Evidence-based design heuristics for idea generation

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How do product designers create multiple concepts to consider? To address this question, we combine evidence from four empirical studies of design process and outcomes, including award-winning products, multiple concepts for a project by an experienced industrial designer, and concept sets from 48 industrial and engineering designers for a single design problem. This compilation of over 3450 design process outcomes is analyzed to extract concept variations evident across design problems and solutions. The resulting set of patterns, in the form of 77 Design Heuristics, catalog how designers appear to introduce intentional variation into conceptual product designs. These heuristics provide 'cognitive shortcuts' that can help designers generate more, and more varied, candidate concepts to consider in the early phases of design.

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How do designers successfully create novel product concepts? One suggested approach is to first generate a wide range of concepts to consider (Cross, 1994; Liu, Bligh, & Chakrabarti, 2003). This requires the ability to create a large number of concepts that differ from each other so that the set of concepts covers the space of possible designs (Gero, 1990; Goel & Pirolli, 1992; MacLean, Young, Bellotti, & Moran, 1991; Simon, 1981). Logically, the idea generation process benefits from considering as many different concepts as possible (Akin & Lin, 1995; Atman, Chimka, Bursic, & Nachtman, 1999; Brophy, 2001; Liu et al., 2003). However, generating a diverse set of concepts can be challenging because designers tend to fixate on specific design specifications, which leads them to generate more concepts with similar features (Purcell & Gero, 1996; Sio, Kotovsky, & Cagan, 2015). For example, Jansson and Smith (1991) observed designers replicating similar solutions to concepts provided as examples, and even including their flaws. Across studies, designers appear to consider only a small set of related concepts when generating ideas (Ball, Evans, & Dennis, 1994; Chrysikou & Weisberg, 2005; Dong & Sarkar, 2011; Linsey et al., 2010;

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Purcell & Gero, 1996; Sio et al., 2015; Smith, 1998; Viswanathan & Linsey, 2013; Youmans & Arciszewski, 2014).

A number of approaches for facilitating idea generation during the early phases of conceptual design have been proposed (c.f. Clapham, 1997; Shah, Hernandez, & Smith, 2002; Smith, 1998). One approach distills knowledge about specific designs into an intermediate-level knowledge base by constructing composites from multiple examples. In Alexander's *pattern language* (Alexander, Ishikawa, & Silverstein, 1977), and Krippendorf's *design discourses* (2005), patterns common in successful design solutions are identified at a component level, linking the designer to a broad range of helpful guidance from past solutions in a refined form (Alexander et al., 1977). This composite knowledge about design has been referred to as *heuristic* knowledge (Fu, Yang, & Wood, 2015). Heuristics are described as 'mental shortcuts' that capture cognitive strategies that may lead to solutions (though not necessarily the best one) (Nisbett & Ross, 1980), and are ubiquitous in human reasoning (Goldstein et al., 2001). Heuristics capture important features of problem situations and solutions that tend to reoccur in experiences (Clancey, 1985).

In software design, Riel (1996) has described the heuristic approach as 'specific experience-based guidelines' that help developers make good decisions. Lawson (1979) observed architectural students solving puzzles through 'trial and error' heuristic approaches. Lawson (1980) concludes, 'An examination of protocols obtained from such closely observed design sessions reveal that most designers adopt strategies which are heuristic in nature… Heuristic strategies do not so much rely upon theoretical first principles as on experience and rules of thumb' (p. 132). When generating new concepts, designers appear at times to offer intuitive responses derived from 'large pools of experience' (Cross, 2011, p. 10) to make a 'best guess' at a new design. Consider the example in Figure 1, a desk chair that reclines to allow the user to lie beneath (rather than in front of) a computer screen.

In comparing this novel design to prototypical chairs, it is evident that the designer changed the user's direction of access. By moving the access point from in front of the screen to below it, an innovative design results. Further, this strategy, 'change direction of access,' may be a useful heuristic to apply in generating designs for other products. For example, applying the 'change direction of access' heuristic to a trackball controller may suggest side rather than top access, and accommodate thumb control rather than palm movements (see Figure 2). Design heuristics like this one may help designers create more, and more diverse, concepts, thereby increasing the likelihood that an innovative concept will result. Understanding how cognitive processes can be stimulated to generate design ideas may lead to more effective methods and tools to support conceptual design (Jin & Benami, 2010).