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CONFIRMATION AND COGNITIVE BIAS IN DESIGN COGNITION

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ABSTRACT

The desire to better understand design cognition has led to the application of literature from psychology to design research, e.g., in learning, analogical reasoning, and problem solving. Psychological research on cognitive heuristics and biases offers another relevant body of knowledge for application. Cognitive biases are inherent biases in human information processing, which can lead to suboptimal reasoning. Cognitive heuristics are unconscious rules utilized to enhance the efficiency of information processing and are possible antecedents of cognitive biases. This paper presents two studies that examined the role of *confirmation bias*, which is a tendency to seek and interpret evidence in order to confirm existing beliefs. The results of the first study, a protocol analysis involving novice designers engaged in a biomimetic design task, indicate that confirmation bias is present during concept generation and offer additional insights into the influence of confirmation bias in design. The results of the second study, a controlled experiment requiring participants to complete a concept evaluation task, suggest that decision matrices are effective tools to reduce confirmation bias during concept evaluation.

1. INTRODUCTION

Design researchers have established an eclectic body of literature regarding design cognition, with research interests ranging from cognitive science and a theory of design (Gero, 2009) to socio-cultural determinants of creativity (Liu, 2000). More recently, researchers have begun to explore the role of cognitive bias in design, e.g., sunk cost bias and physical prototyping (Viswanathan & Linsey, 2011). However, cognitive heuristics and biases have been studied in the field of psychology since at least the 1940's (Asch, 1946).

Cognitive heuristics are intuitive information-processing strategies that have been shown to, in some instances, contribute to irrational judgments and cognitive biases (Tversky & Kahneman, 1982). When cognitive heuristics are relied on during design cognition, they could contribute to known design biases, e.g., design fixation. We believe the existing literature on cognitive heuristics and biases can provide useful insights to further understand design cognition and information-processing biases in design.

This paper first introduces cognitive heuristics and biases, emphasizing their relevance to design. Two studies are then presented that were performed to examine confirmation bias in design. The first study analyzed verbal protocols, collected from engineering students engaged in a biomimetic design practical session described by Cheong et al. (2012), to determine if confirmation bias was present during *concept generation*. The second study examined the effectiveness of decision matrices as tools to mitigate confirmation bias during *concept evaluation*. We conclude by summarizing our results, emphasizing design-relevant implications.

2. BACKGROUND ON COGNITIVE HEURISITICS

There are notable differences between the heuristics of interest to psychologists and those commonly discussed in the design literature. The following section discusses these differences, and elaborates on the relevance of cognitive heuristics and biases in design cognition.

2.1. Heuristics in Design and Psychology

Guindon and Curtis (1988) define heuristics in design as broadly applied principles "that reduce the complexity of a design problem." Aronson et al. (2006) define heuristics in psychology as "mental shortcuts people use to make judgments quickly and efficiently." Although heuristics in design and psychology sound similar, further comparison reveals fundamental differences in their origin and application.

2.1.1. Design heuristics.

Heuristics in design are typically formal rules or procedures deliberately developed for designers to use during the design process. For example, Cormier et al. (2011) developed instructional heuristics for designers seeking to design products that satisfy consumer variation, e.g., a product to be used by both left and right handed people. Design heuristics are essentially tools that designers can use when the situation is appropriate. Although their use may eventually become less cognitively demanding with practice, the initial acquisition and application are conscious and intentional.

2.1.2. Cognitive heuristics.

Cognitive heuristics differ in that they are not developed for application but are observations of natural occurrences. They are, in a sense, innate information-processing strategies that psychologists have "discovered" humans rely on. In addition, they are relied on without an individual's conscious intent (Gilovich et al., 2002) and are not explicitly learned. In fact, cognitive heuristics are often discussed in terms of their adaptive benefit from an evolutionary perspective. Because individuals do not consciously apply cognitive heuristics, they are often unaware of how relying on heuristics could be leading to cognitive biases and irrational judgments.

2.1.3. Using cognitive heuristics in design.

When are they used? Cognitive heuristics are used during cognitive processing, under which design is logically subsumed. These phenomena have been shown to influence a diverse set of complex decision-making tasks, in areas such as interpersonal relationships, medicine, economics, and politics (Gilovich et al., 2002). Given that decision making is a key component of design (Gero, 1990), design decision making, at the least, will be subject to a reliance on cognitive heuristics.

Why are they used? In addition to having an opportunity to rely on cognitive heuristics, designers also have an incentive. A desire to conserve cognitive effort has been proposed as a hallmark of human information processing (Fiske & Taylor, 1984). This desire is one reason why individuals rely on cognitive heuristics, even when they have an incentive not to (Gilovich et al., 2002). It is worth noting that design researchers have found evidence suggesting designers are also motivated to conserve cognitive effort (Guindon, 1990; Cheong et al., 2012). Therefore, we believe that designers may unconsciously rely on cognitive heuristics, to minimize cognitive effort, even when they are highly invested in the design task.

How are they used? There has been little previous design research directly investigating the role of cognitive heuristics and biases. While Viswanathan and Linsey (2011) have argued that the sunk cost bias contributes to fixation during physical prototyping, this is only one design task and one cognitive bias. Determining *how* designers use cognitive heuristics requires additional research into each phenomenon individually. This paper will focus on examining confirmation bias in concept generation and evaluation.

2.2. Relevant Cognitive Heuristics and Biases

Although cognitive heuristics allow for efficient information processing and are generally beneficial, reliance on them may contribute to cognitive biases. A Wikipedia search (as of May 11, 2012) revealed an impressive number of empirically described cognitive biases: 86 in decision making, 24 in social judgment, and 51 in memory. However, not all of these are directly relevant to design cognition, e.g., social biases that relate to judgments in interpersonal relationships.

