space limitations, are not presented here. As our research has moved forward to investigate the development of collaboration skills, we have continued to see these patterns.

There remain a number of questions regarding what collaboration heavy vs. cooperation heavy activity means for the resulting product of *globally collaborative work*. In the majority of cases, groups were successful based on the professor's evaluation of their work. If a group's work is collaboration heavy, we should expect to see more co-creation versus cooperative groups, but also less sociocognitive conflict and less divergence. The environment is often upbeat and even humorous, with less interpersonal conflict. Whereas in cooperation heavy groups we see more epistemic conflict (Doise & Mugny, 1984), more opportunities to defend ideas and develop negotiation skills, but higher risks for conflict amongst group members. Since the final product is pieced together, some groups choose not to make decisions about how to combine their ideas in order to avoid conflict, which can be

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problematic for production. As an example, one group chose on several occasions to do the work twice in two separate ways and submit both to avoid deciding. Meanwhile, balanced groups seem to demonstrate the limitations and positive aspects of both, but does that necessarily mean that it is effective? Based on our results and the evaluation from professors, it does, at least for the primary subject matter; however, more data is needed to know if the pattern holds.

In line with our results and observations, we propose three design properties for collaborative workspaces: First, that systems should facilitate transitions between the various modes of interaction. This means allowing for a space in which individuals can perform individual work, resources that facilitate the coordination and separation of work (such as screen splitting), etc. Second, when designing for in-person collaboration meetings, the meeting space must be considered (Thoring, Mueller, Desmet, & Badke-Schaub, 2018). Facility of movement plays a key role; when students gather around a vertical workspace, collaboration seems to emerge more quickly, where fixed individual spaces encourage students to stay in place and rely on an animator. As such, they may be less inclined to speak and more likely to engage in social loafing. Third, either through facilitation methods or an integrated alert system, forward momentum should be encouraged. Methods to help groups make decisions (such as a voting system), or a smart agent which may detect inactivity and provide feedback or alert a teacher (in case of pedagogical uses) could help fill the gaps when groups struggle to make decisions.

6 CONCLUSION

In this paper, we present the concept of *globally collaborative work* and break it down into its smaller components based on definitions from CSCW/CSCL researchers. We analyse how workspaces influence the emergence of these modes of interaction during collaborative group work. The results suggest that the available workspaces cause students to work in ways that are more cooperative, more collaborative or a balance between the two. We also noted that the activities are not always successful and propose three design principles that we believe would positively influence *globally collaborative work* processes.

Future work will include validation studies and a comparison of group work before and after using these different workspace modalities over the course of several weeks in order to understand how they influence the development of collaboration skills.

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