BENEFITS OF A TANGIBLE INTERFACE FOR COLLABORATIVE LEARNING AND INTERACTION

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Abstract

We investigated the role that tangibility plays in a problem-solving task by observing logistic apprentices using either a multi-touch or a tangible interface. Results showed that tangibility made them perform the task better and have a higher learning gain. In addition, groups using the tangible interface collaborated better, produced a higher proportion of ideal cycles of communication, explored alternative designs more, were more in a state of “flow”. Mediation analysis revealed that exploration was the only intermediary variable explaining the performance for the problem-solving task. Implications of this study are discussed in terms of the benefits of tangibility for education and directions for future research.

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Introduction

For a few minutes, imagine yourself back at 16 and working as a logistic apprentice. Your daily routine is simple and well-established: you wake up early in the morning and you go to your workplace, a warehouse managing various building material. Your tasks are quite simple, and you accomplish them efficiently: move some cement bags from one shelf to the expedition area, clean up the place, indicate some incoming and outgoing merchandise, and refill the bricks' stock. But, once a week, you find yourself sitting in a classroom, where a teacher tries as best as he can to explain you some nebulous concepts accompanied by multiple graphs and mathematic formulas. Then you're asked to fulfill many complicated exercises, that don't really make sense for you, because they are unrelated to your daily routine. This example illustrates some possible problems that can arise from a dual training system.

The swiss vocational training works in this dual mode; It is based on the idea that learning must be situated, meaning that students have to work on authentic tasks taking place in real-world settings, concurrently that they follow school lessons. In other words, the goal is to move the students out of the school and make them learn by interacting in the social and physical context within which the learning will be used (Brown & al., 1989). Moreover this approach argues that conceptual knowledge can't be separated from the situation: in fact, the learning will be less effective without a concrete basis (in our context a professional experience). The ambition of this approach is not only to make people "know what", but also to make them "know how".

The problem of the gap between these two dimensions is very frequent among swiss apprentices. They are facing extremely concrete tasks daily, which are in high contrast with the abstraction level required in school. The DUALT-T project is born from this observation: indeed, it seems that an intermediary step is missing between these two worlds, and technology has the potential to fill this gap. The CRAFT (Center for Research and Support of Training and its Technologies) of the EPFL ("Ecole Polytechnique de

Lausanne”) attempted to solve that problem by creating a tabletop environnement, which allows logistic apprentices to build and manage a small scale warehouse. Instead of using a mouse and a keyboard, the input is given to the software by manipulating shelves and objects belonging to the warehouse (which is called a “tangible interface”). Then, instead of having a monitor, the output is projected on the warehouse to give several additional informations to the users (which is called a “augmented reality”); for instance, it can give feedback about the stock level, the optimal alley width, the frequency of reordering, and even run simulations with miniature forklifts. To summarize, this system offers apprentices the opportunity to watch in real-time how a warehouse functions.

The main hypothesis behind this project is that by bringing the workplace into school, the apprentices will have an intermediary representation which helps them understand abstract concepts and transfer them back into practice. The actual goal of this master thesis is to determine to which extent tangibility influences problem-solving and learning activities. Indeed, we believe that tangibility is a key variable for apprentices, because it links the knowledge gained in the workplace to school’s situations by presenting an additional external representation (i.e. tangibility). We think that interacting with and manipulating physical objects may offer a bridge to better understand abstract concepts, such as graphs or mathematical formulas, and support constructive behavior, like exploration, collaboration and playful learning (for instance). Comparatively, we believe that a mainly digital interface will lead to a less efficient understanding.
If this hypothesis is verified, it will bring the confirmation that tangible interfaces have the potential to make a concept more accessible by reducing the abstraction gap required to understand it.

Moreover, this project is innovative at several levels: it tries to integrate the state of the art in augmented reality and tangible interface in order to improve the classical

education. Another quality of this project is that it combines multiple evidences to demonstrate the effectiveness of an intervention by following a design-based research. It also implies that the whole iterative process is done by scientists in collaboration with professional logisticians; this point is important because the result produced is meant to be directly useable in the school. Finally it integrates the most recent pedagogical theories in terms of CSCL (computer supported collaborative learning).

Context: The Dual-t Project

In Switzerland, 70% of the 16 years old people follow a vocational training after obligatory school. Concretely they work in a company 4 days a week, and spend the 5th day studying in a professional school. This dual training has several advantages for the apprentices: it helps them practicing essential skills in a real workplace and they benefit from a solid theoretical education. In addition, it offers the opportunity to the most gifted apprentices to continue their studies at an academic level afterwards. At first sight, this system seems to be perfectly suited for our society: from the company point of view, it offers cheap working force and the opportunity to select and train future employees; from the apprentice side, it gives close contact with the working world, which brings benefit from professional advices.

However the articulation between these two worlds is difficult because most of the students find it hard to use knowledge from the school. Zufferey, Jermann and Dillenbourg (2008) call this phenomenon an "abstraction gap": it refers to a lack of similarity between two external representations which restrains apprentice's learning. Indeed, they don't have enough information to link the teaching from the school and the experience from the workplace; in order to solve this problem, the DUAL-T project was created. Three applications have been implemented so far: polymecanicians (Fribourg), dental care assistants (Geneva) and logistics managers (Lausanne). For this study we will focus on the last implementation (logistic), which is the "tinker table", a tabletop environment developed by computer scientists and psychologists from the EPFL in collaboration with the CPNV (Centre Professionel du Nord Vaudois). Its goal is to facilitate logistics learning by providing an interactive small scale warehouse for schools. This device has several interesting features like a tangible interface and an augmented reality, which gives it the potential of integrating both concrete and conceptual informations. The "tinker table" chapter gives a closer look at this table

The Tinker Table

As previously said, the solution proposed by the EPFL is an augmented table-top learning environment, consisting of a table where small-scale shelves can be easily moved to create a warehouse. A camera records every movement and sends them to the software, which gives a feedback to the user by a projector. The image created allows the apprentices to see (for example) if the distances are large enough to work or if some goods need to be ordered

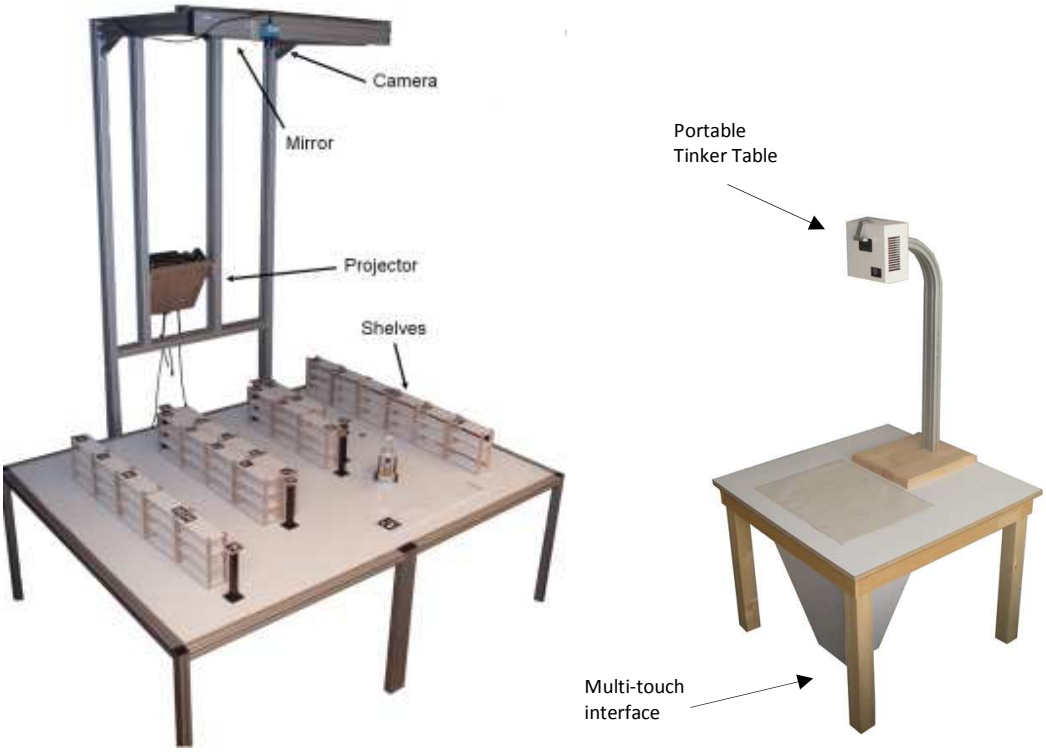

Fig. 1: *the Tinker Table. On the left: the original table (2 x 1.5 m); on the right: small scale table (50 x 37.5 cm), which only needs a plane surface to work with the tangible interface (the table above serves as a flat interface, which is multi-touch).*

The inputs can be twofold: either users move a shelf, or they can use a control sheet (called “Tinker Sheet”; Zufferey, Jermann, Lucchi, Dillenbourg, 2009) to configure the simulation on the warehouse. For example they can start a simulation, increase or decrease the speed of the forklifts, visualize the stock, modify the demand or order some goods. The control sheet is just a simple piece of paper with tags on the top of it; users can set the value just by moving little black tokens. The simplicity of the interface helps users to quickly control the system, and it allows the teacher to flexibly create suitable situations for learning.

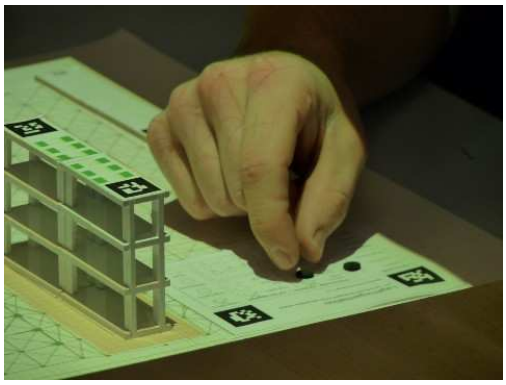

Fig. 2: *user manipulating a “Tinker Sheet”*

The outputs can be manifold: either the user can see the forklifts moving during a simulation, analyze graphics representing the state of the warehouse, spot where there lacks place for a forklift to work, or have some information about the warehouse (number of shelves, efficiency, accessibility …).

