**Physical space and division of labor around a tabletop tangible simulation**

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**Abstract:** We describe a tangible tabletop simulation, the Tinker Table, which is designed to train logistics apprentices in Switzerland. Vocational training is organized following a dual model which combines practice on the workplace and theory in the professional school. Two groups of learners were observed during an activity which consists of optimizing the layout of a warehouse. We propose a descriptive account of how the spatial position of resources and learners influences the type of manipulations which are performed by each of them.

**Introduction**

Recent developments in the field of Tangible User Interfaces have proposed the use of physical objects as interfaces to computer systems (Fitzmaurice, 1996; Ishii and Ullmer, 1997). These interfaces aim at bridging the gap between the physical and the digital worlds, by allowing users to interact with a computer through physical objects. Tangible User Interfaces appear to be well suited to build practice fields (Barab & Duffy, 2000) in domains implying the manipulation, arrangement, or creation of artifacts (e.g. logistics, supermarket sales clerks) and hence to establish bridges between the world of practice and theory. Among interesting properties for learning (O’Malley and Stanton-Fraser, 2004), tangible user interfaces naturally support face to face collaborative activities, which allow multiple users to interact with the system at the same time. An example is the work by Arias, Eden and Fischer (1997) on an environment supporting citizens working on an urban planning task. It allows them to define bus lines using a TUI on a map of their area. Simulations can be run, and the resulting data can be analyzed on a large vertical display next to the tabletop. In Caretta (Sugimoto, Hosoi & Hashizume, 2004), children use physical houses, factories and trees to define the layout of a town and can then observe environmental changes due to a given set of parameters. Several groups can work at the same time on connected environments that influence each other, thus encouraging discussions and negotiations among learners.

Learners are usually free to roam around these tabletop simulations, to tinker with the problem space from different locations around the table, (literally) step back to take distance to reflect about the solution. In this contribution we propose an exploration of how the physical size of the simulation environment as well as the arrangement of materials on and around the simulation table affects the type of actions which are performed by the collaborators. In line with distributed cognition theories (Hutchins, 1995), we hypothesize that the configuration of the physical environment is used as a resource to coordinate actions and influences the adoption of roles by participants. We are interested in whether and how division of labor is related to the physical position of learners and resources.

![Figure 1. Apprentices working with the Tinker Table. On the left, apprentices draw and measure forklift paths on the table with whiteboard markers. On the right, positions around the table are numbered from](image-url)
1 to 6. Apprentices stand around the table and are free to move.

The study concerns the Swiss apprenticeship in logistics management, a profession that involves the storage and transportation of goods (physical flow), the design of warehouses and transportation routes, as well as the management of inventories and information (information flow). During the past two years we designed and developed a tabletop tangible warehouse simulation in close collaboration with teachers from a professional school (Zufferey, Jermann and Dillenbourg, 2008). The simulation allows apprentices to build a small-scale warehouse by placing miniature shelves scaled at 1:16 on a table. The table measures 2 meter by 1.5 meter and offers enough space to accommodate the simultaneous actions of four to five participants (see Figure 1, left). The physical small-scale model is augmented through a video projector placed above the table. All objects (shelves, pillars, loading docks, etc.) are tagged with fiducial markers (similar to a 2 dimensional bar code) which enable a camera to track their position on the table (Fiala, 2005). The information provided by the camera about the precise position of the objects on the table in turn enables the system to project graphical representations (augmentations) on top and around the objects. The physical layout of the warehouse is used as input to configure a simulation that tests its characteristics under realistic conditions. The simulation is controlled by a paper-based interface called TinkerSheets (Zufferey, Jermann, Lucchi and Dillenbourg, 2009). Small tokens can be placed on a paper form which is recognized by the system and allows users to set parameters like the type of warehouse management (e.g. chaotic or place reservation), the number and type of forklifts, or the type of augmentation which is displayed.

Method
We follow the approach outlined by the Design-Based Research Collective (2003) which consists in testing and building working theories to make sense of a field of investigation through an iterative design and intervention cycle. We won’t detail the approach here but invite the reader to consult the excellent overview by Wang and Hannafin (2005): the key points of the approach are 1) that it aims at refining both theory and practice 2) through interventions which are grounded in theories and take place in real-world settings 3) with an active participation of the participants in the design 4) through iterative cycles of analysis, design, implementation and redesign 5) by the use of an array of methods from field observations to controlled surveys 6) leading to results which are articulated to the specific context of the studies. Our investigation follows these principles rather than a series of tightly controlled laboratory studies. Therefore, at this point of the project, we do not base our quest for answers on the statistical refutation of hypotheses.

