My Hands or my Mouse: Comparing a Tangible and Graphical User Interface using Eye-Tracking Data

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ABSTRACT
Tangible User Interfaces (TUIs) have drawn the interest of HCI and learning communities because of their potential positive impact on the learning experience.

In this paper, we describe a preliminary study of a TUI application for training spatial skills of carpenter apprentices. We design a tangible interface to perform a CAD modelling activity in a way that resembles what apprentices do on the workspace: shaping a wooden brick through sequential cuts by using a saw. The core of the study is to compare the effects of TUI and GUI on the user experience, by taking advantage of eye-tracking data. We report two main achievements: first, the successful employment of eye-gaze tool in the TUI research which represents a novelty per-se. Second, a significant impact of the TUI on the user experiment which gives some insights about the cognitive benefit of tangibles.

Categories and Subject Descriptors
H.5 [Information Interfaces and Presentation]: User Interfaces; K.3.1 [Computer Uses in Education]: Computer-assisted instruction

General Terms
Design, Human Factors

Keywords
Tangible Interfaces, Eye-Tracking, Vocational Training

Introduction
One main challenge in designing tools for technical and vocational education is to bring together abstract concepts, such as spatial thinking, and the daily workspace practice. Particularly for craftsmen, the physical contact with their creations is a fundamental feature of the job. Hence, these people can find it really tough to work on virtual representations of objects, for example when using Computer-Aided Design (CAD) software, since it involves the use of spatial abilities to map the 3D worlds on the 2D screen. Spatial skills can be trained[15]. TUIs seem to be well suited for spatial skill training, since the physicality of the tool can support the user in building a mental model of an object and can provide an intermediate level of abstraction between a real object and its representation on the screen[2].

In order to explore what kind of tasks TUIs can be effective for, we designed and developed a new activity for eTapacarp, our online platform for the training carpenters. The activity consists in a CAD task, during which the apprentice virtually shapes a brick according to a given concrete model. This activity is conceived to be the first stage of a whole process which mimics the carpentry fabrication workflow: from the design of an object up to the final concrete realization of the object through computer numerical control machine (CNC) or traditional manual tools.

In this study, we expose the design of our tangible tool and the comparison with a graphical (GUI) implementation. We will mainly focus on the results obtained from eye-tracking data, which provides some insights into the impact of the physicality and concreteness of the interface on the user experience. The differences found in the gaze behaviors represent the main contribution of this study, as well as the employment of eye-tracker in the TUIs research. In the next sections we present: (1) a brief literature review regarding the eye gaze analysis; (2) a description of the exp-
perimental task, the setup and the terminology used in the results section as well as the research questions; (3) a summary of the results; (4) a discussion of the results and the conclusions.

Related Work

TUI interfaces made their first appearance in the mid-1990s [4], but under the name of Graspable User Interface. Later, the name changed to Tangible UI [8] to include also interactive surfaces and ambient media for background awareness. Tangible interfaces have become popular on account of the general assumption that hands-on activities can provide positive educational outcomes. However, it is not clear what features may foster learning gains compared to the use of virtual materials [10]. Some authors questioned if TUIs relate more to entertainment than to learning [11].

In [5], the authors highlight that three-dimensional forms of chemical molecules can be understood more readily through the haptic feedback and the perception of a concrete model than through the virtual representation alone. McNeil and Jarvin [11] identify contributes from the object, which provides an additional resource and activates real-world knowledge, and from the manipulation, which generates motor schema and are supposed to enhance memory and understanding. Moreover, TUIs may be particularly suitable for collaborative learning tasks compared to classical graphical interfaces, because the shared space may allow participants to be aware of each other’s activity, promote joint attention and establish shared references[14].