So far two sizes of this table exist: a big one, which measures 2m by 1.5m (shelves are scaled at 1:16), and a small one, which measures 50cm by 37.5cm (shelves scaled at 1:50). Both systems have advantages and disadvantages: a big table allows the collaboration of large groups of students and stimulates interactions and cooperation, while little tables let teachers split their classroom into several smaller groups. Because they are less expensive and less cumbersome, two or three little tables can be simultaneously used instead of a big one. In addition, a third prototype has been

created, which is identical to the small table, except that it allows multi-touch interaction (no more tangible shelves, only rectangles that you move with two fingers). Consequently, this third table involves a more abstract view of the warehouse.

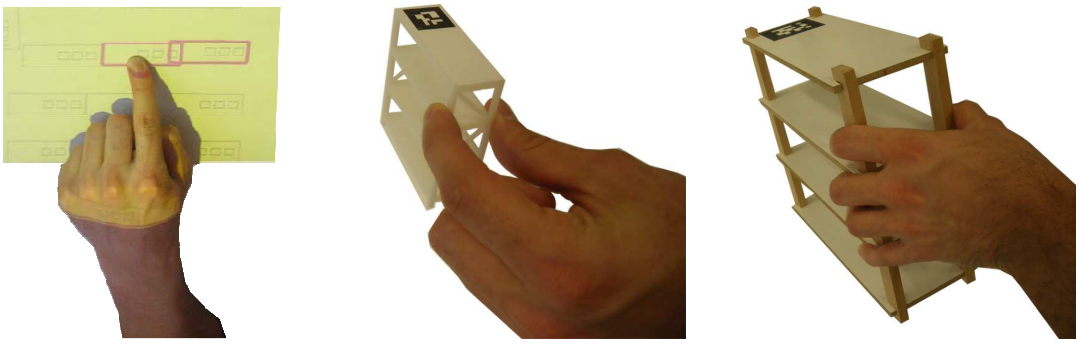

Fig. 3: *three types of interactions involved by each version of the Tinker Table (left: multi-touch, middle: small scale, right: big scale).*

Figure 3 shows that each version of the Tinker Table implies a specific way to interact; this involves differences in term of cognitive activity related to the level of realism, as it will be latter discussed.

What exactly is a Tangible User Interface?

The concept of Tangible User Interface was brought by Ishii & Ulmer (1997) during the ’97 HCI conference. The idea is that we can easily replace the mouse and the keyboard by alternative inputs: for example moving physical objects, gesturing, speaking or moving our whole body; then the computer senses this event and alters its state. Finally, the system provides feedback by changing the environment: either displaying some information, making a sound, changing color or growing. Thus this kind of interface allows very instinctive and natural interactions, which is not always the case with

traditional interfaces. Fishkin (2004) developed a taxonomy which describes the whole spectrum of tangible interfaces, based on two axis': the system can be more or less *metaphorical* (the level of analogy between the system and the real world) and *embodied* (how closely is the input focus tied to the output focus?). Each axis has different levels, from full embodiment (the input device *is* the output device) to nearby, environmental or distant embodiment (the output is away from the input, for example in another screen); from no metaphor (like a command line interface) to noun, noun/verb or full metaphor (for the users the virtual system *is* the physical system). This taxonomy can be highly useful, because it helps researchers differentiate the optimal context for each kind of interface.

Using Fishkin's taxonomy, the Tinker Table has a *nearby* embodiment, meaning that the output takes place near the input object: for example moving a shelf changes the grid projected on the table and informs the user that there is not enough space to work. This level of embodiment is appropriated, because as soon as the embodiment decreases, the "cognitive distance" between the input and the output increase, and thus make the understanding of the system more effortful (for instance having the output on an adjacent monitor). In our case, the goal is to facilitate apprentices' cognitive work by simplifying as much as possible the representation of the warehouse; as a consequence, a high level of embodiment is needed.

In addition it has a noun/verb metaphor, meaning that acting on an object in the system is like acting on it in the real world. We believe that apprentices need a high level of analogy between the virtual and the physical system, because as mentioned before, they work in a professional context 4 days a week. Consequently, we think that they would more benefit from a concrete representation of a situation, compared to a more abstract one. We can imagine that once apprentices have mastered a given level of abstraction, the level of metaphor could be increased (e.g. warehouse management activities with Tinker Sheets only).

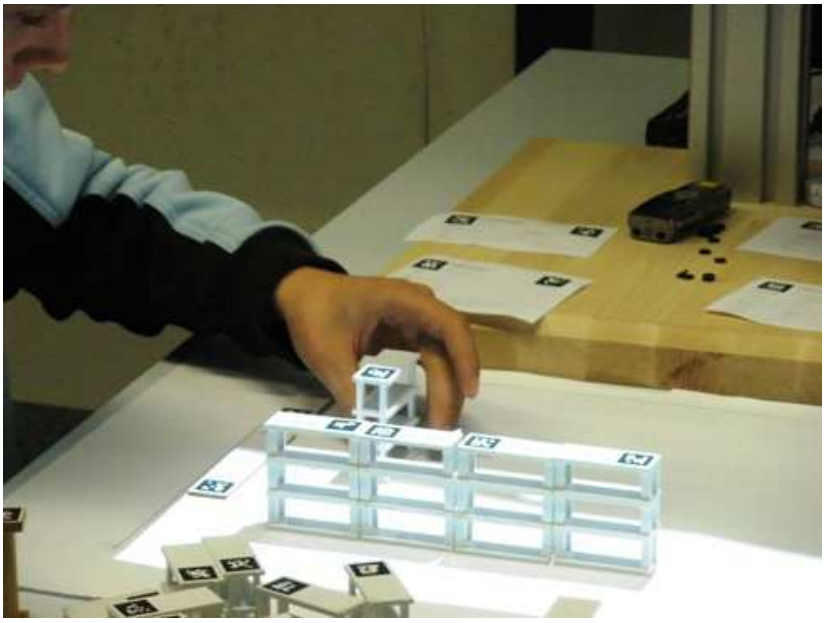

Fig 4: *An apprentice using the tangible interface for building a warehouse.*

Thus neither the embodiment nor the metaphor is complete in the case of the Tinker Table. This distinction is useful for further research, in order to distinguish which level of embodiment and metaphor would more benefit which kind of users.

How an Augmented Reality can be useful

The Augmented Reality (AR) differs from a virtual environment (VE) by one essential characteristic: while VE technologies completely immerse a user inside a virtual world, the AR supplements reality rather than replacing it. It allows the user to sense additional information in order to enhance his perception by combining real and virtual objects. According to Azuma (1997), the AR system combines the following properties:

- It combines real and virtual objects in a real environment
- It runs interactively, and in real time
- It registers (aligns) real and virtual objects with each other

Several examples may be useful to illustrate relevant AR applications. For instance, medical staff could use visualization for accurate biopsy or training purpose; for engineers, virtual annotations on complex mechanical systems; for soldiers, positions of allies on the battle field; pilot vector graphics for tricky trajectories; etc.
However AR is far from the VE in terms of maturity. Due to its youth, Most of the AR applications are prototypes or projects in progress. Moreover, AR faces many additional challenges, such as light management and accurate calibration (mainly). For instance too much light makes the AR disappear, while no light forces the user to stay in a dark room. Besides accuracy relies mainly on the state of the environment: changing it slightly causes endless recalibrations, which can be annoying, or even unacceptable (for instance in a surgery context, causing an incision at the wrong place). This kind of problem can be avoided by wearing special glasses, but it encumbers the use of the system so much that it isn't an acceptable solution for most of the conditions.

However, an AR system can be advantageously used for a learning situation even with that kind of drawback. It can offer additional information, lead the focus of the learner

at the right place, simulate the functioning of a system or even offer alternative views of the situation.

Concerning the Tinker Table, the AR is used in several ways: showing products in the shelves and the distance between them, forklift simulation or graphical representations to see the available stock.

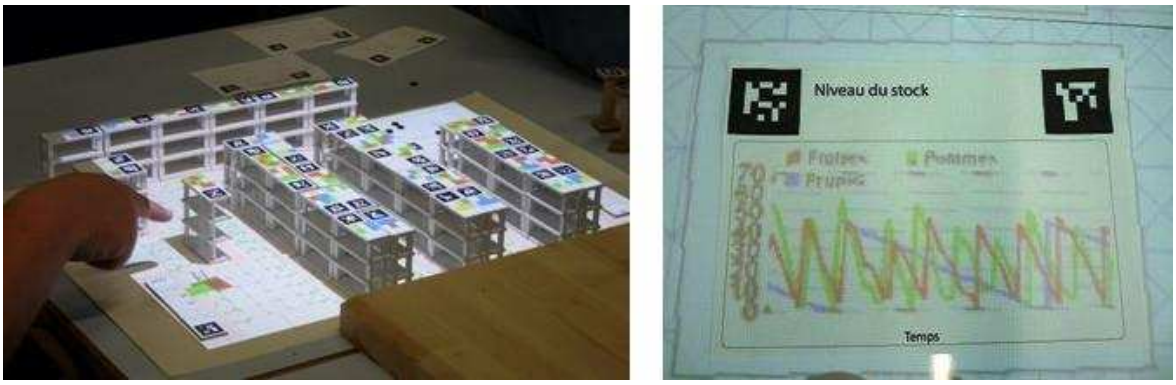

Fig 5: *small scale warehouse with AR (simulation, scaling) and augmented sheet.*

Theoretical context: what does tangibility bring?

