From Design Cognition to Design Neurocognition

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Introduction

Design is one of the most profound acts of humans and is the way in which we intentionally change both the physical and virtual worlds around us. Design is mentioned in the earliest extant writings of humans. It appears in *The Epic of Gilgamesh,* which dates back over 4,000 years. The first mention of design appears around the same time as the earliest writings about mathematics, philosophy and science. Design is one of the ways a society increases its economic and social wealth. Given its longevity it is surprising that the formal study of design dates back only to the twentieth century. The scientific study of design, design science, commenced only about 60 years ago.

In English the word "design" is used both as a noun and a verb and its use is disambiguated by its context. We will, in general, use the word "design" to mean the outcome and "designing" to mean the process of producing a design.

There are many designers and teachers of designing who claim that designing cannot be studied scientifically since its results are not reproducible. Whilst designs can be studied what we are interested in when studying designing are the processes that go to make up the acts of designing. It is assumed that there is some regularity exhibited by those processes and it is those processes and that regularity that is being studied. The scientific study of designing borrows it methods directly from the scientific method. It carries out controlled experiments in laboratories and in-situ studies in the field.

Designing was initially studied within the framework of information processing before moving to an artificial intelligence frame. However, when designing was treated as cognitive processes, it used the frame of cognitive science and the field of research became known as "design cognition".

The talk will present recent advances in the study of design cognition and the extension of those studies into the study of brain behavior while designing – "design neurocognition" in the Gero lab. The Gero lab is a disaggregated lab with projects in locations in multiple countries including Australia, Croatia, France, Italy, Sweden, Switzerland and the USA.

Design Cognition Through Protocol Analysis

Protocol analysis (Ericsson & Simon, 1993) has become the preferred research method for the elicitation of design cognition. Around it a range of analysis methods have been developed (Kan & Gero, 2017) that form the basis of new results. The results presented in the talk are derived from a newly developed model of co-design in teams by Gero & Milovanovic (unpublished) based on the situated version of the FBS ontology, sFBS, (Gero & Kannengiesser, 2014). The model provides for fine grained behavior of individuals in teams.

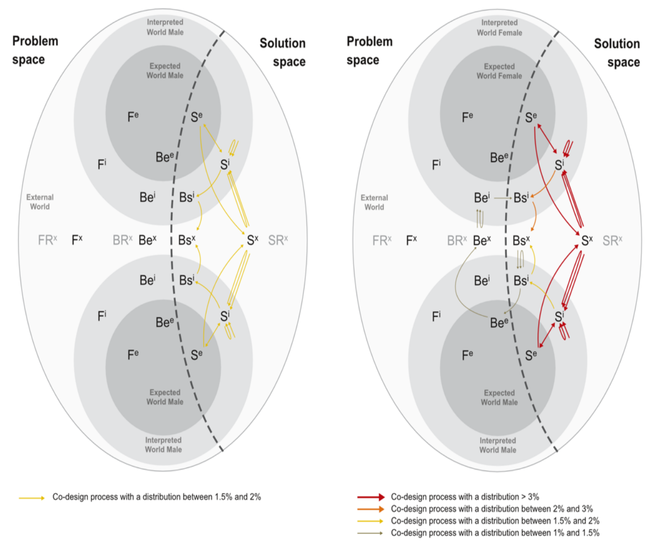
Results from a protocol study of cohorts of two-person homogeneous and heterogeneous teams, where the heterogeneity is due to gender, are presented in Figure 1 (Milovanovic & Gero, submitted). The cohorts were undergraduate mechanical engineering students at a state university in Utah and were given the same design task. In Figure 1, each ellipse contains the sFBS behavior of team members, where the top ellipses represent team member A activations and the bottom ellipses represent team member B activations. For a detailed development of the situated Function-Behavior-Structure ontology consult Gero & Kannengiesser (2004). The links between the activation variables are a measure of the cumulative occurrences of cognitive design processes. The variables outside the team members' individual spaces are externalizations in the forms of verbalizations, sketches or gestures. The externalization of thought through verbalization, gestures and sketching provides the basis for co-designing. The Gero & Milovanovic (submitted) model of co-design uses the notion that co-design occurs when designers cross the externalization boundary.