Data source
The Tinker Table has been used in class on several occasions in two different professional schools and by four teachers. In this contribution, we report observations from a session held in the beginning of 2008. Apprentices were asked to layout a warehouse so as to place as many shelves as possible on the available surface. The warehouse layout activity stems from an exercise that is usually done in class with paper and pencil. The session was run with 15 apprentices during a 2 hour session. The class was split in three groups. Group 1 was instructed to start laying out a warehouse by respecting constraints given by the teacher. Four small-scale pillars were placed on the floor of the warehouse and apprentices had to spare some space in the warehouse for an administrative room. Once group 1 finished its implementation, group 2 was challenged to do better and modify the solution obtained by the first group. Group 3 finally had to analyze the layout produced by group 2 following an ABC analysis (determines where to place different types of items depending on their frequency of movement and monetary value). We use observations from groups 1 and 2 in the analysis presented in the results section. The session was videotaped (with a camera above the table and a fixed camera which captured the general scene) and sound was recorded with ad hoc digital recorders.

Data analysis
The questions we ask ourselves and the context we work in require an exploratory approach. Data analysis was done by reviewing videotapes, and analyzing participation. We compare groups through second-by-second interaction coding. For each second and for each participant we coded whether and to whom participants were talking and whether they were acting (getting, placing or moving shelves). We also identified their position around the table by splitting the periphery of the table into 6 segments labeled from 1 to 6 (see Figure 2, left). The raw data obtained by this coding was then visualized in various forms to reveal the social structure of interaction. Visualizations of the division of labor are very efficient to get a sense of interaction dynamics. However, they need to be complemented with future analyses of the actual content of interaction to enable a deeper understanding of learning processes.

Action types
We distinguished four types of actions which are relevant to describe how apprentices build and simulate a warehouse layout.
• GET: consists of bringing a tangible shelf to the table. Wooden shelves were initially stored on another table 2 meters from the Tinker Table (to the right of position 6 in Figure 2, right).
• ADD: consists of deciding of the initial place of a tangible on the simulation canvas. Groups started with an empty table and placement was a frequent action.
• MOVE: consists of changing the position or the orientation of a tangible which is already present on the table. Several shelves might be moved at a time.
• ADJUST consists of small modifications of the position of the tangibles which are performed to 1) obtain an alley width large enough for forklifts to be able to access the shelf or 2) to ensure that the fiducial markers are well perceived by the camera. These are the most frequent actions in the sessions which we observed.

Results
Figure 2 represents the movements of the four apprentices (labeled A1 to A4) in group 1 (top) and group 2 (bottom) during a 10 and 20 minutes period respectively. It appears from the graphs that A1 mainly stayed at position 1 in both groups. In group 1, A2 and A3 were the most mobile apprentices. In group 2, A3 and A4 moved most around the table.

Figure 2 Timeline of apprentice's position around the table (group 1, top; group 2, bottom). Each line represents the position (1 to 6 on the ordinate) of one apprentice (labeled A1 to A4) around the table.

The three types of action (GET, ADD and MOVE) require different levels of elaboration. Bringing shelves to the table is the simplest action, but it potentially allows the actor to set the pace of the construction of the warehouse and to distribute work by handing shelves to others. Adding a shelf on the table gives the actor the power to determine the construction strategy. The placement of the first shelves had a strong impact on subsequent placements as they defined the direction of the rows and the distance between the rows of shelves. Moving shelves corresponds to doing fine adjustments or rearranging the warehouse after a diagnosis. Figure 3 shows the difference of collaboration patterns between groups 1 (left) and 2 (right).

Figure 3. Distribution of action types in group 1 (left) and 2 (right). A1 to A4 correspond to the four apprentices.

In group 1, the contributions to building the warehouse were rather equilibrated: A4 and A2 both brought shelves to the table. From examining the number of ADD actions we see that A4 often handed the shelves to his peers while A2 also placed them by himself on the table. A1 did half of the MOVE actions but his
peers were also involved (A1 moved the least and spent a long time adjusting the position of shelves to ensure they were recognized by the system).