We believe that tangible interface is a key variable for the efficiency of the Tinker Table. Indeed, we used Marshall's analytic framework (2007) to extract which feature of tangible interface can benefit logistic apprentices (figure 6), and we argue why in the following paragraphs. In our case, we believe that tangibility has the potential to integrate multiple representations, increase collaboration by facilitating interactions, stimulate exploratory activities, engage people in playful learning, improve the quality of the reflection, and increase the playfulness of the task. As a result, we believe that these features will help logistic apprentices to better achieve a task and better learn logistic concepts.

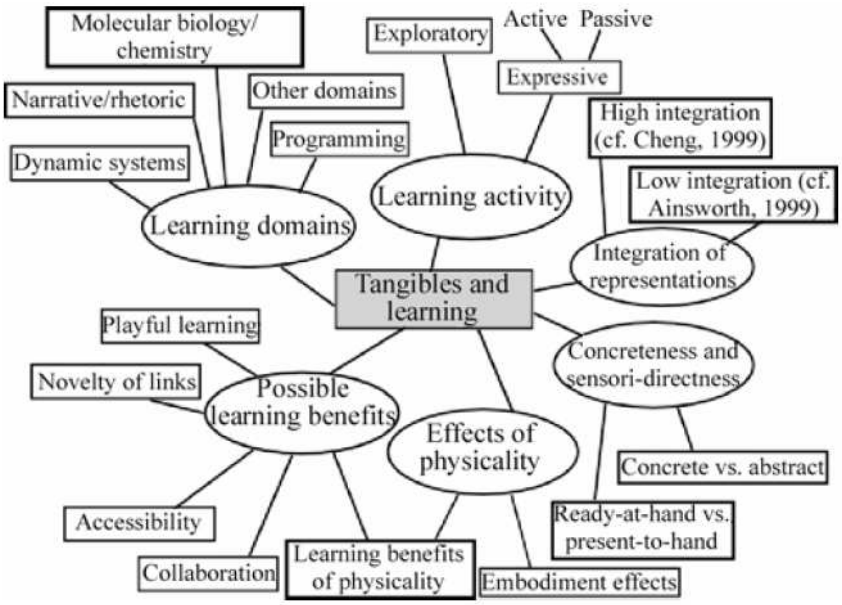

Fig 6: *Marshall's analytic framework on tangibles for learning*

The role of MER (multiple external representations)

External representations can be defined as "the knowledge and structure in the environment as physical symbols, objects, or dimensions (e.g., written symbols, dimensions of a graph, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layouts of diagrams, etc.)" (Zhang, 1997). An appropriate representation can be helpful in multiple ways: for example to reduce the amount of cognitive effort required to solve problems by grouping information or reducing the complexity of a problem (Larkin & Simon, 1987); to alternatively represent reality and thus influence problem solving (for instance Zhang & Norman, 1994, showed that isomorphic versions of the Towers of Hanoi were better resolved when representations externalized more information); to constrain the range of inferences that can be made (for example texts permit ambiguity in a way that graphics cannot easily accommodate; Stenning & Oberlander, 1995). Thus an external representation like the Tinker Table can be useful for students, because it forces them to focus only on relevant elements and constrains their inferences to the warehouse they built by giving them a concrete representation (for example for distance estimation, 3D shelves give an idea of the proportion needed).

However the whole system has to be carefully designed, because learning does not miraculously occur by presenting an external representation. According to Ainsworth (2006), students have to understand the form of the representation (e.g. in the case of a graph, realize that one axis is the stock while the other one is the time), understand the relation between the representation and the domain (e.g. having enough experience to know how to accurately modify the turnover rate of the stock by seeing a graphic), how to select and construct an appropriate representation (there is evidence that creating representations can lead to a better understanding; Grossen & Carnine, 1990; that's why the Tinker table is built on a whiteboard, which allows students to draw their own schemes and graphs). Therefore the external representations have to be strongly adapted to the users' needs and abilities.

Furthermore Ainsworth (1999) argues that *multiple* external representations can provide unique benefits when people are learning complex new ideas. In our case, we believe that the Tinker Table offers two major representations: *an abstract representation*, composed by graphics, schemas, numbers projected by the augmented reality and linked to all the knowledge gained in school; *a concrete representation*, composed by the small scale warehouse and its graspable shelves, connected with all the experiences made in the workplace. Moreover, we believe that this representation can be more or less concrete, depending on the material used: a pen / paper won't likely be used the same way as a big graspable shelf for building a warehouse. Thus, it allows us to draw a continuum from abstract to concrete representations (see figure 5).

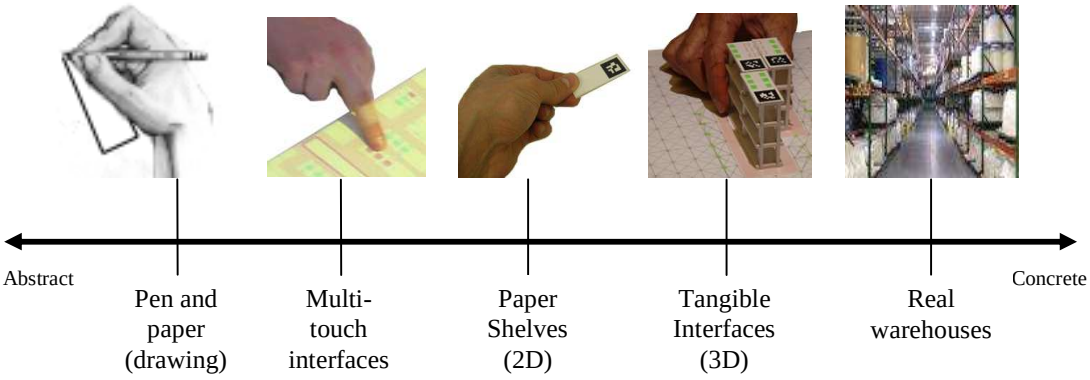

Fig 7: *level of realism yielded by several logistic learning "interfaces"*

It is likely that different material won't be adapted for every user. Novices, for instance, will need to be more on the concrete side of the continuum, because it's a representation they can easily understand. Experts, on the other side, will find a totally abstract material appropriated, because it allows them to make more powerful calculations (like mathematical optimizations). The actual goal of the TinkerTable is to make the apprentices move along this continuum over school training.

According to Ainsworth, MERs can bring several learning advantages: firstly, two representations can complement each other, and encourage learners to try more than one strategy to solve a problem. Secondly, learners' familiarity with one representation can constrain the interpretation of a less familiar one (e.g. miniature shelves help apprentices visualize the full scale warehouse; thus they are better able to know how much space is needed for a forklift to work, even if they are working on the abstract representation). Thirdly MERs support the construction of more abstract and deeper understanding, which increases the likelihood to achieve insight in a problem-solving task. Furthermore, it seems that it also helps the student to transfer his knowledge to new situations (Bransfort & Schwartz, 1999).

Finally a few principles have to be kept in mind in order to build efficient MERs. Ainsworth recommends using the minimum number of representations and minimum information inside the representations, because otherwise it would result in a split attention effect. Moreover the form of the representation must fit to the pedagogical purpose (for example is exploration best promoted by text, graphs, equations or simulations?). Because of that, it was decided to use only two MER for the TinkerTable in order to keep a low level of complexity.
Because there are no absolute rules, working with MERs is quite delicate. Indeed it is difficult to create an interface without knowing users' needs and skills. Design-based research is consequently a very suited method for designing MERs, since it allows us to iteratively develop more adapted representations for apprentices. In our case, observing teachers and apprentices using the table allowed appreciable improvements in term of readability of the representations.

Hence, we believe that the integration of two external representations (in our case a concrete representation, which is the tangible interface, and a abstract representation, which is the augmented reality) that are relevant for the apprentices will bring understanding and therefore learning benefits. Indeed, it is likely that the concrete

representation (in which the apprentice is more comfortable) will help him for understanding the abstract representation of the Tinker Table because these two representations, from our point of view, are strongly complementary. As a matter of fact, we hypothesize that these two representations will communicate with each other, so that the concept presented by the teacher to the apprentice will make sense more easily and more quickly when using the Tinker Table.

Collaboration

From Marshall's (2007) point of view, one attractive characteristics of tangibility is to make a group of people work together in order to solve a specific problem (in our case, discover the formula that regulates the merchandise flow, for instance). The idea of computer-supported collaborative learning (CSCL) is based on two fundamental theories: the "socio-cognitive conflit" (Piaget, 1936) and the "zone of proximal development" (Vygotsky, 1978). Initially Piaget argued that different points of view on a task create a conflict between two (or more) people; then this situation forces protagonists to change their perspective on the problem. The idea is that conflict resolution brings a cognitive restructuration, which produces a more adapted solution. In addition, Vygotsky proposed that the construction of knowledge is socially built. In this view, more capable peers are said to mediate the learning by guiding the participation of the learner, and to progressively give more responsibility to him. As a consequence, the learner internalizes the concept or the knowledge and gradually appropriates theoretical or practical skills. Moreover, he defined the zone of proximal development (ZPD) by "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers". Similarly, it means that with help we can reach much more

elaborated knowledge than alone. Of course the ZPD must be adjusted to our level in order to produce substantial results. For more information about these two theories, see Feldman & Fowler (1997).