The results in Figure 1 show that heterogeneous teams containing one female and one male member exhibit more co-design processes than do homogeneous all-male teams. Further, such mixed-gender teams distribute more of their cognitive effort between the problem and the solution than do all-male teams, who expend more of their cognitive effort on the solution.

The presentation will show results of studying the design cognition of students and tutors in a studio pedagogy setting. It will present the change in student-student design cognition interaction over multiple studio sessions.

From Design Cognition to Design Neurocognition

The drop in the cost of non-invasive brain measurement has opened avenues of research into design neurocognition. In particular EEG and fNIRS, which collect temporal data, are both well suited for design neurocognition studies since design is a temporal activity. fMRI is less suited to study the temporal behavior of designing. It is well suited where high spatial resolution is required.



(a) (b)

Figure 1: (a) Dominant sFBS co-design processes for homogeneous, all-male, teams; (b) dominant sFBS co-design processes for heterogeneous, mixed-gender, teams (Milovanovic & Gero, to appear).

The presentation will report on using a 14 channel EEG block experiment to measure the effect of design task on brain behavior. The tasks range from highly constrained to unconstrained. The total task related power of measured signals is presented in Figure 2 for the pre-task and the four design tasks for 58 participants covering multiple domains. Results for individual domains indicate significant differences due to domain and task.

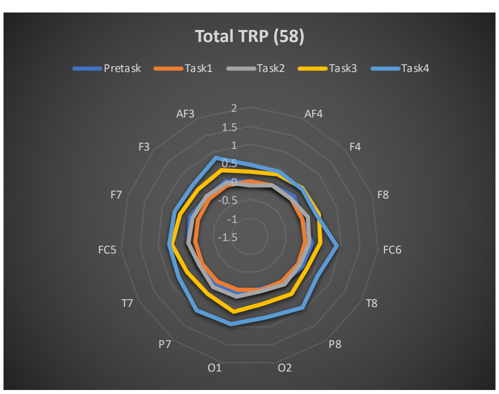


Figure 2: Total TRP for each of 14 channels across all participants for Pre-task, Task 1, Task 2, Task 3 and Task 4 (Vieira, Gero, et al, unpublished data).

While EEG measures electrical signals at the surface of the brain with high temporal resolution, functional near infrared spectroscopy (fNIRS) measures BOLD demand with medium temporal resolution. The presentation will report on an fNIRS experiment that repeats a previous protocol study for which we have cognitive results. The results of dominant hemisphere activation over time are presented in Figure 3 showing an unexpected pattern of behavior. Additional results cover other concept generation techniques.

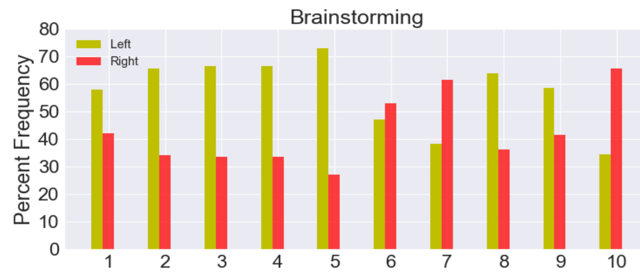


Figure 3: Percent frequency across time deciles of dominant hemisphere during brainstorming (Shealy & Gero, submitted).

These three exemplary results from there different measuring approaches, protocol analysis, EEG and fNIRS, demonstrate the expanding capacity to measure design cognition through measurement of the mind and indirectly through measurement of the brain. Until recently, only measurement of the cognition through the behavior of the mind was reliably available. The development of relatively inexpensive tools for non-invasive brain measurement has opened novel approaches to the measurement of design neurocognition. Bringing cognitive studies of the mind and neurocognitive studies of the brain together offers opportunities to both increase our understanding of designing and to provide the foundation for the development of tools to aid designing and the development of curricula to improve design education.

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