THE EFFECTS OF TANGIBLE USER INTERFACES ON DESIGNERS' COGNITIVE ACTIONS

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Abstract. This paper presents a study of the comparison of tangible user interfaces and graphical user interfaces on designers' cognitive actions. We conducted individual design experiments using the protocol analysis method. The results reveal that designers using the tabletop system with 3D blocks reasoned more about spatial relationships among 3D objects, while the designers using the keyboard and mouse reasoned more about individual 3D objects.

1. Introduction

In recent years, a number of researchers have developed tabletop systems with tangible user interfaces (TUIs) as a new platform for human-computer interaction. The various configurations of tabletop systems, with and without Augmented Reality (AR), support designers in creating and interacting with digital models by coupling digital information with physical objects. Compared to the graphical user interfaces (GUIs), the tactile interaction of the TUIs has the potential to offer significant benefit to designers of 3D physical systems. We use the protocol analysis method to collect think aloud data while a designer designs and analyse the verbal and gestural protocol to characterise the impact of the TUIs on designers' cognitive actions. We have studied design collaboration and found improved spatial understanding of object relationships (Kim and Maher, 2005). In this paper we focus on an individual designer in order to capture verbal think aloud data rather than verbal communication for collaboration to see if we can reproduce the results in a design cognition study.

2. Experiments Set-up: a tabletop design environment with TUIs vs. a desktop design environment with GUIs

In devising an experiment that can highlight the expected improvement in spatial cognition while using TUIs, we chose to compare designers in the following settings: A tabletop design environment with TUIs and a desktop design environment with GUIs (Maher and Kim, 2005). Table 1 shows the experiment settings.

TABLE 1 Experiment settings

	A tabletop environment with TUIs	A desktop environment with GUIs
Hardware	Tabletop system	Desktop computer
Input device	3D blocks	Mouse & Keyboard
Application	ARToolkit	ArchiCAD
Display	Vertical LCD screen & Horizontal table	Vertical LCD screen
Task space	Horizontal table	a mouse & keyboard

The tabletop design environment includes a horizontal projection surface and a vertical display screen to facilitate multiple views of the 3D model. 3D blocks with tracking markers in ARToolKit (Billinghurst, 2000) were placed on the tabletop and used as multiple, specialized input devices, TUIs, where designers manipulate the 3D virtual objects directly. 3D blocks are "space-multiplexed" input devices that can be attached to different functions, each independently accessible. On the other hand, the desktop design environment is a typical computer comprising a screen, a mouse and keyboard. Despite the physical form, the mouse has no physical contextual awareness and the movement simulated by the mouse lacks tactile feedback. The mouse or keyboard produce indirect interaction as a generalised time-multiplexed input device controlling different functions at different times (Fitzmaurice, 1996).

The design tasks are two renovation designs of similar complexity. We changed the order of interaction method and design tasks, so the use of two environments is the major variable in the study. Designers were requested to verbalise their thoughts as they reasoned about 3D objects and their spatial relationships. The data recorded includes verbal account and physical actions given by the designer. We focus on capturing the contents of what designers do, attend to, and say while designing, looking for their perception of discovering new spatial information and actions that create new functions in the design.

3. Analysis

Our coding scheme is classified into three categories: "Cognitive actions" which reflects the content of the designers' cognitive actions including visual and non-visual information, "Co-evolution" which reflects the reformulation

of and extending the design problem, and "Exhibited gestures" which reflects designers' gestures exhibited during the design session. We use a total of five categories in the coding scheme as shown in Figure 1: 3D modelling actions, perceptual actions, set-up goal actions, co-evolution and exhibited gestures. We describe the result of one participant as a case study here.

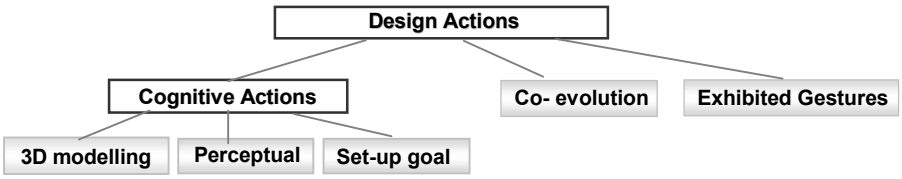

Figure 1. Coding categories

3.1. 3D MODELLING ACTIONS

3D modelling actions refer to the physical actions including the selection and placement of 3D objects. We combined some of the 3D modelling codes into three generic activities since we paid attention to the information of whether or not actions are new for each design action. There is a significant difference in the duration of these design activities across the two design environments. The designer spent twice as much as time revisiting in the TUI session compared to the GUI session (Figure 2).

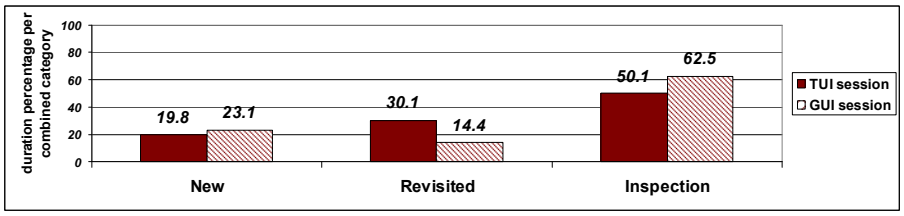

Figure 2. 3D modelling actions in the TUI and GUI sessions

3.2. PERCEPTUAL ACTIONS

Perceptual actions refer to the actions of attending to visuo-spatial features of the artefacts or spaces. We investigated attention to an existing design feature, creation of new design features, and unexpected discoveries as a measure of designers' perceptive abilities for spatial knowledge. Figure 3 shows the number of occurrences of the codes for "object", "spatial relation", and "unexpected discovery".