These two approaches gave birth to socio-constructivism, which in turn influenced the development of CSCL. One instructive article has been written by Dillenbourg (1996) about the evolution of research on collaborative learning. According to him, three paradigms must be taken into account: first of all, the "effect paradigm" specifies that this kind of research produced contradictory results within which positive outcomes largely dominate. Nevertheless it leads us to the conclusion that collaboration is in itself neither efficient nor inefficient, but works under certain conditions (it's the second paradigm, called the "conditions paradigm"). These conditions are mainly the group composition (size and heterogeneity) and nature of the task (type and complexity), meaning that you can't just make people learn by grouping them: actually you have to perfectly adapt the level of complexity to the abilities of the people. However these variables interact in a complex way, which makes the interpretation sometimes difficult. This leads us to the third "interaction" paradigm, stipulating that the focus of interest must shift from conditions-results to conditions-**interactions**-results. It means that researchers have to discriminate what kind of interactions are necessary for which kind of outcomes.

In our case, it means that not only the learning results but also the interactions produced by the Tinker Table must be taken into account. This kind of analysis involves broad observations like verbalizations, movements, level of implications or strategies used, in order to understand the particular cognitive activity induced by this system. For collaboration assessment, two kinds of tools can be used in order to evaluate to which extent people collaborate: either transcribe every utterance, code and count them to have a final "collaboration score", or rate the whole episode with the help of a rating scheme. This second solution is time-saving, and offers a good reliability with the first method. Such a rating scheme has been developed by Meier, Spada & Rummel (2007); according to them, the main characteristics of collaboration are communication (is the

group sustaining mutual understanding? Is there an appropriate dialogue management?), joint information processing (is there a good information pooling? Are they reaching consensus?), coordination (how good is the task division, time management, and technical coordination?), interpersonal relationship (are they polite and respectful?), and motivation (each person shows interest and try to find a solution). Consequently, this tool seems to be suited for rating every collaborative situation.

To our knowledge, the relation between tangibility and collaboration has never been fully studied. Marshall (2007) proposes that tangible interface may be particularly suitable for collaborative learning compared to a classical display, because it allows users to monitor each other's gaze and thus to interact more easily. It might also offer a better view of other's activity, and consequently help users to improve coordination. In our case, collaboration may also be improved by apprentices' confidence: the fact that they are working in a familiar context mixing two representations (an abstract one: grid, graphics, accessibility information; and a concrete one, tangibility, linked to their enterprise experience) may give them a feeling of expertise, and thus push them to more confront their point of view with other apprentices. However this hypothesis is completely exploratory, due to a lack of empirical results.

Exploration

Marshall also proposed that tangible interfaces have the potential to increase exploratory behaviors. The first reason he evoked is that tangibility are more natural and intuitive to use; therefore it may offer a particularly suitable "sandbox" for rapidly experimentating and gaining feedback. As a consequence, the cognitive effort would be less focused on the interface and more on the activity itself. The second advantage he pointed out was that by using physical material, tangibility can constrain student's exploration and lead them to consider more relevant trails for the understanding of a

concept. An example of a tangible interface that affords exploration is the illuminating light created by Underkoffler and Ishii (1998): this interface simulates laser light beams in relation with lenses, lasers and mirrors orientation. The user can thus test the theoretical model embodied by the system. The authors argue that this exploratory activity leads to a better understanding of the theoretical laws explaining light's behavior; however, these assumptions have never been empirically tested, so it's difficult to clearly affirm that a tangible interface encourages exploration, even if there are theoretical arguments in support of this idea.

Cognition and metacognition

Cognitive processes can be observed in several situations, especially during problem-solving phases. Jonassen (1997) proposed a terminology to differentiate well-structured and ill-structured problem solving: the former refers to all the problems that can be resolved by a fixed number of steps (e.g. the tower of Hanoi) while the latter possesses multiple solutions, solution paths and contains uncertainty about which solution is the best. Furthermore according to Artzt & Armour-Thomas (1992), a problem-solving situation can be reduced to 7 steps: read, understand, analyze, explore, plan, implement, and verify. From their point of view these phases can be categorized as cognitive (reading the problem), metacognitive (understanding, analyzing and planning) and cognitive and metacognitive (exploring, implementing and verifying). In their experiment, the more the students used metacognitive thinking, the more they were successful in their problem solving task. However Kung & al. (2007) found contradictory results, which means that it's possibly not only the quantity but also the quality of metacognition that are significant in a problem-solving task. Tschan (2002) also proposed a more sophisticated analysis: in her study, success in a problem solving task was predicted by the number of ideal cycles of communication. According to her, these

cycles contain three phases to be complete: planification, action and evaluation. Accordingly, such findings offer different interesting points of view for the understanding of cognitive processes behind a problem-solving activity.

In our case, it would be interesting to test Tschan's theory with a problem-solving task on a tangible interface, because this kind of situation allows us to observe cognitive and behavioral changes (see the method for more details); besides, logistic allows us to create interesting tasks with conflictual constraints. It also has an ecological validity, because problem-solving and learning are generally considered as similar processes.

Playfulness

Finally some studies suggest that tangibility might be particularly suitable for playful learning, especially among children (Price, Rogers, Scaife, Stanton & Neale, 2003). Marshall also argues that "As interaction with tangible interfaces is assumed to be more natural or familiar than with other types of interface, they might be more accessible to young children, people with learning disabilities or novices, lowering the threshold of participation". But again, this assumption has been poorly studied with experimental methods. We propose that this feature plays a positive role among logistic apprentices.

Other empirical studies

Very few studies have directly tested the effect of tangibility. Triona & Klahr (2003) have compared a task where the children had either to point and click or to grab a physical material. They found that subjects performed equally well in both conditions, meaning that nor the tangibility nor the computer was more efficient. Even if this study is not enough to prove that tangible material isn't improving learning, it indicates that

tangibility alone may not be a panacea. It is possible that the learning situation needs a mediatory variable to be really effective (like integrating relevant MERs and therefore level of abstraction). And it is also possible that the gain cannot be measured only by learning between pre-test and post-test. As Marshall proposed, there can be accessory benefits like enhanced collaborative learning, increased engagement, playful learning, etc… Changes in these variables may bring several benefits on the long run, so it's essential to take a deeper look at them during experiments. Moreover cognitive processes have to be more closely observed, in terms of strategies and level of abstraction.

Summary

The influence of tangibility on problem-solving situations and learning has been poorly studied until now; indeed, we lack empirical results for determining how this kind of interface influences behavioral and cognitive activities. However, many theoretical points of view make us think that tangibility may positively influence the performance of a problem-solving task, and at least four intermediary variables: collaboration, integration of representations, exploration and proportion of ideal cycles of communication.

Hypotheses

Given the fact that our goal is to observe how tangibility can influence problem-solving, our hypothesis is that tangibility represents an additional external representation that is relevant for the user and thus facilitates and enhances the problem-solving process. In our case, the fact that tangibility represents the workplace may help the apprentices to make better use of the knowledge gained there.

In order to test this assumption, we need two conditions that are as much as possible comparable from the point of view of usability; we are facing an important problem here, because it's difficult to design a warehouse situation as easy to manipulate as a tangible interface. Working with a paper and a pen does not allow the same type of tinkering, and would be time consuming. Therefore the two systems would not be very comparable: with a pen, half the time would be spend to erase, measure and redraw the warehouse, which involves completely different strategies and consequently would not answer the question of the specific influence of the tangibility. Working with 2D paper shelves could also be an option, because it's effortless and fast to reorganize the whole warehouse. However, the fact that you can grab and manipulate the pieces of paper makes the system partially tangible. The solution imagined here is to use the multi-touch table developed by the CRAFT. This system is as easy to use as the Tinker Table (you can move a shelf just by moving your finger on the multi-touch surface) and it has no tangible component (everything is included in one dimension, the augmented reality projected on the table). The comparison between those two interfaces allows us to entirely isolate the "tangibility" variable, which is the main goal of this work.

Consequently, we think that a tangible interface offers an additional representation which can help the apprentice to better understand a logistic situation by linking professional experience with the school knowledge. Comparatively, the multi-touch

interface has only a 2D representation, which offers a more abstract representation of the warehouse, and thus may be more related to school experiences.

It is quite reasonable to presume that apprentices are more comfortable in a mixed workplace-school than in a complete school situation, because they spend 4/5 of their time in the first one. As a consequence, their knowledge is for the most part constituted where they work. Thus, we think that different learning tools can be designed along an "abstract/concrete" continuum (see figure 7), where the utilization of a pen and a paper would be less adapted to apprentices' needs, because of their strong utilization in abstract situations; whereas a tangible interface is more on the "concrete" side of the continuum, and consequently easier to apprehend.

Moreover, we hypothesize that a multi-touch interface is closer to a paper / pen utilization than a tangible interface, because even if they are able to quickly organize a warehouse, run simulation and offer a representation of a warehouse's functioning, it lacks concrete relationships to real warehouses. Hence, our main prediction is that apprentices would better perform either learning or a problem-solving task with a tangible interface than with a multi-touch interface. This hypothesis is also related to several intermediary variables, which are detailed below.

Additionally, we hypothesize that the activation of the knowledge gained on the workplace would be visible by several observations. For instance, apprentices would have a more realistic representation of the distances due to the 3D property of the shelves and/or to their work experience; they would build a more efficient warehouse, because they are better able to see how time consuming a bad layout is for the forklift driver.

Besides, it would be interesting to test the theory of Tschan (2002) concerning the proportion of ideal cycles of communications. According to our hypothesis, the

“tangible” group would better perform the task because their two representations of the warehouse (the “school” and the “professional” representation) act in a complementary way and thus help them to better understand the problem and then picture potential solutions. As a consequence, we believe that they will have a more significant proportion of ideal cycles of communication compared to the multi-touch group. If the predictions of Tschan can be generalized to every problem-solving task, this ratio would be a good predictor of the performance.

Moreover, we would expect an improved collaboration between the dyad in the “tangible” condition. The reason for this is that by increasing the resemblance of the material and the workplace, apprentices will feel more confident and thus collaborate more, because they consider themselves as equally capable colleagues.

