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The effect of Tangible User Interfaces on Cognitive Load in the Creative Design Process

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ABSTRACT

The aim of the study is to investigate how Graphical User Interfaces (GUI) and Tangible User Interfaces (TUI) affect the creative design process in design education through cognitive load. A simple design problem was introduced to 30 design students in two groups. One group was provided with a TUI that was operationalized through a Desktop Augmented Reality Environment (AR) the other group was provided with a GUI that was operationalized through a Desktop Virtual Reality Environment (VR). After using the two systems the cognitive load of each interface was measure through the NASA TLX tool.

Theories from cognitive psychology, information sciences, and design cognition were combined to provide an explanatory mechanism of how these media types affect the design process. The results indicate that epistemic action in TUI's such as AR interfaces reduces cognitive load thereby reducing fixation in the design process and enhancing the creative design process.

Keywords: Augmented Reality, Design, Cognitive Load

Index Terms: K.3.1: [Computers and Education]: Computer Uses in Education; J.5: [Arts and Humanities]; I.3.7: [Computer Graphics]: Three-Dimensional Graphics and Realism

1 INTRODUCTION

The use of digital tools in design education has dramatically increased through years. These tools have been commonly used as representational collaborative and communicative media. Among the various digital tools, Graphical User Interfaces (GUI) have been more popular.

More recently the use of Tangible User Interfaces (TUI) have increased as well [1]. In the light of such usage it is important to understand how these tools affect design and design education.

Kirsh and Maglio [2] introduced the concepts of epistemic action and pragmatic action. They discussed how expert players of the popular video game Tetris conserve their cognitive resources by trying different positions of the Tetris cubes rather than trying to figure it out in their minds. These experimental moves, which they termed epistemic actions, allow the players to use their cognitive resources for something else. Fitzmaurice [3] used the same terms in discussing tangibility in user interfaces. He introduced the concept of graspable user interface (considered to be similar to TUIs) and suggested that the tangibility in interfaces such as Augmented Reality (AR) interfaces allow more epistemic action, thereby reducing the cognitive load and conserving mental effort.

Few studies have focused on cognitive load in the realm of design and design education. The current study focuses on understanding the theoretical connections between cognitive load and interface type by bridging theories of cognitive psychology, information science, and design cognition theory

The results of this study provide a better understanding of how users are affected by such interfaces and can be used to formulate a comprehensive structured pedagogical agenda for digital design. Additionally, knowledge gained through this exercise can be applied to design education and design practice in order to promote creativity in the design process.

2 COGNITIVE LOAD AND TANGIBLE INTERACTION

Cognitive load theory was first defined by Sweller [4]. He described it with regard to instructional design. Sweller suggested that the design of the instruction should not overload the learner's mental capacity. The working memory of an individual has limited capacity and overwhelming the working memory reduces the effectiveness of the instruction. For example, if an interface is complicated and is difficult to navigate, a higher workload will be imposed on the learner, thereby reducing effectiveness of the learning process. Similarly, if an interface used in the design process imposes a higher workload on a designer, the effectiveness of the design process is reduced. Cognitive load can be defined as the total amount of mental activity on working memory at an instance in time [5]

Cognitive load is often discussed in tandem with split-attention effect. Split attention effect is described as the effort that a learner has to make to understand pictorial and textual information. Slijepcevic [6] stated that the split attention effect may be reduced by TUI's such as AR because they operate by "integrating multiple bits of visual information into one view" (p 2) thereby reducing the cognitive load. Moreover, many studies have suggested that cognitive load can be reduced by TUI's [7], [8].

Kirsh and Maglio [2] defined epistemic action and stated that epistemic action reduces cognitive load. They further elaborated that epistemic actions denote physical actions that improve cognition by reducing the memory involved in computation, reducing the number of steps involved in mental computation, and reducing the probability of error of mental computation. Furthermore, Wilson [9] stated that cognitive

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processes are deeply rooted in the body's interactions with the world. She stated that people off-load cognitive work onto the environment. Wilson explained that when people off-load the cognitive task two strategies are used. The first strategy uses preloaded representation from prior learning and the second strategy reduces cognitive load by using epistemic actions to change the working environment. By using interfaces that offer tangibility, as in the case with TUI's, the resulting epistemic action can be hypothesized to reduce cognitive load.

