An Overview of Design Cognition between Experts and Novices

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1. Introduction

In field of design science, human subjects are commonly used to conduct experimental studies. As design is essentially a cognitive process, the results derived from these research will be very sensitive to the cognitive levels of human subjects used. There has been a trend to utilize students as participants in design experiments. Students act as a convenient source since they are readily available to researchers in universities and that they can be considered relevant to the area of study based on their majors. However, as compared to industry professionals or experts, students are likely to have a lower cognition skill in the area of interest given their limited training and experience. Therefore, the research results generated using students may be very different from those provided by experts. As a result, this raises a question of the utility of students test subjects in research and whether the results derived can be extended to industry practices.

These doubts have been raised by Smith and Leong (1998) where they carried out observational studies on groups of students and professional engineers to understand the behavioural differences. Subsequently, there has been attempts over the past decade to understand the differences of cognition and behavioural differences between students (novices) and industry professionals (experts). However, little of these works are targeted at understanding the validity of using novices as experimental test subjects in design studies.

In general, experts are able to solve problems in their domains more quickly and accurately than novices. However, there has been evidence on the existence of an "inverse expertise effect" where novices can perform equal to or better than experts in some problems (Adelson, 1984; Haerem & Rau, 2007; Tolsgaard & Gustafsson, 2007). This requires closer look into different aspects of problem solving studied in literature to see what the main differences between experts and novices are.

As the cognitive skills of the novices may not be as well developed as the experts, we hypothesize that design cognition of novices in deriving design solutions would not be as well developed as the experts. Therefore, cognitive design research done using novices would not be indicative of the cognitive processes adopted by the experts in the industry. It is our goal to review and analyze past work to compare experts and novices to determine cognitive and behavioural differences between novices and experts. This will enable us to draw conclusions on the utility of students as experimental test subjects to prove this hypothesis.

2. Approach

In this study, experts are defined as people who are working in the industry with at least 3 years of working experience and novices as students or working professionals with less than 2 years of working experience. Working professionals with 2 to 3 years of working experience were not considered as the cognitive skills of these group of people are still in phase from being a novice to an expert and may not be representative of either groups. Papers that used the term expert-novice outside this definition were excluded from the study. For example, papers that contained comparisons between junior year students as novices and senior year students as experts do not meet our definitions and were thus excluded.

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Consequently, 16 papers related to design cognition or thinking process were included in the study to compare experts and novices from different fields including design science, engineering and psychology (Ahmed, Wallace, & Blessing, 2003; Atman, Adams, & Cardella, 2007; Ball, Ormerod, & Morley, 2004; Björklund, 2013; Bonnardel, 1999; Bonnardel & Marmèche, 2004; Casakin, 2004; Casakin & Goldschmidt, 1999; Dixon, 2011; Gonçalves, Cardoso, & Badke-Schaub, 2014; Kavakli & Gero, 2002; M. H. Kim, Kim, Lee, & Park, 2007; Kristensson & Magnusson, 2002; Ozkan & Dogan, 2013; Seitamaa-Hakkarainen & Hakkarainen, 2001; Smith & Leong, 1998). Each paper was independently read by two of the authors. Each author then independently extracted qualitative metrics on novice and expert performance.
Once the assessment of the papers was completed, the papers were categorised according to the stated objective or topic area of the papers. Under each category, an affinity analysis was completed to compare and contrast desired and undesired behaviour and processes from each paper, and whether the experts or novices performed better from the papers.

3. Discussion

Based on the objectives, the papers compared the different aspects of design information processing in experts and designers. These aspects can be categorized into three different classes. "Cognitive strategies" refers to methods that people used to solve problem including all sort of reason, planning and arithmetic (Mayer, 1998). "Cognitive processes" defines how designers used their knowledge during process of design (Palmer, 1978) and "Cognitive representations" indicates the hypothetical internal cognitive symbol that denotes external realities and mental processes that makes use of such symbols (Wang and Chiew, 2010). The results of the categorization are shown in Figure 1.