Two additional observations derived from Marshall (2007) can also be useful. This author proposes that tangible interfaces have the potential to make a situation playful, because of their novelty and their originality. It would be interesting to test this assumption by assessing the pleasantness of the interface; we believe that a flow questionnaire is well-suited for this purpose. Furthermore, a tangible interface is thought to be more adapted for explorative behavior, which is useful for an ill-defined problem. Consequently, we propose that apprentices in the tangibles condition will try more alternatives patterns then those in the multi-touch condition. It makes this variable an acceptable predictor for the global performance.

Finally, we will assess if the apprentices have learned something, with the help of a pre-test and a post-test. This is not our main hypothesis, because the time allowed for the task is short and the task itself is pretty simple.

Operational hypothesis

More specifically, our main hypothesis is the following:

- Logistic apprentices learn and perform better in a problem-solving task with a tangible interface compared with a multi-touch interface.

Our secondary hypotheses concern mediatory variables:

- In the tangible condition, apprentices have a better representation of the warehouse, including a better estimation of the distances;
- The proportion of ideal cycles of communication is a significant predictor of the global performance (according to Tschan, 2002);
- The collaboration is also improved in the group working with the tangible interface, because of a better feeling of competence;
- Playfulness (measured by a flow questionnaire) is increased among the apprentices in the “tangible” condition;
- The exploration is also increased in the “tangible” condition, because the interface is more familiar and natural;
- All the previous variables act as mediatory variables between condition (tangible or touch interface) and the performance.

Method

Design-based research

The project relies on design-based research. Practically, the development of the tinker table required iterative developments in collaboration with field specialists and close contact with real world conditions. Wang & Hannafin (2005) have proposed a definition which captures its main characteristics : design-based research is “a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories”. This kind of design is well suited for this context, because it connects researchers with teachers and apprentices from the “real world”. More specifically, it helped us identifying the research question and therefore building this experimental study.

Population

The subjects were 82 (9 female and 73 male) apprentices from the CPNV (“Centre Professionnel Nord Vaudois”) between 16 and 40 years old (mean = 20, SD = 5.4). The dyads were composed by following alphabetically the class list and were randomly assigned to either the tangible or multi-touch condition. 30 apprentices were following first year lessons (N = 16 in the touch condition, 14 in the tangible condition), and 48 second year lessons (N = 18 in the touch condition, 30 in the tangible condition). Among the 41 dyads, two were excluded because of technical problem during the experiment. All of them already used the Tinker Table at least one time, so they were comfortable with technical utilization.

Procedure

The experiments took place at the CPNV in Yverdon (CH). More precisely, the school let us use a big meeting room at the multimedia library, which was soundproof. A wall was completely transparent and was nearby a study room. However, it was empty most of the time, and even if there were some people the apprentices didn't notice them or didn't care about them. Consequently they were doing the task without any social pressure. The experiment took place during several normal lesson days; the groups composed by the teacher were allowed to leave the classroom during approximately one hour in order to participate to the experiment. The experiment room was close to the classroom, so the apprentices weren't disoriented to get to the right place.

When the two apprentices arrived at the experiment room, the dyad was randomly assigned either to the "tangible" or the "multi-touch" condition. The experimenter welcomed them and thanked them for their participation. Then, they were asked to individually fill the pre-test (appendix 1) during approximately 5 minutes. Generally the apprentices didn't spend more than 10 min on the test, and they had the occasion to do it the more carefully possible. After that, the experimenter took the sheets back and brought them to the small-scale Tinker Table. He told them the following instructions "you have to build a warehouse in order to put the maximum number of shelves possible. This is your primary goal; moreover the efficiency will also be assessed (meaning the mean distance from each shelf to each dock). During the first stage, you will have approximately 10-15 minutes to build your warehouse without any information about the correct distance in order to let a forklift move and work. The only forklift useable here is a Gerber. Then you will have 10 additional minutes with indications about the right distances in order to rearrange your warehouse. Try to make most of the shelves accessible and to maximize the space used". He also explained them that they can use a control sheet in order to observe the evolution of their warehouse.

The following informations were “augmented” on the paper: number of shelves, number of places accessible, mean distance to the expedition dock, mean distance to the reception dock, and mean distance to both docks. Then, as explained to the apprentices, they had some time to build the first version of their warehouse (minimum: 10 minutes, maximum: 15 minutes). If they were finished before this delay, the experimenter told them that they had more time to improve their layout. If they weren’t finished after 15 minutes, the experimenter told them to finish their last move and he went to the second stage. It was done by putting a sheet with tags above the camera, which made the grid appear. Then they had 10 minutes to correct their layout. During the last 5 minutes, the experimenter repeatedly gave them the time remaining in order to make them finish in time. The whole exercise was recorded by two cameras and one AKG – C 400 BL micro.

After the building task, they were asked to individually fill the post-test (appendix 2), which was identical as the pre-test, except that the warehouses’ layout varied. They had the same amount of time as the pre-test to complete it. And finally they had to fill a questionnaire, which addressed three types of questions: demographical (age, sex, study year…), in relation with their capabilities to estimate things in the warehouse (distance, specific situations …) and the flow questionnaire (for more details, see appendix 3). They had all the time they wanted for this last step, but no one exceeded 60 minutes for the whole experiment. Once they had completed the whole task, they were thanked for their participation and asked to get back to the classroom.

Material

The model of the Tinker Table used was the small-scale one, which includes the tangible interface (with video recorder on the top) and the multi-touch interface (with infrared recorder in the inverted pyramid under the table). The table is 107 x 107 cm large and 197 cm high. The surface projected (and therefore exploitable for the apprentices)

measures 38 x 53 cm. The whole system was moved from the EPFL to the CPNV a week before the experiments and appropriately tested in order to be sure that the system was fully functioning.

The manipulation of the shelves was twofold: either the participant was moving a small rectangle projected by touching the table (the multi-touch condition) or he was arranging the warehouse by grabbing them.

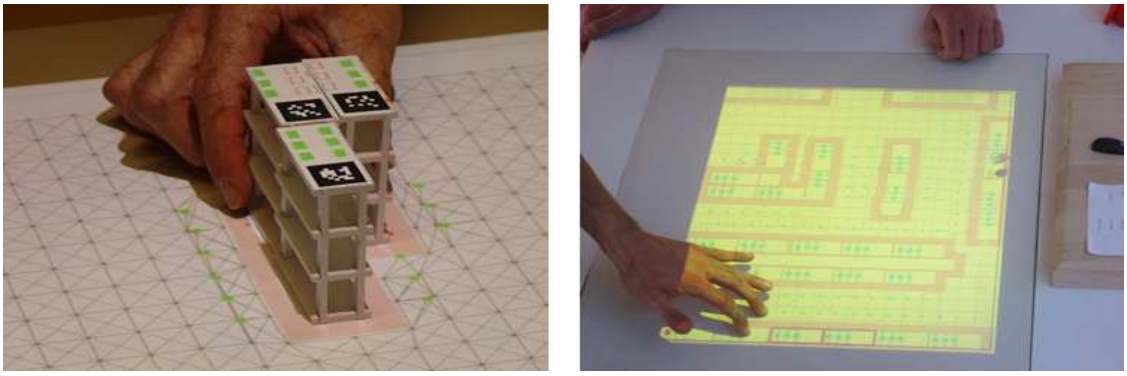

Fig 8: *tangible condition (left) and multi-touch condition (right)*

Each dyad was recorded with one webcam at the top of the table and one video recorder on the side. An additional microphone (AKG – C 400 BL) was used to record the apprentices' voices in order to get a proper sound signal.

Finally several questionnaires and observation grids were employed. First, an ad-hoc pre-test / post-test were designed to observe learning gain (annexe 1 and 2). Second, the collaboration was assessed by an adapted grid of the rating scheme developed by Meier, Spada & Rummel (2007); and third, we measured the flow with an adapted questionnaire of Novak, Hoffman & Yung (1998; annexe 3).

Measures

Main performance was measured by counting the number of accessible shelves in the warehouse. We also assessed the efficiency of the warehouse by analyzing the log files of the experiments (measured by calculating the mean distance from every docks to every shelf). Exploration was also measured with the experiment's logs, by counting the number of moves for every object (docks or shelves).

In our problem solving task, we looked at the general performance, but also between a pretest and post-test measure. In addition, we observed motivational, behavioral and cognitive changes. Firstly, collaboration was assessed by the rating scheme developed by Meier, Spada & Rummel (2007). As described before, several dimensions were used to capture the main characteristics of collaboration (according to them: communication, joint information processing, coordination, interpersonal relationship and motivation); then the total score was obtained by calculating the average of every dimension. This kind of scheme was highly useful to quickly estimate the quality of collaboration in a small group.

Secondly, we used a flow questionnaire to capture the main characteristics of the playfulness variable. Csikzentmihalyi (1990) has proposed the following definition for this concept: "flow - the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it". We won't detail the theory here but invite the reader to consult the book by Csikzentmihalyi (1993) which details every aspects of this theory. In our case, it is relevant to consider the study by Novak, Hoffman & Yung (1998), within which they developed a tool for assessing the user's flow state. This questionnaire can be easily adapted to different situations and help us assessing how much users enjoy a task. For example, we asked the apprentice to rate items like "I forgot about my immediate surroundings when I was building my warehouse", "building a warehouse challenges me", "building this warehouse challenged my capabilities to

their limits", "I consider myself knowledgeable about good warehouse building techniques", or "I felt excited during this task".

Finally, this problem solving task was analyzed as previously explained: by differentiating cognitive and metacognitive episodes (Artzt & Armour-Thomas, 1992) and by analyzing proportion of ideal cycles of communication (Tschan, 2002).