We reviewed the psychological literature on heuristics and biases and discuss those that we feel are the most relevant to design in Appendix A (see Table 1 for a brief summary). For further information see Gilovich et al. (2002).

Table 1: Design-relevant cognitive heuristics and biases.

Heuristic or Bias	Description
Availability	Making judgments based on the most available information in memory
Representativeness	A belief that a single instance of a category represents all instances of that category
Anchoring	Using a baseline stimulus as a reference point for evaluating all other stimuli
Effort	A belief that the value of something is attached to the amount of effort put into it
Sunk Cost	Pursuing a strategy because of previous investment, despite the risk of further losses
Framing	Allowing the frame (positive or negative) of a problem to influence decisions
Hindsight	A belief that the outcome of an event was predictable or more likely, only after having knowledge of the outcome
Primacy and Recency	Remembering information presented first and last in a series more exactly than information in the middle
Mere Exposure	A tendency to express a preference for stimuli following brief exposure
Illusory Correlation	Perceiving correlation where none exists

3. CONFIRMATION BIAS

Confirmation bias refers to a tendency to seek out evidence, or interpret evidence in such a way, that is consistent with pre-existing beliefs, at the expense of considering belief-inconsistent information (Nickerson, 1998). A confirmatory bias is evident even when individuals have no vested interest in the belief being evaluated. For example, Koriat et al. (1980) show that people typically attempt to find out if a belief is true, rather than prove that it is false. Nickerson (1998) reports that confirmation bias can lead individuals to fail to use disconfirming evidence to adjust beliefs, accept confirming evidence too easily, misinterpret disconfirming evidence, and fail to consider the diagnostic value of supportive evidence.

3.1. Confirmation in Design

Previous research suggests that confirmation bias is one of the most prevalent biases in human reasoning (Nickerson, 1998). Based on our recent work, we hypothesized that designers would exhibit a strong confirmation bias. We also felt that confirmation bias was relevant to our previous research on design fixation (Hallihan & Shu, 2011), and believe confirmation bias could prevent designers from fully considering the value of alternative design solutions.

The following sections report on two studies aimed at better understanding confirmation bias in design cognition.

4. STUDY 1: CONFIRMATION BIAS IN CONCEPT GENERATION

Confirmation bias has been extensively studied in psychology, but further research is needed to evaluate its influence in design. As a first step towards this, we examined verbal protocols collected from engineering students engaged in a concept generation task. We aimed to determine whether or not designers exhibit a confirmatory bias, and to identify factors that influence this bias during concept generation.

4.1. Method and Procedure

A previous experiment by Cheong et al. (2012) collected design protocols from 30 engineering students, engaged in a biomimetic design practical session as part of a 4^{th}-year mechanical design course. The students were split into 9 groups of 3 or 4 to work on a biomimetic design problem for 20 minutes. They were provided with a description of a biological phenomenon that they were instructed to use as a source of inspiration to solve a given design problem. The students' dialogues were recorded and transcribed in 9 design protocols. For a full description of the methodology see Cheong et al. (2012). For the purpose of this study, these protocols were qualitatively analyzed to evaluate whether or not designers exhibit a confirmatory bias during concept generation. A useful overview of the utility of protocol analysis in design research is provided by Cross (2001).

4.2. Qualitative Coding

Merriam (2009) recommends that the coding scheme used for qualitative analysis should be developed to inform the unbiased evaluation of the research question. A central component of the confirmation bias is that it manifests itself in a tendency to seek out or interpret evidence in a way that will confirm pre-existing beliefs. Our analysis was structured to first identify designer beliefs, and then evaluate instances of designers seeking or interpreting evidence pertaining to those beliefs as either confirmatory or disconfirmatory.

4.2.1.Coding beliefs.

A belief was coded as any instance when a designer verbalized a statement that conveyed his or her intent to influence the design process in a desired direction, e.g., suggesting a design strategy or providing feedback regarding the current design solution. Knowledge of the designer's intent within the context of the design process established the nature of the belief. Given that beliefs are subject to change, we identified instances when a designer stated conflicting beliefs and coded relative to the most recently affirmed belief.

4.2.2. Coding confirmation and disconfirmation.

We then identified instances when a designer either sought or interpreted information that was relevant to a previously identified belief. That instance was then coded as either confirmatory (an attempt to validate or support the belief) or disconfirmatory (an attempt to invalidate or criticize the belief). Ambiguous cases were excluded to mitigate bias.

An example of the coding of a confirmatory case is seen in Figure 1; the biological phenomenon was an Emperor Penguin's thermoregulatory capability, the problem asked participants to improve the efficiency of a wet scrubber that removes pollutants from exhaust gases (Cheong et al., 2012).

Designer A makes a statement coded as a ***belief*** that the shape of the penguin's feet (part of the analogy) should be incorporated into the design solution.	*A: I'm thinking that the penguin's feet really looks like the scrubber, I'm not really sure of the shape of the scrubber, but I, I, [sic] I think the scrubber looks like the feet of a penguin.*
For the next several minutes the group discusses potentially relevant features of the analogue. Designer A repeatedly mentions the importance of the penguin's feet and is criticized by Designer C.	*C: I don't think the penguin's feet is uh important, like in this example. It's actually not relevant, like relevant is the vein and the, and the [sic] artery, how they create the heat transfer…*
Designer A temporarily stops discussing this aspect of the analogy. However, a moment later he makes a statement that is evidence he is reinterpreting the problem scenario to ***confirm*** his belief.	*A: Yeah, well we can also bring outside knowledge to this, to this design problem. Um, I think the wet scrubber looks exactly like a penguin's feet. I've, I've [sic] seen one of them in the, (interrupted)*
Designer B interrupts and questions the belief.	*B: You've seen one of them? Well, well [sic] what do they look like?*
Designer A validates his belief.	*A: They look like a penguin's feet.*

Figure 1: Protocol analysis of a confirmatory case.