Eye-tracking methodology has been rarely employed for exploring TUIs, although it has been highly promising in interaction and usability research. The gathering of gaze movements and events provides a huge amounts of data and the main challenge is to find appropriate ways to use and interpret the data [9]. Fitts, Jones and Milton [3] have employed eye-trackers to discover differences in the gaze patterns of pilots using two control systems for the aircraft. The article reports the number of fixations and the percentage of dwells on an area of interest, which are correlated with the importance of the area, as well as the average duration of the fixations or the average duration of the dwells, which provide indications of a participant’s difficulty extracting information from the area.

Other interesting metrics are the return time, which is the average time it takes until a participant returns to an area already looked at, and the transition between areas of interest. The first can serve as a measure of the working memory and to reveal an area of fundamental interest for the task accomplishment, while the latter indicates connected components and suggests how to improve the design of the interface [6].

In the context of Computer Supported Collaborative Learning (CSCL), joint attention in collaborative learning tasks has been explored through the use of dual eye-tracking. In [12], the authors used synchronized eye-trackers to evaluate the level of collaboration between two programmers working on a section of code. Results suggest a positive correlation between productivity and high joint visual recurrence. Schneider, Abu-El-Haija and Reesman [13] applied network visualization in order to embed moments of joint attention to a mouse-based implementation? In order to answer these questions, we will look for variations of gaze patterns between two experimental conditions, tangible and virtual.

Experimental Setup

Research Question. This study aims to identify the kinds of tasks that exploit the properties of tangible user interfaces to facilitate spatial reasoning. Manipulating a mental model of an object, as well as linking such a model to a virtual representation can be challenging. Hence our hypothesis that having a tangible object can support spatial reasoning activities [1].

However, what happens when the physical object becomes completely different from its virtual representation during the task, passing from a state of “literal” correspondence to a “symbolic” one? If the tangible object and the virtual representation are not co-located2, it might be that after a while the user forgets the physical properties of the tangible object, leading to a “tokenization” (e.g. using it as a mouse). Our questions are: is there any advantage in using TUIs when the physical-virtual correspondence changes during the task? Do tangibles bring any benefits compared to a mouse-based implementation? In order to answer these questions, we will look for variations of gaze patterns between two experimental conditions, tangible and virtual.

The cutting activity. The cutting activity has been designed to teach the fundamentals of CAD software through a practice familiar to carpenters, such as cutting an object with a saw. The rationale for adopting this task in carpentry learning is its grounding in the real-world context, since it is inspired by the workflow of carpentry.

In the beginning of the activity, the participant received a styrofoam model that (s)he had to cut (Figure 1). The starting shape was a parallelepiped brick displayed on a screen (Figure 2a). The virtual brick laid on a grid, whose concrete counterpart was a paper workspace taped on the table in front of the user. The grid was the only measurement tool available during the task. The screen representation did not allow to change the point of view and the brick could only be moved on the grid and rotated only along the vertical axis.

The saw was depicted on the screen as a cutting plane, which could be moved on the grid and tilted. Moreover, when in horizontal position, it was also possible to change its elevation from the ground.

The cutting activity proceeded through a sequence of interactions between the plane and the brick: when the user decided to cut, the cutting plane split the brick into two or more fragments (Figure 2b). Each fragment could then be

1 A dwell is a lumped sequence of fixations on the same object or area.
2 In the same location and close spatial proximity
3 These constraints came from technical limitations in detecting the tangible objects with webcams.
selected and deleted; otherwise it was possible to perform a new cut in order to achieve more complex shapes (Figure 2c and 2d). All actions were reversible.

![Styrofoam Models](image1)

**Figure 1: Styrofoam Models**

![Task Sequence](image2)

**Figure 2: Example of task sequence**

**Design.** There were two experimental conditions: tangible and virtual. In the tangible condition, participants used a styrofoam brick to manipulate the virtual object on the screen and some physical tools to control the cutting plane and to trigger the cut. The tangibles could be freely arrange within the workspace and could be removed from the workspace.