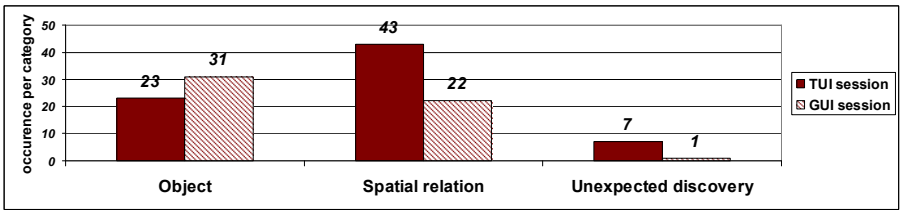

Figure 3. Perceptual actions in the TUI and GUI sessions

The designer spent more time reasoning about spatial relationships among 3D objects while using 3D blocks. We interpret the above findings as empirical evidence for the changes in designers' spatial cognition when using a TUI because they suggest that the designer's perception of the spatial relationships is improved in the tabletop design environment.

3.3. SET-UP GOAL ACTIONS

Set-up goal actions refer to the actions of introducing new design issues or functions, which should be carried through the entire design process as one of the design requirements. This category highlights the designer's ability to extend the problem space by capturing important aspects of the given problem. If a design issue emerges for the first time, it is defined as the Situated (S) - invention of issues (Suwa, 1998). Figure 4 shows the differences in the number of goals generated in the two design sessions.

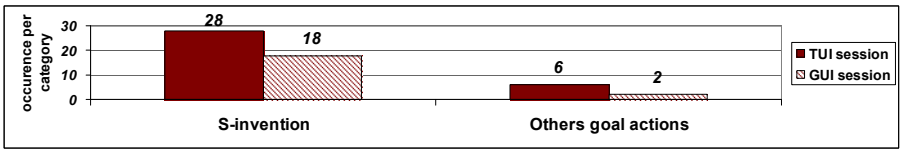

Figure 4. Set-up goal actions in the TUI and GUI sessions

This result indicates that the TUI environment may stimulate the designer to find new functional relationships, which extends the problem space.

3.4. CO-EVOLUTION

Co-evolution refers to design activity that explores the spaces of problem requirements and design solution iteratively, two spaces evolving separately and affecting each other. The amount of time spent in the two design spaces is measured and shown in Figure 5. The TUI session shows a longer duration in "problem space". Christiaans reported that the more time a subject spent in understanding the problem, and using her/his own frame of reference in forming conceptual structures, the better able s/he be achieve a creative result.

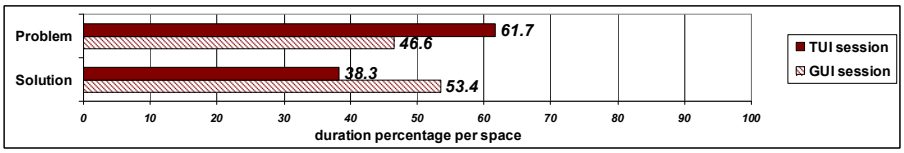

Figure 5. Co-evolution in the TUI and GUI sessions

3.5. EXHIBITED GESTURES

This category refers to the designers' movements other than the 3D modelling actions. Speech and gestures together characterise the designers' understanding of spatial relationships among entities, which are closely related to and may even be beneficial for cognitive processing. The measurement of gestures is shown in Figure 6.

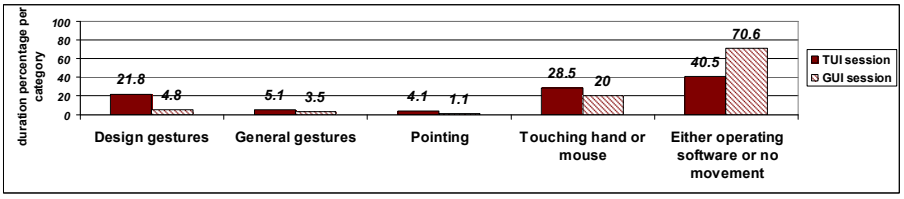

Figure 6. Exhibited gestures in the TUI and GUI sessions

It was observed that the designer often touched the 3D blocks in the TUI session like the speech-accompanying gestures using the mouse in the GUI session. The most significant difference is that the designer did whole body interaction with the representation, using "design gestures" such as large hand movements, in the TUI session, compared to looking in the GUI session.

5. Conclusion

The empirical results of this case study indicate that when using a tabletop system with TUIs, the designer attends to or creates new spatial relations between artefacts or spaces more than when using a GUI. Further, a change in the designer's spatial cognition encouraged him to discover hidden features or spaces, leading to the invention of new idea issues. Creative design seems more to be a matter of the reformulation of a problem by defining and understanding the problem space. Thus, we consider the tabletop system with TUIs as a very powerful platform for creative design that involves reasoning about 3D objects and their spatial relationships. Knowledge of the implications of the differences in spatial cognition can be a basis for a guideline on the tabletop systems for design applications. More protocols of individual designers are being analysed to reinforce these findings.

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