There were instances when group members would disagree with each other and present evidence aimed at disconfirming someone else's belief, e.g., Designer C above. However, these cases were not coded as disconfirming because the designer presenting disconfirming evidence could be doing so to support his or her own beliefs. Instead, the evaluation focuses on how the designer being presented with the conflicting information reacts in terms of evaluating the new evidence, i.e., accepting disconfirming evidence is failing to exercise a confirmatory bias and coded as disconfirmation.

4.2.3. Analytical validity.

It is possible that participants internally vet their ideas before vocalizing them. This was not a true talk-aloud experiment and participants were working in groups (see Cheong et al., 2012), which may have resulted in pressure on individuals to only vocalize ideas they felt confident about. In addition, participants may have felt pressure to avoid externalizing disconfirmations to avoid appearing critical.

Together, these factors could have biased the dialogue towards confirmation. However, we feel that this scenario represents a realistic design situation, and that the results observed are a realistic representation of the influence of confirmation bias during biomimetic concept generation by novice designers.

4.3. Results

The following section reports on the results of the protocol analysis, including descriptive statistics and a discussion of a number of insights gained through observation.

4.3.1. Descriptive statistics.

A total of 107 instances were identified as confirmation or disconfirmation of a design belief. Figure 2 compares the ratio of confirmation to disconfirmation for each group.

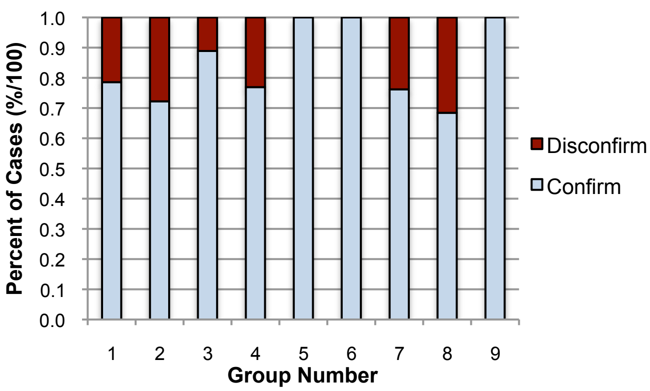

Figure 2: Ratio of instances of confirmation compared to instances of disconfirmation by group.

The average ratio across all groups was 83% confirmation and 17% disconfirmation (*SD* = 12.1%). The data indicate that participants' discussions were heavily biased towards confirmation during the concept generation process.

4.3.2. Qualitative observations.

While qualitatively coding the protocols, we made many observations that provide additional insight into the nature of confirmation and disconfirmation in design. The following discussion highlights some of our most interesting findings.

Ignoring the facts. When designers hold beliefs that can be contradicted by factual evidence, it is reasonable to assume they will fail to demonstrate a confirmatory bias. However, we observed numerous instances of belief perseverance in the face of contradicting evidence, which resulted in participants misinterpreting or ignoring relevant information. For example, in one instance a participant thought collecting demographic data would be a useful strategy. A group member mentioned that the design brief stated demographic data was not available (which was correct). Still the former participant attempted to persuade the group to gather demographic information, a non-optimal response given the feedback he had received.

Confirmation bias could contribute to design fixation or an unwillingness to compromise on design ideas; if designers discount or ignore the criticisms of others, they will be less likely to see a need to alter their current design strategy.

Confirming analogies. Participants were given a design task that required them to use a pre-determined biological analogy to inspire solutions for a specific design problem. When participants developed solutions that utilized some aspect of the analogy, they frequently failed to consider if the analogy was being applied inappropriately. This tendency may have contributed to improper analogical transfer. The ability to identify relevant differences between a target design and source analogue may facilitate analogical reasoning, however this hypothesis requires further research.

Seeking validation. Confirmation bias may influence the way designers question each other. Participants frequently asked affirming questions, e.g., "*What part of this idea do you like?*" However, validating the strengths of existing concepts does little to better the design situation, since these questions do not solicit information that would be informative to improve concept quality. If designers sought information that highlighted flaws in their ideas they would be better equipped to resolve those issues, resulting in improved concepts.

Confidence. We also observed that an individual's perceived confidence regarding their knowledge of the design problem or analogy influenced their reliance on the confirmation bias. Participants who were highly confident seemed more resistant to disconfirming evidence. However, relying on confirmation bias during decision making has been demonstrated to inflate confidence (Nickerson, 1998). Given the observational nature of this analysis, we are not able to determine the direction of this relationship. However, reducing overconfidence seems like a promising approach to minimize reliance on confirmation bias.

Disconfirmation. Instances of disconfirmation were primarily observed when participants accepted evidence that contradicted a design belief, or when designers actually identified potential limitations of their own ideas. In both of these cases disconfirmations were often associated with a perceived lack of confidence in the belief in question. Designers who lack confidence in their ideas might be quick to self-criticize, similarly when criticized they might be hesitant to defend ideas. This observation again suggests that overconfidence in design is associated with non-optimal judgment arising from a reliance on confirmation bias.

Design criticism. Participants were often hesitant when criticising the ideas of other group members. This could have multiple causes, e.g., lack of self-confidence, courtesy, etc. However, even when criticisms were expressed, they were often vague or irresolute. This unfortunately makes it easier for a designer to dismiss criticisms, and perpetuates a confirmatory bias. We regularly observed designers failing to see a flaw in their strategy until they were criticized multiple times with the flaw explicitly pointed out, i.e., specific criticism was more effective than general criticism.

A possible antecedent of this behaviour is perpetuated through the principles of brainstorming. A central principle of brainstorming is that criticism is not allowed (Dieter, 2000).