Results

Main hypothesis: the performance

The main hypothesis was that participants would better perform in a problem-solving task with a tangible interface than with a multi-touch interface. This was mainly measured by the number of shelves accessible in the warehouse, and secondarily by the efficiency of the layout (e.g. the mean distance from each dock to each shelf). The descriptive indices for the main performance (number of shelves) are as follows:

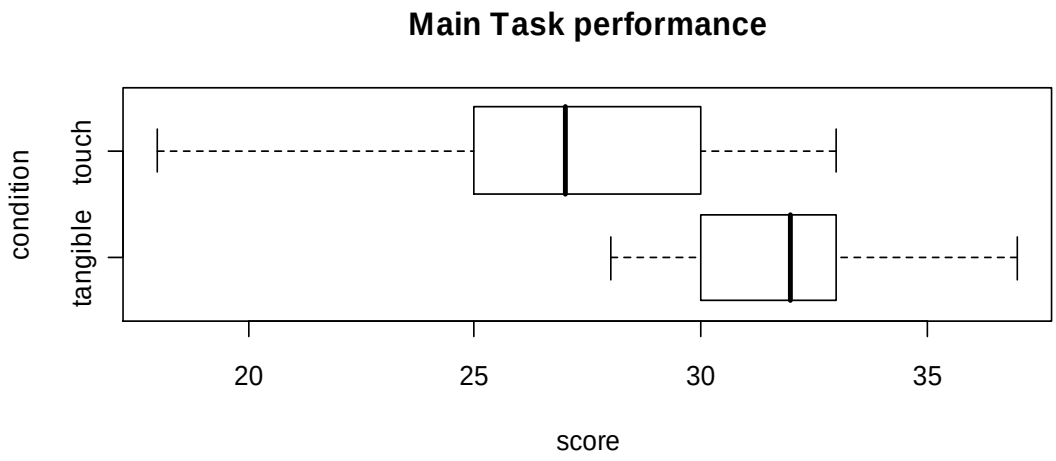

Fig. 9*: boxplots of the performance (number of shelves) between the multi-touch and tangible conditions*

As expected, participants in the tangible condition performed better than with the multi-touch interface, $t(32) = 4.873$, $p < .001$, meaning that they placed significantly more accessible shelves on the available surface.

Moreover, we also assessed the efficiency of the warehouse (meaning the mean distance from every dock to every shelf). Five dyads (3 in the tangible condition; 2 in the multi-touch condition) were excluded due to dock inaccessibility. We found that compared to the touch group (N = 15, mean = 17.3, SD = 4.51), the tangible group (N = 19, mean = 14.8, SD = 3.96) tendencially built warehouses with shorter and more direct alleys, $t(32) = -1.73$, $p = .09$.

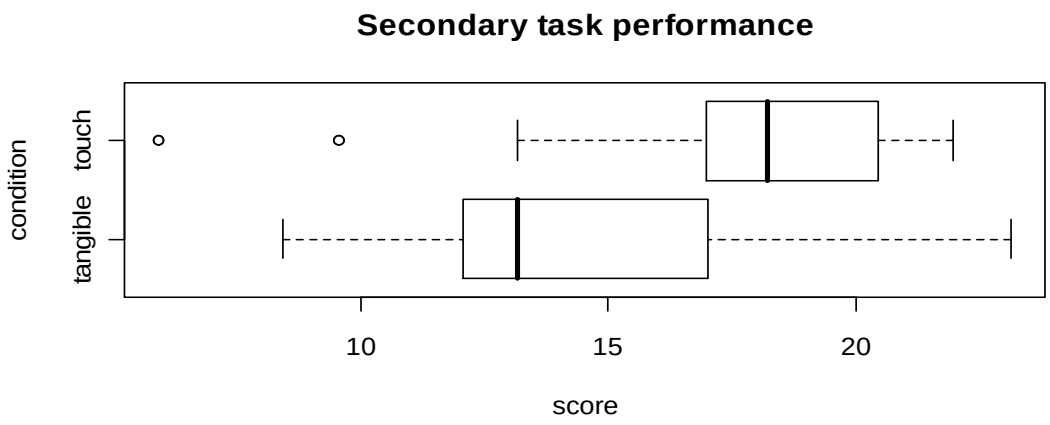

Fig. 10*: boxplots of the efficiency of the warehouse, between the multi-touch and tangible conditions. Low scores mean shorter paths, and thus increased efficiency.*

Moreover, it was hypothesized that using a tangible interface would provide a better learning gain than using a multi-touch interface. Measured by an appropriate pre-test / post-test, we computed a score for every subject by subtracting pre-test performance from the post-test. Then we followed the procedure described by Kenny, Kashy & Cook (2006) for dyadic analysis with undistinguishable members and independence within the dyad. Theses authors propose a multilevel analysis in order to analyze data from dyads.

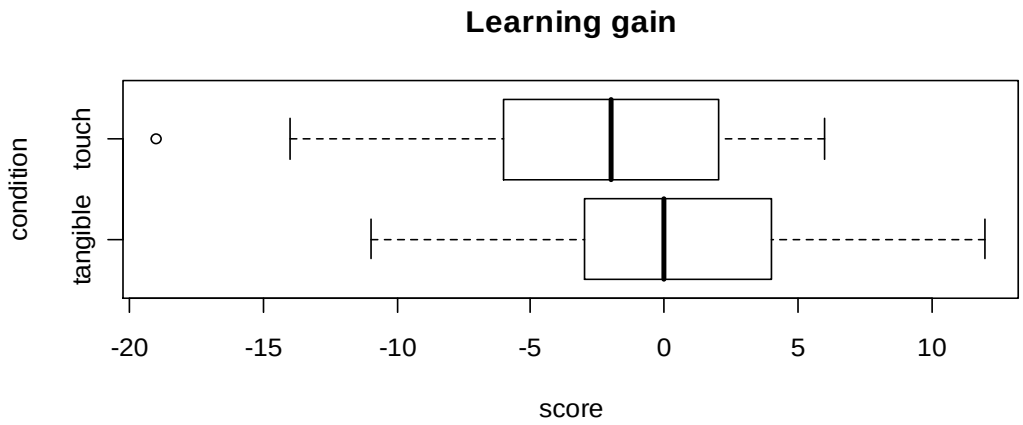

Fig. 11*: boxplots of the learning gain between the multi-touch and tangible conditions.*

Descriptive data are as follows: for tangible condition, m = .43 (SD = 5.4) and N = 44; for touch condition, m = -2.5 (SD = 5.9) and N = 34. The multilevel analysis with the group ID as a random factor yielded a significative effect, $F(1,37) = 6.68$, $p < .05$, meaning that the tangible group better succeeded than the touch group.

Secondary results: mediatory variables

As mentioned, the secondary hypothesis proposed that several variables (e.g. the collaboration between the members of the dyad, a good representation of the warehouse including accurate distance estimation, a state of flow, a higher proportion of ideal cycles of communication, and more exploration) played a mediatory role for explaining the performance.

Table 1

Mediatory variables

	Mean (SD) and t-test values				
	Exploration	Distance estimation	Playfulness	Collaboration	Proportion of ideal cycles of communication
Tangible	196.18 (72.9)	53.35 (10.6)	80.2 (6.9)	32.1 (4.3)	19.73% (.09)
Touch	130.35 (28.6)	51.3 (14.7)	76.2 (8.7)	27.2 (4.9)	11.76% (.09)
T-Test	$t(37) = 3.86$	$t(37) = 0.508$	$t(76) = -2.2$	$t(37) = 3.1$	$t(37) = -2.2$
Cohen's d	1.19	0.16	0.51	1.06	0.88
	$p < .001$	$p = .61$	$p < .05$	$p < .01$	$p < .05$

Referring to table 1, apprentices explored more alternative solutions in the tangible than in the touch condition ($p < 0.001$). They also found the tangible system more playful ($p < .05$), collaborated more ($p < .01$) and the proportion of ideal cycles of communication was significantly higher in this condition ($p < .05$). However they didn't better estimate the distance in the tangible or touch condition ($p = .61$).

The method used to estimate the influence of the mediatory variables is based on the article of Preacher & Hayes (2008). Unfortunately, this procedure doesn't take into account multilevel designs, but considering that the intraclass correlation isn't significative for the only individual variable (playfulness, measured by the flow questionnaire: $r = -.344$, $p = .879$), it is quite reasonable to conduct analysis on individual level (Kenny, Kashy & Cook, 2006).

We tested for simple mediation using Preacher & Hayes' bootstrapping methodology for indirect effects based on 5000 bootstrap resamples to describe the confidence intervals of indirect effects in a manner that makes no assumptions about the distribution of the indirect effects. Interpretation of the bootstrap data is accomplished by determining whether zero is contained within the 95% CIs (thus indicating the lack of significance). Results for multiple mediation showed that only exploration (CI: [0.02; 1.13]) was a mediator for performance.

Complementary analysis

We also tested which variable had a positive effect depending on the condition. Pearson's correlations showed that collaboration, $r = .57$, $p < .05$ (N = 17), and playfulness, $r = .53$, $p < .05$ (N = 17), were strongly related to a better performance in the touch condition. In the tangible condition, the only significant correlation was exploration, $r = .47$, $p < .05$ (N = 22).

Discussion

The purpose of this study was to identify how a tangible interface could influence a problem-solving task (and more broadly, learning). Following Dillenbourg's third paradigm (1996), a second focus of interest was discriminating which kind of behavioral and cognitive changes were necessary for a positive outcome. Hence five intermediary variables were studied in order to answer the following questions: to which extent apprentices explored the layouts of different warehouses, how playful the task was, to which extent they collaborated, if the integrations of multiple external representations brought secondary benefits, and how a tangible interface changed the quality of their cycles of communication.