In virtual condition, all the tools were virtually on the screen as graphical elements and they were controlled with a mouse. In both condition the target shape was provided as a styrofoam object.

**Materials.** eTapaCarp is a web application based on HTML5 standards and JavaScript. The platform is designed to be low-cost, since one of the main issues that affect the distribution of TUIs in the classroom is the high-cost of the technology. The web-based interface allows students to use the system in all classrooms equipped with computers as well as at home or on their mobile devices. Moreover, a web application is easier to maintain and offers a wider possibility of diffusion and visibility.

The setup of the TUI activities requires the presence of a webcam to detect the objects and tools, which are identified by one or more fiducial markers. This allows to get their positions and orientations relative to the workspace. The workspace and the objects are rendered on the screen from a fixed perspective camera view. The calibration between the workspace world coordinates and the virtual space is demanded to a routine, which computes the homography between the two spaces.

Figure 3a shows the tangible implementation of the activity. The styrofoam brick in the blue circle is used to control the model on the screen. In the beginning of the task, the dimensions of the two bricks, the real one and the virtual, are the same, but, as the task progresses, the correspondence becomes less and less literal. The control styrofoam brick is smaller than the target styrofoam shapes, since this choice avoids that users in TUI condition might be facilitated, for example by overlapping the brick and the model. The elements in red circles define the ground line of the plane. At construction time, the plane is perpendicular to the grid and passes through this line. The wheel in the green circle tilts the plane between -90 and 90 degrees. Even if there is no physical constraint for the wheel, the angle is constrained to that range. When the plane reaches the horizontal position, the slider highlighted in violet allows to change the plane elevation. Finally, the tool in yellow acts as a utility knife and triggers the cuts (detailed view in Figure 3b).

In the virtual condition, the tools are replaced with their graphical counterparts on the screen controlled with the mouse (Figure 3c). The user drags and drops the brick on the workspace and rotates it through a knob interface (the blue circles). The two markers defining the plane line are replaced by the two spheres in red circles, which are draggable as well. The knob in green and the slider in violet replace respectively the wheel for tilting and the slider for changing the elevation. The utility knife has been replaced by a button.

The only graphical elements shared between the two implementation are a set of colored buttons to select the fragments, a text field containing the current tilt angle of the plane, and two buttons to delete a fragment and to undo the last action (Figure 3c fuchsia squares).

**Participants.** Eighteen undergraduate students took part to the experiment, 2 females and 16 males, from 2nd to 4th academic year, 7 Mechanical Engineers and 11 Microtechnique engineers. They had a prior knowledge of the 3D modeling and CAD software thanks to their academical curricula. Each participant has been randomly assigned to one of the two experimental conditions. However, the analysis excluded two participants (both female) from our population as they represented outliers in the distributions of the duration.

**Procedure.** First, the participant filled out a questionnaire about age, gender, academic background, skill level in using CAD software, hours per week spent in using CAD, habit of playing 3D videogames and hours per week spent playing. Additionally, we asked them to write the titles of CAD software and videogames.

After the questionnaire, each student performed a pre-test to evaluate mental rotation skills: the first test was a mental rotation test, including 12 questions. Each question allowed 2 possible correct answers and the participant was asked to mark both of them to get one point; the second test was about paper folding. It included 10 questions with only one
correct answer per question. The time limit for each test was 3 minutes.
At the next stage, the participant started using the interface. This stage included 3 parts: (1) the demo, in which we explained the task through a demo session in order to get acquainted with the system. When the participant felt to be ready, we move to the next trial; (2) the trial 1, the target shape was symmetrical (Figure 1a). The minimum number of cuts to achieve it is 6 cuts, producing 10 fragments; (3) the trial 2, the target shape was asymmetrical, which made it the more difficult trial (Figure 1b). The minimum number of cuts to achieve it is 5 cuts, producing 5 fragments.
At the end of the task, a short interview about the experience was conducted.