However, criticism facilitates the identification of opportunities for improvement, and is an integral part of knowledge construction in design (Bardzell et al., 2010). Encouraging designers to withhold criticism could be fostering a culture that is ineffective in offering valuable criticism, i.e., providing sufficiently detailed criticism, communicating criticism effectively, and one that is unable to respond to criticism appropriately, i.e., recognizing the value of criticism, maintaining a sense of self-efficacy in the face of criticism.

While deferring judgment in brainstorming may encourage divergent thinking, designers will also benefit if they recognize the value of criticism and effectively offer and respond to it. In addition, the value of criticism is inherently tied to the design process being used. Design-by-analogy is a unique situation because concepts that incorrectly apply the source analogue are easily identified, however the absence of this distinction in brainstorming may limit criticism's value.

4.4. Protocol Analysis Summary

The results of the protocol analysis suggest that confirmation bias is present, and can have an undesirable influence, during concept generation. Qualitative observations suggest false confidence and avoiding criticism contribute to perpetuating confirmation bias. To further investigate this phenomenon, we performed the following experiment.

5. STUDY 2: MITIGATING CONFIRMATION BIAS IN CONCEPT EVALUATION

Sixteen participants (2 female, 14 male) from the University of Toronto participated in the study. Participants completed two problems that required them to evaluate a provided belief. Problem 1 was intended to replicate Wason's (1968) experiment on confirmation bias. Problem 2 was intended to examine the effect of an intervention to mitigate confirmation bias in a concept evaluation task.

5.1. Problem 1

Problem 1 was based on Wason's (1968) card task, in which participants are asked to test the condition: *If a card has a vowel on one side, it has an even number on the other side*. Participants are shown 4 cards: a vowel, a consonant, an even number, or an odd number on the side facing up (see Figure 3), and asked to select the cards they think are necessary to test the condition. This task simplifies to a test of the condition *If P* (vowel) *then Q* (even number) by selecting among four alternatives that represent: *P, NOT P, Q,* and *NOT Q*. The only choice that allows participants to falsify (disconfirm) the rule is *NOT Q*. Wason (1968) observed that all participants selected *P*, and approximately 75% of participants selected *Q*. Selecting Q only allows one to confirm *If P then Q,* as observing *If NOT P then Q* does not invalidate the original belief. Very few participants (19%) selected *NOT Q* and fewer still (13%) selected *NOT P*.

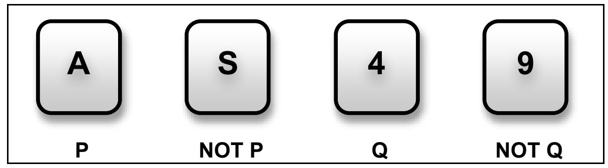

Figure 3: Alternatives to test the condition, "If a card has a vowel on one side it has an even number on the other."

5.1.1. Method.

We modified Wason's original task and provided participants with stimuli more relevant to engineering. We asked participants to evaluate the belief: *Washing machines that are highly water efficient are also highly energy efficient*. Participants were given a set of stimuli (see Figure 4) representing the conditions *P* (Water Efficient), *NOT P* (Water Inefficient), *Q* (Energy Efficient), and *NOT Q* (Energy Inefficient). Participants were then asked to pick two of the four machines that they would like to learn the remaining information about (the relative energy or water efficiency) in order to optimally evaluate the belief. Participants exhibiting a confirmatory bias were expected to test the belief by examining the *P* and *Q* conditions. To falsify the belief, participants must select the *NOT Q* condition as it provides the only opportunity to collect data that would demonstrate *If P then NOT Q.*

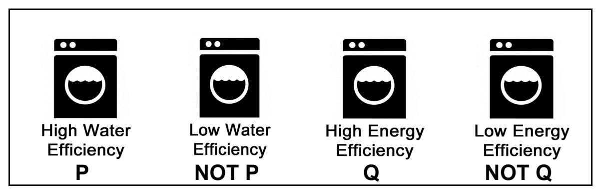

FIGURE 4: Problem 1 stimuli, lettered conditions (P, Q, etc.) not shown to participants.

5.1.2. Results.

The data collected from Problem 1 can be seen in Table 2. All participants selected the Water Efficient (P) washing machine as necessary to evaluate the belief, however the remaining decisions were distributed between the other alternatives. One participant decided to only select the Water Efficient machine, and none of the others, resulting in a total of 31 selections from 16 participants.

Table 2: Results from Problem 1.

	Water Efficient *(P)*	Water Inefficient *(NOT P)*	Energy Efficient *(Q)*	Energy Inefficient *(NOT Q)*
Participant choices (%)	16 (100)	6 (37.5)	5 (31.3)	4 (25.0)

These data indicate the presence of a confirmatory bias in our sample. Only 25% of participants selected the *NOT Q* case in their decision. The remaining 75% (including the participant who selected only the High Water Efficiency machine) chose instances that would allow them to confirm the belief, or were irrelevant to evaluating the belief.

5.1.3. Discussion.

These results closely replicate the findings from earlier experiments on confirmation bias (Wason, 1968) but with a situation more relevant to design. Interestingly, three of the four participants who avoided the confirmation bias were law students. Post-experiment interviews revealed that these participants recognized that a statement in the form *If P then Q* does not imply *If Q then P*. This eliminates the *Q* alternative as an option. These participants also all reported that they selected the *NOT Q* condition because they understood it could provide evidence to disprove the statement. Cosmides (1989) hypothesized that individuals are better at detecting disconfirming evidence when it can be perceived as the violation of a social contract. These participants' legal education may help them to perceive contractual violations in a wider range of tasks than other participants. However, this effect did not seem to influence performance in Problem 2.

5.2. Problem 2

Problem 2 was intended to examine the effectiveness of an intervention meant to mitigate confirmation bias in a more complex task involving concept evaluation.