Results provided evidence that first and second year apprentices better resolve a problem-solving task with a tangible interface than with a multi-touch interface. This means that tangibility is well-suited for the understanding and the search for solutions of a logistic problem. However it must be kept in mind that our results concern our specific sample (logistic apprentices who are at the beginning of their studies; so we may call them "novices") with a specific task (space optimization in a warehouse, which is a pretty simple problem considering that it does not involve any mathematical abstraction; so we may call this task a "basic" problem). We do not have any results concerning expert users, or complex tasks; nevertheless our results about behavioral and cognitive changes between the tangible and the multi-touch interfaces allow us to formulate some hypotheses concerning that point. This will be discussed later on.

Our results also suggest that tangibility may enhance learning compared to a multi-touch interface. Indeed, apprentices using the former interface had a better learning gain than the apprentices using the latter, even if the "touch" group performed the post-test less well then the pre-test. This can be explained by a complexity gap between the two tests, because the layouts of the warehouses in the post-test were more complex and more difficult to analyze than those in the pre-test. This argument is

supported by the fact that apprentices performed equally well between the pre/post-test for the questions unrelated to the layouts of the warehouses and had more difficulties in answering questions related to them. If they would have “unlearned” how to analyze a warehouse and how to optimize it, it would have been observable on every question. Consequently, we can suppose that tangibility improves learning for “novice” users working on “low-level” problems.

Our main hypothesis for explaining these differences was that the integration of a concrete representation (linked to professional experience) and an abstract representation (linked to school knowledge) would explain why tangibility enhanced performances. The operationalization of this idea was done by asking the apprentices to estimate the distance necessary for a forklift to work during the building their warehouse (first half of the task, approximately 10 minutes). We believed that when using a tangible interface, an apprentice would more likely see himself in the warehouse, driving the forklift (for instance, because it is a knowledge he gained in the workplace), and consequently better judge which space was necessary to work because he could more easily access his professional experience. Unfortunately, this yielded no significant results, probably because their motivation to build a warehouse with many shelves was stronger than their motivation to carefully respect the specifications of a warehouse; indeed, when one apprentice said that an alley was too short, the other one generally answered “yes but… we can put more shelves this way, and maybe it’s enough; after all we can correct it afterwards”. As a result, future studies have to create a more appropriate measure order to appropriately answer this question.

Moreover the study of cognitive and behavioral changes during the task brought us many insights about how apprentices solved the problem. The only variable that yielded a significant intermediary effect was the exploration (measured by the number of shelf’ moves). This means that the most important behavior predicting performance in this “basic” task was to explore as many layouts as possible, and the apprentices using the

tangible interface benefit from this very fact. It implies that tangibility has the potential to increase exploration, and by this medium to enhance performance of a basic problem-solving task.

Collaboration was also increased by tangibility, even if it was correlated with success only in the touch condition. This can be explained by the fact that in the tangible group, it wasn't necessary to coordinate the work since one person alone could build the whole warehouse. In the touch group it wasn't so easy, because the representation of the warehouse was more abstract, and thus the apprentices felt more the need to plan their action and coordinate their efforts. So we can hypothesize that the more you go on the abstract side of the logistic interfaces, the more the collaboration becomes important and thus a predictor of performance. Moreover, the question to be addressed here for future research would be to test if collaboration enhances performance in more complex problems with a tangible interface, and if experts would more benefit from this advantage than "novice" apprentices.

Results also showed that playfulness was increased in the tangible condition, which indicates that apprentices felt that the task was more adapted to their capacities, that this exercise was a challenge for them, and that they felt excited about the task (these are illustrative items from the flow questionnaire). However this measure was only correlated with success in the touch condition, meaning that everyone had very high flow scores in the tangible condition; as a consequence, it did not affect their performance. Hence, the more the apprentices were in the flow in the touch condition, the more they scored good results.

Finally we also followed Tschan's methodology (2002) for assessing the quality of the cycles of communication. We found that the tangible group had a significantly higher proportion of ideal cycles compared to the touch group; this means that the quality of the communication was improved by working on the tangible Tinker Table. But again, this variable wasn't a mediator for performance, so we can imagine that a high proportion of ideal cycles of communication is maybe more important in a more complex problem-solving task. This result shows that the proportion of ideal cycles of

communication and performance may be correlated, but not causally related. Since Tschan only tested her result with a hierarchical regression analysis we cannot claim that a high proportion is the cause of a good performance, but only predicts a good achievement.

Conclusion and future work

As a result, we can conclude that tangible interfaces have the potential to enhance not only problem-solving tasks and learning, but also to promote constructive behavior (exploration, collaboration) and cognitive activities (being in a flow state, have ideal cycles of communication). Even if every variable mentioned is not intermediary for explaining the performance or the learning gain, we can hypothesize that it will likely produce positive outcomes in the long run. Indeed our task was pretty short and simple, so therefore we need to observe more ecological gains (for instance the effect of this system after several months of utilization).

This study has, however, several limitations. The main practical drawback is that the experiment was performed on prototypes. As a consequence, each system had disadvantages: the multi-touch table sometimes slowed down when too many shelves were placed on it, and the projection on the tangible interface frequently blinked due to light conditions, thus causing trouble for the cameras to detect the tags; therefore apprentices lost quite some time “micro-touching” the shelves in order to make them appear for the system. This caused a loss of time in both situations and consequently introduced a bias in the experiment. Besides, a conceptual limitation of this study is the limited scope of implication of these results: a more complete factorial plan would have been more appropriate to determine the influence of tangibility.

Therefore future research is needed to explore at least four dimensions (figure 9): firstly, what is the influence of the users' expertise when using the tangible interface. Are they advantaged or disadvantaged by the concreteness of the interface? Does it limit the understanding of a concept or on the contrary, improve it (1)? And linked to that question, what is the influence on moving on the concrete-abstract continuum for designing interfaces (2)? Are experts more comfortable being on the abstract side, or do they benefit equally or more from a concrete interface? Our hypothesis is that the more you move along the abstract continuum, the more it will be suited to expert users. However this needs to be assessed in additional empirical studies. Thirdly, we believe that the size of the group plays a role in the way the group works because every situation is not appropriate for collaboration (3).

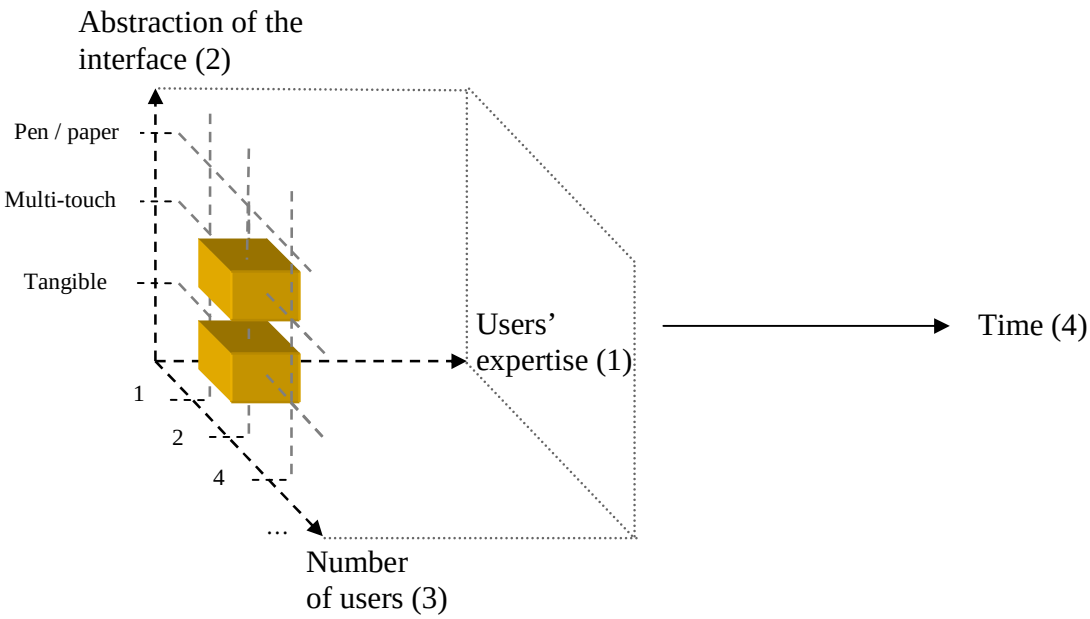

***Fig. 12**: Area studied (yellow cubes) and dimensions to be explored*

Finally, probably the most important need is to evaluate the long-term benefits in a real classroom (4). This would imply an expensive experimental setting; nevertheless this point is crucial for determining the real benefits that the Tinker Table could bring in an ecological environment.

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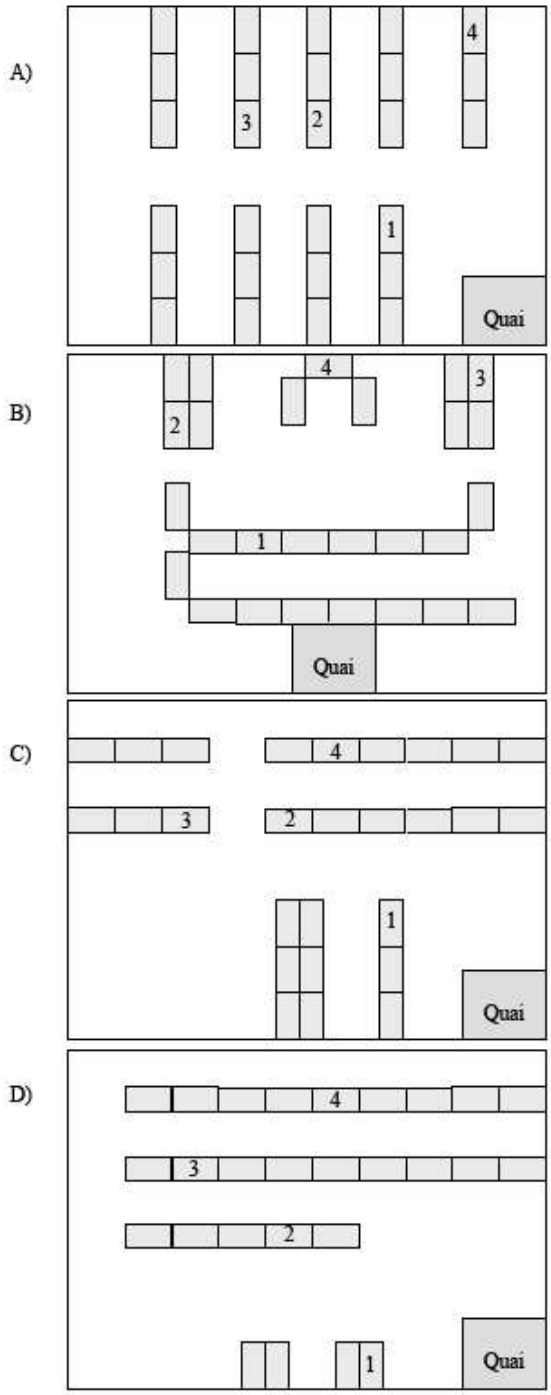
Appendix

This is the material used during my experiment at the CPNV. It includes:

1. The pre-test
2. The post-test
3. The final questionnaire (about demography and the flow state)

1. Pre-test



Voici quatre entrepôts A, B, C et D ; chacun contient le même nombre d'étagères (40) et dispose d'un quai de réception et d'expédition. Les numéros 1, 2, 3 et 4 sont quatre palettes à sortir de l'entrepôt.