Results
The statistical tests used ANOVAs on linear models or, whenever this was not possible, we employed non-parametric tests. Repetitions were taken into account using mixed effect models when needed.
In the next sections we will use the abbreviation "ScreenOBJ" to indicate the virtual object displayed on the left part of the screen and the area around it. "ScreenGUI" refers to the right part of the screen containing the graphical interfaces. In the tangible setup it contains only the buttons to select the fragments and delete them, the undo button and a label showing the current tilt angle of the plane. In the virtual setup, this area contains also all the graphical control elements to rotate the brick, change the elevation of the plane etc., as mentioned previously.
The term "Brick" will be use to denote the styrofoam control brick available only in the tangible setup, whereas the term "Shape" will refer to the target styrofoam objects. The "Brick", the "Shape" and the "ScreenOBJ" form the set of the representation areas of interest(AOIs), since they embed spatial information of the object the participants are working on. The term "Workspace" will refer to the paper workspace and identifies an area of interest only for the tangible condition, since in virtual condition the user had no brick and no tool on the grid. Finally, we define an "Out" area which refers to everything not covered by the other AOIs. This area contained the mouse and sometimes the tangible tools not in use.
These six terms and the relative AOIs will be referred mostly in the eye tracking results(Figure 4).

Quality of Outcomes and Time Performance. The quality of the solutions the participants came up with has been assessed by asking five raters to give a score between 1 and 4: (1) the shape is completely different from the model; (2) one major mistake, but the target shape is still recognized; (3) shape is mostly correct, really minor mistakes; (4) correct shape. The inter-rater reliability was 0.93. We did not appreciate any relevant differences in the quality of the final solution between the two conditions as shown in table 1: in general, the solutions for trial 1 were mostly correct with an average score above 3, while for trial 2 the average score was 2.6.
The time to accomplish the tasks was slightly higher for the tangible conditions, in which participants took around 2 extra minutes compared to the virtual setup in both trials, as shown in Table 2. However, the difference was not significant (for trial 1 F[1,14]=2.48,p=.13, for trial 2 F[1,14]=1.08,p=.31). By including time before the first cut for trial 1, the one-way test reveled that participants in the tangible condition performed the first cut earlier compared to the ones in virtual condition. In particular, the first cut was performed on average after 51 seconds (SD: 13 s) using the TUI, whereas it happened after 1 minute and 6 seconds (SD: 14 s) using the mouse, and the difference was statistically significant (F[1,14]=4.33,p=.05). However, for trial 2 the time differ-

Nevertheless, the paper workspace was also present in the virtual condition.
Fragments Created. When using the tangible and virtual interface, the participants respectively performed on average 10.5 cuts and 8.75 cuts for trial 1, whereas 7.37 cuts and 6.75 cuts for trial 2; however, the difference was not significant: for trial 1, \( F[1,14]=2.54, p=.13 \), for trial 2, \( F[1,14]=0.36, p=.55 \). Surprisingly, we found a significant difference between the two conditions in terms of number of fragments created during the tasks: as shown in Figure 5, the group using tangible interface created on average 67% fragments compared to the virtual condition in trial 1, and 46% in trial 2 (for trial 1 one-way Welch’s \( F[1,9.26]=7.13, p=.02 \), for trial 2 \( F[1,14]=5.03, p=.04 \)).

### Table 1: Average Quality Scores

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangible</td>
<td>3.05 (SD 0.63)</td>
<td>2.65 (SD 0.52)</td>
</tr>
<tr>
<td>Virtual</td>
<td>3.08 (SD 0.83)</td>
<td>2.67 (SD 1.16)</td>
</tr>
</tbody>
</table>

### Table 2: Average Duration

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangible</td>
<td>8 min and 16 s (SD 3 min and 8 s)</td>
<td>9 min and 42 s (SD 3 min)</td>
</tr>
<tr>
<td>Virtual</td>
<td>6 min and 7 s (SD 2 min and 10 s)</td>
<td>8 min an 6 s (SD 3 min and 8 s)</td>
</tr>
</tbody>
</table>