5.2.1. Method.

Participants were provided with a brief background on design fixation (Jansson & Smith, 1991) and then told that their task was to evaluate the validity of the belief: *The presence of an example causes designers to fixate and incorporate elements of the example in their solutions.* To evaluate this belief they were provided with an example solution and six associated concepts (see Figure 5), generated by subjects from a previous experiment (Hallihan & Shu, 2011), along with a brief description of each concept. Two of the concepts (1 & 3) incorporated multiple elements of the example solution, while the others (2,4,5,6) did not. These design concepts were selected because they provided the participants with substantial evidence to disconfirm the belief.

5.2.2. Decision matrix to mitigate confirmation bias.

Participants were divided into two groups for Problem 2. Participants in the treatment group received additional instructional material based on a modified version of the Analysis of Competing Hypotheses (ACH) methodology. ACH was developed by Heuer (1999) as a decision-making tool to improve the forecasting accuracy of information analysts. The 8-step method helps analysts generate a matrix that facilitates the comparison of alternative hypotheses and the evaluation of the relevance and diagnostic value of gathered evidence. It has been demonstrated to reduce reliance on cognitive biases, including confirmation bias, in complex decision-making tasks with uncertain outcomes. In addition, it was demonstrated that ACH aids participants in evaluating more information regarding a decision than participants relying solely on intuition (Brasfield, 2009).

We provided participants in the treatment group with the Modified Analysis of Competing Hypotheses (MACH) procedure. The modified version was reduced to 5 steps and instructed participants to generate a matrix to compare and evaluate conclusions regarding the decision task with respect to the available evidence (design concepts 1-6). Participants in the control group performed the evaluation task intuitively. Our hypotheses were that the treatment group would be less biased by confirmation in their evaluations, and evaluate the concepts more thoroughly than the control condition.

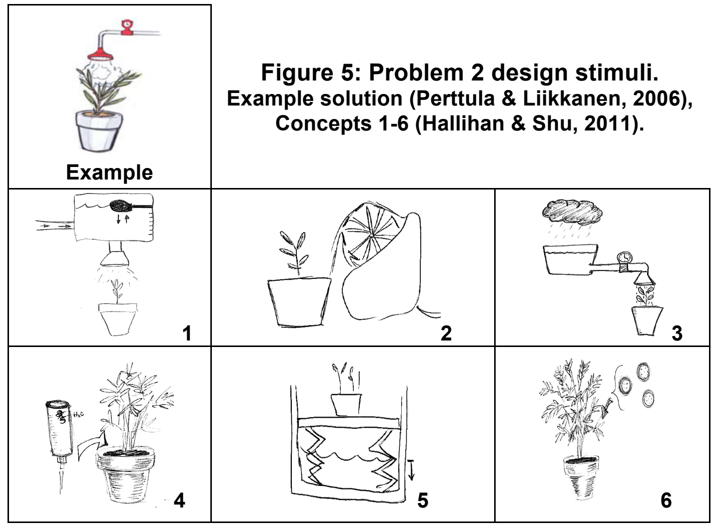

Figure 5: Problem 2 design stimuli.
Example solution (Perttula & Liikkanen, 2006), Concepts 1-6 (Hallihan & Shu, 2011).

5.2.3. Measurement.

Participants in the control group were instructed to use blank sheets of paper and point form notes to record all relevant information that they considered during their evaluation. Participants in the treatment condition externalized their evaluation using the MACH matrix. These self-generated records were analyzed to measure confirmation and disconfirmation. Written documentation indicating the consideration of evidence, or argument for, confirming the fixation hypothesis was counted as one instance of confirmatory evidence. Similar documentation that disconfirmed the fixation hypothesis was counted as one instance of disconfirmatory evidence. The total number of instances were counted for each participant. Examples of collected and coded data can be seen in Figure 6 (with matrix) and Figure 7 (without matrix).

Before beginning to solve each problem, participants were questioned to ensure they understood the problem as intended by the researchers. After completing each problem, participants were interviewed, which provided an opportunity for the researchers to ensure they were properly interpreting the participants' written notes.

Participants were given as much time as necessary to reach what they deemed to be an adequate solution for both problems. However, their performance was timed to allow for comparison of the duration of problem solving between the treatment and control conditions. Timing began once participants read and indicated they understood the instructional materials and began problem solving.

Degree of Fixation	Features of Design From Example	Features of Design from Outside Sources
Concept 1 High Fixation	- Overhead release of water(C) - Fed by water line(C) - Sprinkler head(C) - Periodic release at intervals (requiring timer)(C) - Valve of some kind(C)	- Ball float valve(D)
Concept 2 Medium Fixation	- Fed by water line(C) - Overhead release of water(C)	- Water wheel release(D) - Continual release of water at fixed tempo (no timer required)(D)
Concept 3 High Fixation	- Overhead release of water(C) - Sprinkler head(C) - Fed by water line(C) - Periodic release at timed intervals (requiring time)(C)	- Natural cloud source /fed by rainwater(D)
Concept 4 Low Fixation	- ? [*sic*]	- Dripper release(D) - Continual release of water at natural tempo(D) - Soil fed stream(D) - No water line(D) - No timer required(D)
Concept 5 Low Fixation	- Timer required(C)	- External movement brings plant to water (instead of bringing water to plant)(D) - Hydraulic lift required(D) - No flow of water stream(D) - Higher relative energy required(D)
Concept 6 Low Fixation	- ? [*sic*]	- No water stream(D) - No timer required(D) - No external movement(D) - Sponge fed(D) - Soil fed hydration(D)

Figure 6: Participant generated matrix, coded as 12 disconfirming(D) and 18 confirming(C) instances.

Top Left: incorporates water line(C) and a similar looking sprinkler head(C)
Top Middle: incorporates a house water line(C)
Top Right: incorporates many elements(C), except the water line(D)
Bottom Left: seems to incorporate no elements(D)
Bottom Middle: incorporates predetermined intervals(C)
Bottom Right: seems to incorporate no elements(D)

Figure 7: Participant generated notes, coded as 5 disconfirming(D) and 3 confirming(C) instances.