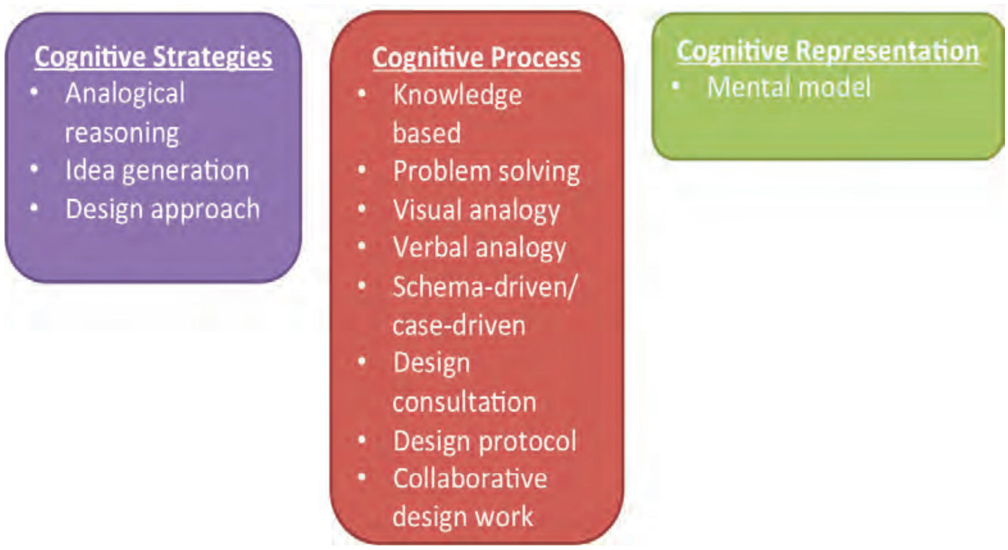

Figure 1: Affinity diagram of spotted trends from the review papers

From these categories, the papers were analysed for how experts and novices are described on each sub-category. These results are shown in Table 1.

Table 1: Comparison of novices and experts through key words from reviewed papers

Category	Attribute	Sub-category	Novices	Experts	Sources
Cognitive Strategies	Analogy reasoning	Near-domain / distant domain	Distant-domain	Near-domain	Ozkan & Dogan (2013)
	Idea generation	Top-down / bottom-up	Bottom-up	Top-down	Dixon (2011)
	Design approach	Serial way / Parallel way	Serial way	Parallel	Seitamaa-Hakkarainen & Hakkarainen (2001)
		Systematic / Trial and error	Trial and error,	Systematic	Ahmed, Wallace, & Blessing, (2003)
		Confidence	Less confidence	Very confidence	
		Stimulus	Limited range of sources (intra-domain)	Wider range of source (inter-domain)	Gonçalves, Cardoso, & Badke-Schaub (2014)
Cognitive Process	Problem solving	Time Optimization / Inefficiency	Inefficiency	Time Optimization	Atman, Adams, & Cardella (2007)
		Generalized approach / Centric approach	Generalized approach	Centric approach	Bonnardel (1999)
	Visual / Verbal analogy	Fixation	Less fixation	More fixated	Bonnardel & Marmèche (2004)
	Visual analogy	Search cycle	Longer search cycle	Shorter search cycle	Casakin & Goldschmidt (1999)
		Between domain / within domain	Between domain & within domain	Between domain	Casakin (2004)
	Analogy (schema-driven vs case-driven	Knowledge	Case-driven	Schema-driven	Ball, Ormerod, & Morley (2004)
	Design Protocol	Attention focus	Defocused	Highly focused	Kavakli & Gero (2002)
	Knowledge based (Limit commitment mode)	Ideation / Fixation	Less creative	More creative	M. H. Kim, Kim, Lee, & Park (2007)
	Creativity		More original	Less creative, more fixation	Kristensson & Magnusson (2002)
	Collaborative design work	Systematic way / Unorganized way	Unorganized way	Systematic way	Smith & Leong (1998)
Cognitive Representation	Mental Representation	Interconnection	Less interconnection	More interconnection	Björklund (2013)

It is found that novices and experts approach a design problem differently. Novices look at the problem space extensively based on problem specifics and generate ideas based on intra-domain sources and limited familiarity using explicit and concrete forms of case-based reasoning. They think through serially and iterate again through trial-and-error strategies should any constraints are discovered along the way. Hence, the abstraction level of their proposed design solution is low and of low confidence, although the novelty of the proposed design solution is high. Due to the lack of experience, they need more external stimuli for ideation/getting new knowledge. To address the gap in experience, novice should be taught on how to link analogies / make analogies. If given sufficient training, novices are able to generate more creative ideas than experts.

Experts derive inspiration from functional analysis, scenarios and past experience within their domain (schema-driven), which itself demands less external stimulation. Experts have a parallel thought flow and consider the constraints (add more as they deemed fit) concurrently while generating a design solution. Due to the multiple considerations, they tend to have a longer decision time per design iteration as compared to the novices. They tend to end up with fewer proposed design solution than novices because of the more in-depth thought processes. This results in proposed design solutions that have a high level of abstraction that explains the depth, representations and interconnectivities but tends to center on their experience. To address this perceived fixation, experts have to be stimulated with ideas outside their domain. Another way is to introduce inter-domain sources to inspire creative solutions.

4. Conclusion

Based on this analysis of experts and novices, this paper show that prior knowledge is important to allow designers to strategize, process and represent the design solutions. Experts are found to be more practical, structured, detailed and more control of actions during design. However, novices are found to consider larger space of solutions; they are able to generate more ideas but are also less realistic.

Using novices (students) as participants are sufficient to validate research in the area of creativity methods and processes. Methods beneficial to novices would be beneficial to experts though the degree of benefit will not necessarily be the same.

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