In group 2, the distribution was much more uneven. One apprentice (A3) took the role of the “boss”: he was giving orders to his peers but did almost no action. He only added 3 shelves and never moved one. A4 did all of the GET actions, bringing the shelves to the table and placing a significant part of them by himself (ADD actions). The movements of existing shelves were mostly taken over by A1 and A2.

Complementary analyses of the distribution of speech time confirm this difference (Figure 4). In group 1, the participation in dialogue was more or less equilibrated. After listening to the dialogue, we found that A2 took over the most reflective role while participating in the implementation as well. Typical reflections concerned evaluation of the solution (e.g. “there you can’t drive with a forklift”, “it’s laid out like a snake”) as well as the problem solving strategy (e.g. “we are not making sense here”, “we should have made a sketch beforehand”). The collaboration is different in group 2 because A3 took a very dominant position and gave orders to his colleagues (e.g. “I want that shelf here”, “turn this one around”). One apprentice (A1) did not participate much in the dialogue.

Figure 4. Collabograms for group 1 (left) and group 2 (right). The transitions show the number of seconds each apprentice spent talking. The arrows indicate whether speech was addressed to someone in particular or to all participants. The self-referencing arrows (e.g. from A4 to A4) represent speech addressed to the whole group.

To summarize our findings, we saw in group 1 that frequent movement through all locations (except location 1) was associated for A2 with an implementation activity which was also accompanied by a reflection role. In group 2, frequent movement through all locations (except location 1) was associated for A3 with the activity of directing the implementation and for A4 through places 4, 5 and 6 (closest to the shelves store) with the activity of getting and adding shelves on the table. In group both groups A1 did not move much and produced most of the move actions. In group 2, these used to be mainly adjustment actions. It appears from these two examples that the less involved apprentice takes refuge on location 1, as far as possible from where the action is.

Discussion

Our analyses have shown that there is a spontaneous division of labor among apprentices during problem-solving which is accompanied by a specific occupation of the space. This has potentially positive as well as negative effects. On the positive side, the distribution of roles allows one apprentice to take some distance and offer reflective comments (session 1, group 1). This is similar to the spontaneous division of labor which happens when two people use a computer (Miyake, 1986): one becomes the “doer” while the other becomes the “thinker”. From complementary observations carried out since this study, it seems that the appearance of differentiated roles is predominant in groups of size bigger than 2 where specializations appear as a complement to the “leader” role. These specializations concerned actions which are more related to minor adjustments (removing and adjusting shelves). The negative effect of division of labor is that in each of the two cases we analyzed, one apprentice was less involved than the others. One possible explanation is that these apprentices were free-riding (Sheperd, 1993) at the expense of their colleagues’ efforts. This explanation is rather unlikely as the participation of each apprentice was publicly available for inspection, and the problem was intellectually challenging.

The spatial disposition of learners and resources orients the roles adopted by learners. It is worth noting that in both groups, the least active apprentices took position on the farthest place from the shelves store. In group 2, one apprentice carried all the shelves from the shelf store to the simulation table. His occupation of
location 1 gave him exclusive access to the shelves and allowed him to place half of them. The size of the simulation workspace matters as well. The large size of the table did not allow all apprentices to work simultaneously on the layout activity: the layout typically started at one end of the table (position 6) and progressed towards the other end (position 1). It is therefore not surprising that the two under-participating apprentices in position 1 did not get a chance to manipulate shelves early in the interaction.

Conclusion
The investigation of spatiality and its relation to collaboration in tangible simulations appears as a promising avenue for research. The disposition of resources and the position of learners in the environment affect the division of labor spontaneously adopted by the learners. Several challenges stay ahead of an extension of this research. First, in order to address socio-cognitive processes we need to investigate more deeply the content of conversations among apprentices. In this contribution we used a superficial coding of speech production in terms of intensity rather than quality. We nevertheless gained some useful insight from observations conducted during the collaborative sessions. The feasibility of such a content-based coding needs developments in automatic signal acquisition and filtering. The simultaneous tinkering and arguing of five apprentices around a warehouse design makes transcription and intelligibility almost impossible. In groups of 2 to 3 apprentices this problem is less important.

Concerning pedagogical design, the insight we gained through our analysis will inform the design of future lessons around the Tinker Table. To alleviate participation problems, teachers already adapted their lesson design to include specific roles for each apprentice.

References

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