5.2.4. Results.

The data collected from Problem 2 are seen in Table 3. Three participants exhibited behaviour that we believed would unduly influence our analyses. Participant 7 was assigned to the treatment group, but did not follow the MACH procedure as outlined. Participants 6 and 12 were assigned to the control condition, however they utilized matrices to formalize their decision process in a way that simulated the treatment condition. While we originally intended to test the hypothesis that the MACH instructions would mitigate confirmation bias, these three cases confounded the original comparison. Therefore, we compared participants who utilized matrices to formalize their decision process with participants who relied on intuition without a matrix (Matrix: Yes, No).

Table 3: Conditions and Data for Problem 2.

Sub No.	Group	Matrix	Major	Confirm	Disconfirm	Time (min)
1	MACH	Yes	Zoology	8	10	15.7
2	Control	No	Genetics	4	4	6.3
3	MACH	Yes	Sociology	7	8	14.4
4	Control	No	Medicine	3	1	6.8
5	MACH	Yes	Law	9	9	20.2
6	Control	Yes	Law	12	18	20.5
7	MACH	No	Law	1	2	9.7
8	MACH	Yes	Law	4	1	10.2
9	MACH	Yes	Eng.	11	16	35.9
10	Control	No	Eng.	8	6	19.3
11	MACH	Yes	Eng.	5	11	17.9
12	Control	Yes	Eng.	6	18	22.8
13	Control	No	Eng.	5	3	11.8
14	Control	No	English	7	11	11.6
15	Control	No	Law	4	2	5.3
16	Control	No	Eng.	2	3	15.2

Effect of matrix. A one-way multivariate analysis of variance (MANOVA) was used to examine the differences between groups (Matrix: Yes, No) with respect to evidence evaluated (confirming, disconfirming). There was a statistically significant difference between groups, $F(2,13) = 4.95$, $p = 0.025$, Wilks' $\lambda = 0.57$, partial $\varepsilon^2 = 0.43$.

Follow-up comparisons (see Figure 8) were performed using independent samples t-tests, with the Bonferroni Correction ($\alpha/2 = 0.025$). There was a statistically significant difference, $t(14) = 2.69$, $p = 0.018$, in the amount of confirming evidence evaluated: Matrix ($M = 7.75$, $SE = 1.00$), No Matrix ($M = 4.25$, $SE = 0.84$). There was also a statistically significant difference, $t(14) = 3.15$, $p = 0.07$, in the amount of disconfirming evidence evaluated: Matrix ($M = 11.38$, $SE = 2.05$) No Matrix ($M = 4.00$, $SE = 1.13$).

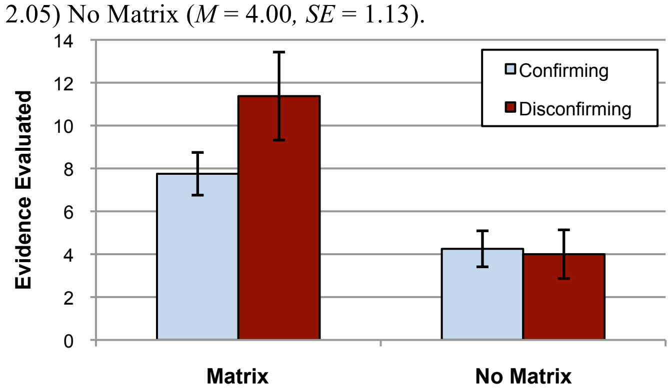

Figure 8: Mean quantity of confirming and disconfirming evidence evaluated in Matrix and No Matrix conditions.

Effect of time. As expected, there was a strong and statistically significant correlation between the amount of time participants spent solving the problem and the quantity of evidence evaluated: confirmatory ($r = 0.72$, $p < 0.01$), disconfirmatory ($r = 0.76$, $p < 0.01$). There was no interaction between time and the type of evidence evaluated. Although the Matrix group identified significantly more evidence than the No Matrix group, there was no statistically significant difference in the number of items evaluated per minute.

Participant conclusions. With respect to the belief participants were asked to evaluate, twelve of the sixteen concluded that there was a significant amount of evidence available to both support and reject the fixation hypothesis. The remaining four participants (4, 8, 10, & 16) concluded that the fixation hypothesis was well supported by this data. Participants 4 and 8 evaluated more confirmatory evidence than disconfirmatory, and participants 10 and 16 evaluated more disconfirmatory evidence than confirmatory. The later case may be a result of those participants failing to properly evaluate the diagnostic value of contradictory evidence, a known consequence of confirmation bias (Nickerson, 1998).

5.2.5. Discussion.

We examined the effect of using matrices as decision aides to reduce confirmation bias in concept evaluation. A number of methods already exist in design textbooks that utilize matrices to facilitate concept evaluation, e.g., Pugh's Concept Selection Method, Weighted Decision Matrices, Analytic Hierarchy Process (Dieter, 2000). Our findings suggest the use of formalized matrices did help participants identify more disconfirmatory cases. Because the concepts evaluated (see Figure 5) provided more evidence against the fixation belief than for, and after comparing the ratio of confirmatory to disconfirmatory evidence evaluated between groups (see Figure 8), we would conclude that the use of matrices allowed participants to perform a less biased and more thorough evaluation of the data. It could be argued that the observed effects were due to the increased time spent on the task in the Matrix condition relative to the No Matrix condition. However, participants in both cases decided themselves when they "reached an optimal conclusion." Therefore, we believe that the observed differences were more likely facilitated through the use of a matrix than time alone.