Gaze Analysis. Since the experiment duration varied among the participants, we conducted further analyses on the dwells in terms of percentages. Figure 6 shows the overall partition of the dwells on each AOI for the two trials. The first result is the sum of the average dwells spent on the "ScreenGUI" and "Workspace" using TUI is nearly equal to the average dwells spent on the "ScreenGUI" using GUI in both trials. Since these areas contains most of the control tools, this result has positive implications for the design of the interface (for trial 1 \( F[1,14]=0.21, p=.64 \), for trial 2 \( F[1,14]=0.27, p=.61 \)).

The average percentage of dwells on the tangible brick constitutes a non-negligible amount in both trials. By restricting the analysis only to the representation AOIs, it is evident that the average percentages of "ScreenOBJ" are not statistically different between the two condition in both the trials: for trial 1, tangible avg=72.32 (SD 10.30), virtual avg=72.43 (SD: 17.41); for trial 2, tangible avg=59.93 (SD 10.83), virtual avg=57.10 (SD 20.31). As a consequence, we can state that the "transfer" to the "Brick" is from the "Shape". Moreover, Table 3 shows that TUI users allocate less time to "Shape" compared to GUI participants and such difference is close to be significant in both trials (for Trial 1 Welch’s \( F[1,8.74]=4.64, p=.06 \), for Trial 2 \( F[1,14]=4.24, p=0.05 \)).

![Figure 5: Number of fragments created](image)

![Figure 6: Proportions of dwells on the AOIs](image)

### Table 3: Percentage of dwells spent on the "Shape" over the total dwells spent on representation AOIs

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangible</td>
<td>13.47 (SD 6.19)</td>
<td>27.56 (SD 17.41)</td>
</tr>
<tr>
<td>Virtual</td>
<td>27.17 (SD 7.12)</td>
<td>42.89 (SD 20.38)</td>
</tr>
</tbody>
</table>

In order to explore differences in the average duration of dwells between conditions, we employed linear mixed model. Given the nature of the test, the user identifier was taken into account as grouping factor. In general, the results indicate that tangible participants had on average shorter dwells towards the "Shape" area compared to virtual ones in both the trials. For trial 1, tangibles users on average spend 616 ms on the "Shape" area.
Comparing the average duration of the dwell on the "ScreenOBJ", we notice an increase in the average duration of this area when using the virtual interface. The results from the linear mixed model analysis suggests that in trial 1 tangible users looked at the AOI on average 1.5 s (Est. = 1590.65, Std.E. = 100.71, t(14) = 15.79, p < .00). This average increases by 420 ms in the virtual condition (Est. = 163.72, Std.E. = 2.56, p = .02). The same trend is visible for trial 2, but less significant. In this case, the average duration for tangible users is almost 1.5 s (Est. = 1499.37, Std.E. = 108.19, t(1662) = 13.85, p < .00), but the increment using the graphical interface is only 291 ms (Est. = 291.92, Std.E. = 171.08, t(14) = 2.45, p = .02).

An overview of the transitions among AOIs is shown in Figure 7 and Figure 8. On each direct edge is reported the average percentage of transitions between the two areas over the total transitions. As expected, the transitions between "ScreenOBJ" and "ScreenGUI" characterize the virtual condition, since all the tools lie on the screen. As well, these transitions play an important role also in tangible condition during the trial 1, as shown in Figure 7b. As for the percentage of dwells, in trial 1 (Figure 7) the transitions between "ScreenOBJ" and "Shape" of virtual condition are split almost equally among the three representation AOIs in the tangible setup. The same effect does not emerge so clearly in the trial 2 (Figure 8), where the transitions on the "Brick" are less prevalent, mainly due to the "Out" area, which absorbs most of them.