3 METHOD

The research question posed was "How does interface type affect cognitive load?" The hypothesis was that "The type of user interface used in design problem solving affects the cognitive load exerted by the user interface"

Thirty volunteers participated in the study. After announcing the research opportunity to design students (juniors and seniors) at a Midwestern university in the US, students were offered a chance to participate in the study. The participants were then randomly assigned to the two TUI and GUI interaction environments. All 30 participants completed the entire study. Only one participant was male; all other participants were female. One participant was in the age group of 30-35; all other participants were in the age group of 18-25. In the GUI group, 7 participants were juniors and 8 were seniors and in the TUI group 9 were juniors and 6 were seniors.

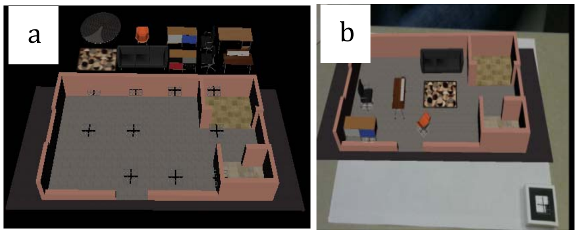

Figure 1: Floor plan of the office space in the a.)TUI and b.)GUI

In this study the task was to arrange furniture within a small 15'X10' office space. The floor plan was rectangular and had openings for windows and doors. The participants were asked to consider object manipulation, spatial and logical iterations, context, and user-behavior issues, while also keeping in mind visual appeal, composition, environmental consideration, and ergonomic factors. The software BuildAR (a software developed by Hitlabs, New Zealand) was used in developing the experimental environment. Although the primary use of BuildAR is in creating Desktop AR scenes, it can be used to create both 3D AR and VR desktop scenes. BuildAR uses fudicial markers in order to overlay the virtual objects in physical space. In simulating the VR environment the screen transparency was set to 0 and in simulating the AR environment the screen transparency was set to 100.

After completing the design the participants were administered the NASA Task Load index (TLX) tool to measure the cognitive load imposed by the two interfaces.

NASA TLX is a two part evaluation procedure consisting of both weights and ratings. By combining both a composite score is obtained. In the first part of the evaluation the participant was provided with 15 possible pairs of combination of the six sub scales, mental demands, physical demands, temporal demands, own performance, effort and frustration. The participant was instructed to circle one of the subscales in each pair that contributed to the workload of the design task. At the end the number of times each subscale was circled was tallied (the scores ranged from 0 to 5). The numbers were considered as the weight of each subscale and were entered in the Sources of Workload Tally Sheet from the NASA TLX tool. This was considered the weight score for the subscale.

Figure 2: a.) Subjects working in a.) TUI and b.) GUI

In the second part of the evaluation, the participant was provided a sheet with the subscales and rating scales. Participants circled the scale based on the magnitude of the effect of the particular subscale on the design task. This was considered the raw score for the subscale. Using the Weighted Rating Worksheet, the raw score was multiplied by the weight score for each subscale to obtain an adjusted rating for each subscale. The sum of the adjusted ratings of each subscale was then divided by 15 to give an absolute workload or the cognitive load of the design task in the respective interface (TUI and GUI).

4 ANALYSIS & DISCUSSION

Cognitive load of all 30 participants was calculated and compared between the TUI and GUI interfaces. One-way Analysis Of Variance (ANOVA) found a statistically significant difference between the two interface types (F(1,28) = 4.395, p = .0045). The results suggest that the cognitive load in the TUI was lower than in the GUI.