Resistance to formalized methods. Three of the participants reported that using the MACH matrix was an unnatural way for them to think, including Participant 7 who actually refused to use the MACH table in his evaluation. Previous research has also shown that individuals often resist the use of formal decision-making tools, instead preferring to rely on intuitive methods (Brasfield, 2009). This resistance limits the utility of any formalized method and may negate its potential benefits if participants apply it incorrectly; this was observed in a number of participants who failed to consider disconfirming evidence in their construction of the matrix.

Cognitive effort. The resistance to use a procedure, and the failure to properly apply it, may arise if the procedure requires increased cognitive effort to utilize. Given a limited information-processing capacity, any method that requires additional processing may result in decreased cognitive effort allocated to other concurrent tasks. This may in turn lead to an over reliance on cognitive heuristics in an attempt to minimize cognitive effort expenditures. However, even among novice matrix users, the written record of the decision process could lessen working-memory load, freeing up cognitive resources. Measures that assess cognitive workload, e.g., NASA TLX (Hart & Staveland, 1988), could be used to examine the demand imposed by these methods in future research. Anecdotally, the two participants in the control condition who used matrices spontaneously evaluated the most evidence out of all the participants, and were both above average in the number of items evaluated per minute. We believe that educating individuals on the use and benefit of these methods will increase their value through a decrease in the cognitive demand associated with using them.

Design relevance. The use of matrices to formalize the process of concept evaluation is not new to design. However, this research highlights another benefit of their use, namely the mitigation of cognitive biases, specifically confirmation bias. Comparing the effectiveness of different existing concept evaluation methodologies in mitigating cognitive bias is an interesting area for future research. One of the benefits of matrices in mitigating confirmation bias is that they allow individuals to see how arguments that support the selection of one concept may apply equally well to an alternate concept. A benefit of the ACH procedure specifically is that it encourages users to generate disconfirming evidence; this formalizes the process of criticising ideas and may make it easier to both administer and respond to criticism.

Additional insights from the protocol analysis suggest that successful methods should compensate for individuals' avoidance of criticism, preferential treatment of initially generated concepts, false sense of confidence, and failure to consider disconfirming evidence.

Empirical limitations. Although we did observe statistically significant differences between experimental groups, the relatively small sample size limits the statistical reliability of these findings. In addition, the sample included both non-engineers and engineers. While we did not initially intend to sample non-engineering students, their inclusion in the study provided valuable insights, e.g., the possible moderating effect of a legal education.

6. CONCLUSION

We hypothesized that confirmation bias was a particularly influential bias in design cognition. The presence of confirmation bias during concept generation was identified through the analysis of design protocols collected from engineering students engaged in a biomimetic design practical session. Results of this analysis led us to conclude that confirmation bias can lead designers to:

- Ignore or discount factual contradictory information
- Fail to identify the misapplication of analogies
- Fixate on initial ideas

In addition, the influence of confirmation bias may be magnified by overconfidence and a hesitance to be critical of others. Finding ways to encourage designers to voice criticisms clearly and handle criticism effectively may mitigate the confirmation bias during concept generation. Negative feedback and increased personal accountability for decisions have both been shown to decrease overconfidence (Arkes et al., 1987). Interestingly, avoiding criticism reduces the presence of both of these factors, which we hypothesize contributes to an increased reliance on confirmation bias.

Jin et al. (2006) have proposed that formalized methods may enhance the concept generation process. We are interested in how formalized methods may be used to mitigate the influence of cognitive heuristics and biases in concept generation. One possibility is that the use of tools like ACH can help individuals determine the depth and breadth (quality and quantity) of the concept generation process and adjust accordingly. A matrix that over emphasizes alternative concepts without incorporating relevant evidence or supporting arguments for those concepts, may indicate that the concept generation process is overly focused on quantity and not quality. On the other hand, too few or highly similar concept alternatives may indicate fixation. In addition, the development of new concept generation procedures could benefit from incorporating steps to mitigate cognitive biases.

The results of our second study provide valuable insights into the use of matrices as concept evaluation tools. Although these methods can help mitigate confirmation bias, they can be met with resistance and misapplied, limiting their benefit. In addition, the cognitive effort required to use a method could hypothetically lead to an increased reliance on cognitive heuristics to offset this demand. Adequate training on the use of any new methodology will likely address these issues.

We have proposed that design cognition can be better understood by considering the psychological literature on cognitive heuristics and biases. We have outlined a number of these that we think are particularly relevant to design, and have briefly discussed their relevance to design, e.g., design fixation and the availability heuristic (see Appendix A). We believe that the application of cognitive heuristics in design is a promising area for further research.

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APPENDIX A

The Availability Heuristic

Tversky and Kahneman (1973) report that the availability heuristic is relied on when making judgments based on the information that most readily comes to mind. This can lead to biased information processing when the “availability” of information is overly influenced by factors that do not reflect its actual diagnostic value, e.g., overestimating the occurrence of shark attacks because they are highly salient incidents and are thus more available in memory (Plous, 1993). The availability heuristic can influence simple judgments based on frequency estimates, but has also been shown to influence more complex and serious judgments in real life, e.g., medical decisions involving complex surgery (Gifford–Jones, 1977).

The Representativeness Heuristic

The representativeness heuristic biases judgment by leading individuals to assume that a member of a category is a prototypical representation of that category as whole (Kahneman & Tversky, 1972). This often leads to drawing inaccurate conclusions about large groups from small samples, e.g., stereotyping. This heuristic can also lead individuals to ignore base-rate information. For example, the base rate for a coin coming up heads or tails is $p = 0.5$. However, after seeing a coin toss come up heads 5 times in a row, most individuals intuitively feel that the next toss has a higher than 50% chance of coming up tails. This is because of a belief that a small sample of tosses should be representative of the outcome of a large number of tosses, even though the base rate for the outcome of each individual toss is still $p = 0.5$ (Plous, 1993).