Table 4 and Table 5 show the average percentages of transitions between the representation AOIs for the tangible setup. In both cases, we notice a ScreenOBJ centric distribution, which for trial 1 exhibits an equal distribution of transitions between Brick - ScreenOBJ and Shape - ScreenOBJ. However in trial 2, the transitions toward the Brick account only for the 25.36% (Sd: 13.70%), which is still an interesting proportion, but definitely smaller than the one toward the Shape (62.04% sd: 18.54%). Finally, the transitions between "Brick" and "Shape" amount only a small percentage of the total transitions in both trial 1 and trial 2, respectively 10.42% (sd: 9.67%) and 12.59% (sd: 9.48%).

### Table 4: Adjacency matrix of transitions among representation AOIs in Tangible Condition for Trial 1

<table>
<thead>
<tr>
<th></th>
<th>Shape</th>
<th>Brick</th>
<th>ScreenOBJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>5.72 (sd: 4.37)</td>
<td>21.29 (sd: 6.18)</td>
<td>19.72 (sd: 8.65)</td>
</tr>
<tr>
<td>Brick</td>
<td>4.7 (sd: 5.71)</td>
<td>22.7 (sd: 6.59)</td>
<td>25.67 (sd: 7.69)</td>
</tr>
<tr>
<td>ScreenOBJ</td>
<td>22.7 (sd: 6.59)</td>
<td>25.67 (sd: 7.69)</td>
<td>25.67 (sd: 7.69)</td>
</tr>
</tbody>
</table>

### Discussion and Conclusions

The aim of this study is to explore the impact of a tangible interface compared to graphical interface when performing a task which involves a change of the coupling between a physical representation and a virtual one over time. The fact that the average percentages of dwells on the "Workspace", "ScreenGUI" and "Out" AOIs do not exhibit a significant difference between the two conditions may be an indicator about the homogeneity of the two interfaces, in the sense that there is no considerable overhead or penalty in the adoption of either the tangible control tools (i.e. wheel for the tilt angle) or their virtual counterparts. From the point of view of the TUI design, these results indicate that a tangible interface can be effective as well as intuitive and engaging.

![Figure 7: Transitions for Trial 1](image)

![Figure 8: Transitions for Trial 2](image)
The significantly higher average number of fragments created when using TUIs suggests a "conservative" strategy among the participants. Given that the average number of cuts does not differ in both conditions, our interpretation is that users tend to keep most of the fragments till the end and delete the unnecessary ones afterwards. This way, they keep a reference between the physical brick and its virtual representation on the screen, which otherwise would be lost. Furthermore, six out of eight participants confirmed this strategy explicitly during the final interviews. However, another explanation could be a tendency to minimize the switching among the tools, preferring the use of one tool during longer periods instead of switching between the brick, the plane, the mouse etc.

The physical feedback provided by the brick seems to provide a positive effect on building a mental representation of the shape and the task: the shorter time before the first cut using TUI may indicate a more readily comprehension of the model and its 3D representation. The similar time till the first cut in the trial 2 is probably due to a learning effect. However another explanation could be the novelty effect of the TUIs, that is lost in the second trial.

Although the literal correspondence between the physical control brick and the graphical model gets increasingly lost with each cut, the eye-gaze data shows a considerable percentage of transitions and dwells toward such as area, indicating that participants kept on looking at the control brick. The hypothesis that the tangible brick becomes a "token" was not confirmed. This suggests that the participants continued perceiving the tangible object and its physical properties.

Moreover, there are significant differences in the gaze behavior on the "Shape" and "ScreenOBJ", which is surprising since the contents of the two areas are the same in both conditions. The average duration of the dwell on the "ScreenOBJ" is lower using TUIs, despite the average percentage of dwells being the same in both conditions. Longer duration is typically related to a difficulty in extracting information, thus this result suggests that the physical brick can help in understanding the graphical model. Indeed, our interpretation is that it is more difficult to extract information from 3D object without the support of a physical object, which contains information that eyes and hands can easily perceive, such as the depth. On a screen, depth is obtained from 3D object without the support of a physical object, which contains information that eyes and hands can easily perceive, such as the depth. On a screen, depth is obtained using dashed lines, which involves the additional cognitive step of decoding the order of surfaces and lines from their rendering properties.