Table 1

One-way ANOVA Summary Table for Interface Type and Cognitive Load

	Sum of Squares	df	Mean Square	F	p
Between Groups	5.309	1	5.309	4.395	.045
Within Groups	33.821	28	1.208		
Total	39.130	29			

5 CONCLUSION

The main research question of the study focused on the effect of user interface type on the Cognitive load imposed by the interface. Tangibility in user interfaces such as AR interfaces offers epistemic action that reduces the cognitive load, thereby reducing fixation effects in the design process as compared to other interfaces such as GUI's

The study showed that the cognitive load was lower in the TUI as compared to the GUI. That difference between interfaces was significant. . Epistemic actions offered by the tangibility in interfaces such as AR appear to reduce cognitive load imposed by the interface, thereby reducing fixation and enhancing the creative design process.

Few studies suggest a connection between cognitive load of a system and fixation in the design process. Results of these studies suggest that by reducing cognitive load, fixation in the design process can be reduced. The current study suggests a correlation between epistemic actions and fixation in the design process.

AR is being introduced to different fields and different education levels. One such current trend is its adoption in K-12 education. Instructional design relies on reducing cognitive load in order to improve learning efficiency. As the current study suggests, AR imposes a relatively low cognitive load on the user, and therefore can be adopted efficiently into education curricula.

Even though TUI's such as AR has existed for several decades, there is a gap in the knowledge about how human factors affect the use of AR. Better understanding of user experience factors in AR environments is important for a number of reasons. Cognitive load effects how people interact and perceive technologies. With the emergence of new hardware that has the capability of supporting TUI applications, interest in how to use this technology efficiently has been increasing. Such studies are only currently becoming accessible to researchers because of the recent maturation of the technology.

Furthermore this finding can be applied to areas other than education. For example, AR devices such as the Epson Moverio BT200 are being introduced for use in operations and maintenance in facility management. As more devices such as these become available, knowing which technologies have less cognitive load is important. Chandrasekera [10] described a method of using AR in design critiques as an alternative to physical prototyping and he observed user perception of the technology. The results of the current study provide additional justification for using AR in the design process.

Future directions are seen in replicating the current study and using neuroimaging technology to understand the changes in brain function during the design process. Chandrasekera & Yoon [11] used a neuroimaging device to analyze the changes in brain function during the design process. Even though a comprehensive analysis was not performed, the preliminary results showed a connection between brain function patterns and the associated cognitive load.

REFERENCES

[1] Stouffs, R., Janssen, P., Roudavski, S., & Tunçer, B. (2013). Computer Vision and Augmented Reality Technologies in Experimental Architectural Design Education at the AA. Paper presented at the Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2013).

[2] Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. Cognitive Science, 18(4), 513-549.

[3] Fitzmaurice, G. W. (1996). Graspable user interfaces (Doctoral dissertation, University of Toronto).

[4] Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12(2), 257-285.

[5] Cooper, G. (1998). Research into cognitive load theory and instructional design at UNSW. Retrieved August 8: 2003. http://dwb4.unl.edu/Diss/Cooper/UNSW.htm

[6] Slijepcevic, N. (2013). The effect of augmented reality treatment on learning, cognitive load, and spatial visualization abilities. (Doctoral Dissertation, University of Kentucky).

[7] Haniff, D. J., & Baber, C. (2003). User evaluation of augmented reality systems. Paper presented at the Information Visualization, 2003. IV 2003. Proceedings. Seventh International Conference.

[8] Klatzky, R. L., Wu, B., Shelton, D., & Stetten, G. (2008). Effectiveness of augmented-reality visualization versus cognitive mediation for learning actions in near space. ACM Transactions on Applied Perception (TAP), 5(1), 1-23.

[9] Wilson, M. (2002). Six views of embodied cognition. Psychonomic Bulletin & Review, 9(4), 625-636.

[10] Chandrasekera, T. (2014). Using augmented reality prototypes in design education. Design and Technology Education: an International Journal, 19(3), 33-42.

[11] Chandrasekera, T., Yoon, S.-Y (2014). Using augmented reality tools to enhance design creativity. Paper presented at the Environmental Design Research Association Conference, New Orleans.