Exercice 1 : Classer ces quatre entrepôts (A, B, C et D) en fonction de leur utilisation de l'espace (dans lequel pourriez-vous rajouter le plus d'étagères ?) :

(rajouter le plus) 1 ____
2 ____
3 ____
(rajouter le moins) 4 ____

Exercice 2 : Classer ces quatre entrepôts en fonction de leur rapidité de navigation (lequel met le moins de temps pour ramener, une par une, les palettes 1, 2, 3 et 4?).

Vous pouvez dessiner le chemin suivi par le chariot élévateur sur les plans:

(moins de temps) 1 ____
2 ____
3 ____
(plus de temps) 4 ____

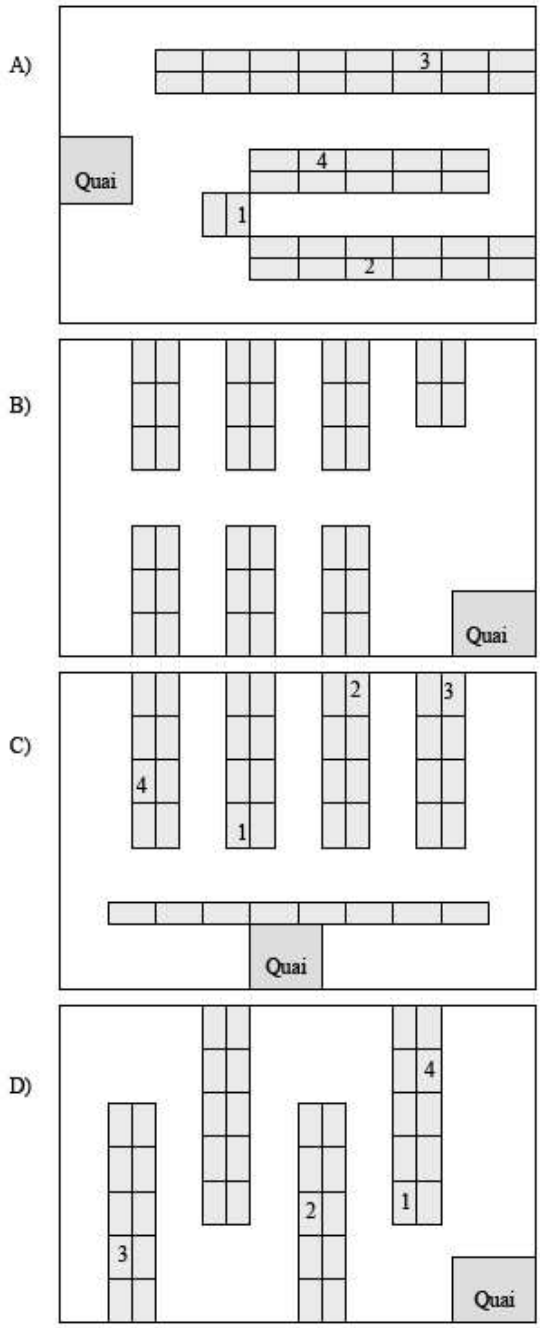
Exercice 3 : Pour **gagner de la place** dans un entrepôt il faut (cochez ce qui convient, plusieurs réponses possibles):
___ des allées courtes
___ des allées étroites
___ des allées longues
___ des allées larges

Pour **gagner du temps** dans un entrepôt, il faut :
___ des allées courtes
___ des allées étroites
___ des allées longues
___ des allées larges

Exercice 4 : Si vous deviez choisir un de ces entrepôts comme lieu de travail, lequel vous plairait le plus ?

Le mieux : ____
Pourquoi : _____

2. *Post-test*



Voici quatre entrepôts A, B, C et D ; chacun contient le même nombre d'étagères (40) et dispose d'un quai de réception et d'expédition. Les numéros 1, 2, 3 et 4 sont quatre palettes à sortir de l'entrepôt.

Exercice 1 : Classer ces quatre entrepôts (A, B, C et D) en fonction de leur utilisation de l'espace (dans lequel pourriez-vous rajouter le plus d'étagères ?) :

(rajouter le plus) 1 _____
2 _____
3 _____
(rajouter le moins) 4 _____

Exercice 2 : Classer ces quatre entrepôts en fonction de leur rapidité de navigation (lequel met le moins de temps pour ramener, une par une, les palettes 1, 2, 3 et 4?).

Vous pouvez dessiner le chemin suivi par le chariot élévateur sur les plans:

(moins de temps) 1 _____
2 _____
3 _____
(plus de temps) 4 _____

Exercice 3 : Pour **gagner de la place** dans un entrepôt il faut (cochez ce qui convient):
___ des allées courtes
___ des allées étroites
___ des allées longues
___ des allées larges

Pour **gagner du temps** dans un entrepôt, il faut :
___ des allées courtes
___ des allées étroites
___ des allées longues
___ des allées larges

Exercice 4 : Si vous deviez choisir un de ces entrepôts comme lieu de travail, lequel vous plairait le plus ?

Le mieux : _____
Pourquoi : _____

3. *Final Questionnaire*

Questionnaire

Paire n°

Participant n°

Questions générales

Nom :

Sexe : Homme / femme

âge : .....

Année au CPNV : 1ère / 2ème

Aviez-vous déjà utilisé la table (petite ou grande version) avant aujourd'hui?

Oui O | Non O

Questions concernant l'exercice

A quel point l'entrepôt que vous avez dû construire ressemble à l'endroit où vous travaillez?

pas du tout O | un peu O | moyennement O | assez O | beaucoup O

Travaillez-vous avec des palettes sur votre lieu de travail? Oui O | Non O

Travaillez-vous avec des étagères sur votre lieu de travail? Oui O | Non O

Travaillez-vous avec un Gerber sur votre lieu de travail? Oui O | Non O

Selon vous, quel était la surface totale de l'entrepôt (que vous avez construit) en sachant qu'il a été réduit 50 fois?

..... m^2

Selon vous, quel autre chariot élévateur serait adapté à votre entrepôt?

.....

Pendant la construction, avez-vous favorisé l'efficacité de l'entrepôt ou la place disponible?

.....

Pendant la simulation, imaginons qu'un chariot élévateur passe plus de temps devant une étagère pour saisir une palette. Selon vous, est-ce possible dans la réalité? Si oui, quel en serait la cause?

.....

Questions sur votre appréciation de l'exercice

	Pas du tout d'accord		Moyennement d'accord		Complétement d'accord
Je suis doué pour organiser un entrepôt	1	2	3	4	5
Je pense connaître les bonnes façons de construire un entrepôt	1	2	3	4	5
J'en connais moins que la plupart des gens sur la façon De construire un entrepôt	1	2	3	4	5
Cet exercice représentait un défi pour moi	1	2	3	4	5
Cet exercice était représentatif de mes capacités	1	2	3	4	5
Mes capacités étaient tout juste suffisantes pour bien réussir cet exercice	1	2	3	4	5
Je n'ai pas eu besoin de beaucoup de créativité pour réussir cet exercice	1	2	3	4	5
Je me suis senti(e) libre pour construire cet entrepôt	1	2	3	4	5
L'entrepôt que j'ai construit n'est pas très original	1	2	3	4	5
Construire cet entrepôt n'était pas très intuitif	1	2	3	4	5
J'ai pensé à d'autres choses sans rapport pendant cet exercice	1	2	3	4	5
J'étais totalement concentré sur cette tâche	1	2	3	4	5

	Pas du tout d'accord		Moyennement d'accord		Complétement d'accord
J'ai oublié l'environnement qui m'entourait pendant la tâche (p.ex. la présence de l'expérimentateur)	1	2	3	4	5
J'avais l'impression d'être en face d'un vrai entrepôt	1	2	3	4	5
Je me sentais excité pendant la tâche	1	2	3	4	5
j'étais calme pendant que je construisais mon entrepôt	1	2	3	4	5
J'avais l'impression d'être passif pendant la tâche	1	2	3	4	5
J'étais content de faire cet exercice	1	2	3	4	5
Je me sentais irritable pendant cet exercice	1	2	3	4	5
J'ai essayé d'expérimenter différentes choses pendant l'exercice	1	2	3	4	5
Cela m'a plu d'essayer différentes possibilités	1	2	3	4	5
Je me suis ennuyé pendant la tâche	1	2	3	4	5
Je me suis senti frustré pendant cet exercice	1	2	3	4	5