The lower percentage of dwells on the "Shape" in the virtual condition compared to TUI does not necessarily mean that participants look less at the area, but it indicates a split of the attentions between the two areas. "Shape" represents the final goal, so it embeds all the information required to achieve the task, however the tangible representation acts as a control and embeds the digital information in physical form, which maximizes the coupling between manipulation and the underlying computation, reducing the abstraction between the physical action and the virtual action on the screen [7]. The direct alignment between the physical world system in which the shape is located and the virtual one could reduce the mental effort: the "Brick" provides a bridge between these two spaces, since it is located in the real world and, at the same time, on the screen. Thus, what the user perceives in the physical world is also presented in the virtual one. Moreover, we believe that the longer average dwell duration on the "Shape" in virtual condition indicates a difficulty with coding the execution plan directly in the graphical interface rather than a difficulty with reasoning about the shape per-se. The simple action of positioning the 3D object in the virtual condition required a sequence of clicks or drag-and-drop actions, forcing the user to perform an extra mental effort, whereas manipulating the tangible brick was immediate and direct.

The graph plots show the centrality of the "ScreenOBJ" and its strong connection with the "ScreenGUI". Besides their relative proximity, the small size of the color palette for distinguishing the fragments of the block may have played a big role in increasing their connectivity: when there were more then 10 fragments, the pigeonhole principle forced the
users in a “trail-and-error” behavior, which increased the percentages of transitions. In order to check this hypothesis, we aim to plot the transitions over the time and check the presence of an accumulation toward the end of the task or before a delete action.

Regarding the representation AOIs, the transitions between "Brick" and "Shape" in TUI are quite rare: intuitively, this result can be explained by the fact that the two areas represents diametrically opposed stages of the task, the initial state and the final one. Hence, the major transitions involve always the "ScreenOBJ": the Brick-ScreenOBJ references are needed especially to visualize the effect of the plane intersection after the positioning of the TUIs, and, obviously, the Shape-ScreenOBJ transitions accounts for the actions of matching and planning.

Our study is preliminary in nature and focused on comparing TUI and GUI. The study was conducted in a laboratory setting with a relative small number of participants. Additionally, we discovered some technical issues that could negatively impacted the user experience. For example, when moving the two plane fiducial markers, participants tended to occlude them and the plane disappeared from the screen. Moreover, precise aligning the plane on the paper workspace grid was more difficult than doing it on the virtual grid using the mouse. These two factors might have discouraged participants from moving the plane, and made them prefer the manipulation of the brick, which appeared more stable. Finally, all final solutions were mostly correct, which led to a ceiling effect. All participants were skilled in CAD software and modelling.

In conclusion, two main results came out of this study: first, eye trackers can be used as a research tool to capture variations among participants using TUIs. Its implementation in TUI research represents a novelty and we believe that this result contributes to encourage its adoption as research tool to study the cognitive effects of tangibles, particularly, in order to facilitate the design of "hands-on" learning activities. Second, during the experimental task, the participants in the tangible condition have shown gaze values which can be interpreted as indicators of less demanding mental efforts, suggesting some cognitive advantages in using TUIs even when the tangible object and its virtual representation do not share the same geometrical information. For a follow-up study, we plan to implement longer TUI activities in real carpentry classroom with large numbers of students with a range of spatial abilities. An extended version of the activity could include actually cutting the physical control brick after simulating the cut virtually. This way will give us the chance to validate our intuitions on a larger population out of the laboratory and to assess whether our TUIs are effective in improving the apprentices’ learning outcomes.

1. REFERENCES