The Anchoring Heuristic

Tversky and Kahneman (1982) observed that individuals rely heavily on initial reference points during estimates of frequency or probability. This is referred to as the anchoring or adjustment heuristic; essentially individuals automatically adjust their judgments relative to a reference point that may not be relevant. Tversky and Kahneman illustrate how the anchoring heuristic can lead to biases in evaluating the outcome of compound events. For successful product development, a series of events must occur; even when the individual likelihood of success for each of these events is high, the overall likelihood of each of them occurring can be very low. The anchoring heuristic can lead to overly optimistic estimates for the outcome of conjunctive events, like product design, because the success of an individual event is an anchor that biases the perception of the overall likelihood of success.

The Effort Heuristic

The effort heuristic leads people to evaluate alternatives based on the amount of effort that went into developing them, as opposed to relying on more diagnostic evaluation criteria. For example, if individuals believe something took a great effort to develop they will have difficulty disentangling the actual value from this perception of effort (Kruger et al., 2004). Reliance on this heuristic could lead individuals to make decisions that disregard the true value of an alternative.

Sunk Cost Bias

The sunk cost bias refers to a tendency to maintain a course of action due to previous investment, e.g., money, action, time, etc., despite the fact that the prior investment should no longer logically be influencing the decision (Arkes & Blumer, 1985). Viswanathan and Linsey (2011) examined the potential effect of sunk cost bias on fixation, suggesting that the act of building a physical prototype represents an investment, which in turn leads designers to fixate on the current design strategy to avoid a loss of the invested effort.

The sunk cost bias can also lead to more harmful design outcomes than fixation. Designers and manufacturers may consciously decide to launch products with known design flaws to avoid losses associated with re-designing the product or launching late. While these decisions are usually planned to be cost-optimal they do not always result that way, e.g., the Ford Pinto's unsafe fuel tank (Birsch & Fielder, 1994).

Framing Bias

It has been repeatedly shown that even when given a choice between normatively equivalent outcomes, individuals' decisions are heavily influenced by how the choice is framed, e.g., emphasizing negative or positive outcomes. Tversky and Kahneman (1981) originally discussed framing as it applied to risky choice problems involving gains or losses. However, Levin et al. (1998) provide a summary of research demonstrating the influence of framing on risk preference, attribute evaluation, and behaviour adoption, in numerous contexts. Generally, individuals are more likely to act if the action prevents a loss, as opposed to providing a gain. These framing effects can influence behaviours with serious implications. For example, Meyerowitz and Chaiken (1987) found that women were more likely to perform a self-breast exam when informed of the negative consequences of avoiding the exam, than women who were informed of the positive consequences of the exam. These effects could contribute to design fixation, e.g., a designer may be less likely to abandon their current course of action if they are focused on the associated gains, instead of the potential losses.

Hindsight Bias

Agans and Shaffer (1994) define the hindsight bias as the "unjustified increase in the perceived probability of an event due to outcome knowledge." This results in a false sense of confidence when making judgments relating to outcomes that individuals have knowledge of. This confidence is unjustified because without knowing the outcome, the ability to predict it is severely limited. The hindsight bias can lead individuals to discredit others who were unable to predict seemingly obvious outcomes, as well as preventing individuals from learning from past events (Fischhoff, 1975).

Primacy and Recency Effects

The primacy and recency effects influence the way information is remembered. When presented with a series of stimuli, individuals remember the information presented first and last more accurately, and weight that information more heavily than information encountered in the middle (Steiner & Rain, 1989). This can lead to a failure to give consideration to information presented in the middle of the series.

Mere Exposure Effect

The mere exposure effect is a tendency for individuals to develop preferences for stimuli, merely due to repeated exposure to them (Gilovich et al., 2002). This could contribute to individuals exhibiting a preference for pre-existing ideas.

Illusory Correlation Bias

Chapman (1967) reports that illusory correlation bias can lead individuals to report correlations between events that are not actually correlated, overestimate correlations, or report correlations in the opposite direction. The illusory correlation bias has been hypothesized to result from the availability or representativeness heuristics (Mullen & Johnson, 1990). For example, Chapman (1967) presented participants with a series of word pairings and asked them to rate how frequently each pairing occurred. Participants reported that semantically linked words, e.g., bacon-eggs, co-occurred more often than words with no semantic link, e.g., tiger-notebook, even though the number of pairings was equal in all cases. Chapman and Chapman (1969) also demonstrated that pre-conceived beliefs often lead people to perceive correlations that ***confirm*** those beliefs, e.g., personality traits and physical appearance, such as untrustworthy people have tiny eyes.

Topical Mental Accounts

When making judgments involving multiple attributes, people generally have difficulty accurately integrating all the relevant attributes at once. According to Kahneman and Tversky (1984) only those attributes obviously and directly relevant to the current aspect of focus are considered. Topical mental accounting has been demonstrated to lead to biased purchasing behaviours. For instance, Thaler (1980) found that people would be more willing exert the additional effort of driving to a different store to save \$5 on a \$15 calculator, than to save \$5 on a \$125 coat; even when they are told they are purchasing the two items together. In this example, individuals only consider the value of savings relative to the item cost, instead of the multi-attribute purchase cost.

Design Relevance

We believe that these biases and heuristics have the potential to influence design cognition. For example, Hallihan and Shu (2011) previously hypothesized that the associative strength of design stimuli in an individual's memory would be predictive of fixation on that stimuli; this could easily be the result of reliance on the availability heuristic. Tversky and Kahneman (1973) point out that while memory works by strengthening connections between events that frequently co-occur, availability works inversely to that, using the "strength of associations as a basis for the judgment of frequency." Another possibility is that the anchoring heuristic could lead designers to evaluate all subsequent ideas relative to an "anchoring" example provided, which may also explain the presence of fixation effects.

This discussion is intended to introduce this body of literature to the design community. We believe there is great potential for this literature to further our understanding of design cognition.