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PROBLEM OR SOLUTION FOCUSED? ILL-DEFINED DESIGN PROBLEMS AND THE INFLUENCE OF DESIGN ABILITY

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1. Introduction

Important to the success of conceptual design ideation is an ability to propose solutions to often ill-defined design problems [Rittel and Webber 1973]. When exploring solutions to this type of problem the designer must rely upon past experience and heuristic strategies to evaluate the suitability of proposed solution ideas [Nelson and Stolterman 2003]. As such, an ability to engage in solution ideation appears to provide opportunities to co-evolve an understanding of the problem and appropriate concept solutions. That is, to reflect-in-action upon the suitability of potential solution candidates [Schon and Wiggins 1992]. Taking as a theoretical framework the epistemology of knowing-in-practice proposed by Schon [1983, 1987], we report a comparative statistical analysis aimed at examining the influence of a design education upon frequencies of and transitions between naming, framing, moving and reflecting activities when addressing a typically ill-defined design problem.

The notion of an ill-defined or wicked problem can be used as a means to distinguish designerly problems [Dorst 1996] from those of the sciences [Archer 1979]. In an early study, Rittel and Webber [1973] describe a category of 'wicked' problem that often contrasts with the problems of the sciences. For, unlike the continuous search for objective truths that defines the scientific tradition, Ill-defined, designerly problems are never definitively solved, having instead a potentially infinite number of ways to proceed towards problem resolution. As such, the goal of design problem resolution is not a deep understanding of an objective truth, but the creation of the new or an improvement to the existing [Simon 1996]. Thus, an understanding of the design problem depends upon and is critically influenced by attempts made towards its resolution. As indicated in Rittel and Webber's [1973, op cit, p.161] seminal report, "the problem can't be defined until the solution has been found".

A defining characteristic of design ideation then is an ability to both evaluate the appropriateness of proposed solutions and, at the same time, develop understanding of the design problem based upon a subjective interpretation of the quality of solution ideas. However, design expertise appears to develop at a slower pace than scientific knowledge and skill [Lawson and Dorst 2009], [Cross 2011]. Thus, an ability to both effectively define the design problem, through exploration of the appropriateness of solution attempts, is founded upon the designer's use of past experience; the designer's accumulated experiential skills and knowledge. Within the application of experience-based knowledge a co-evolution of both problem definition and solution development appears critical to the appropriateness of conceptual propositions.

Dorst [2011] cites abduction [Roozenburg 1993] as reasoning that supports a co-evolution of solutions in parallel to an understanding of an ill-defined design problem. In contrast with deductive and inductive reasoning, often found when engaging tame or well-defined problems, abduction requires a reasoning where both the nature of the 'what' (the thing needing attention) and the 'how' (working principles by which it may operate) are unknown. Only the required value of the desired result is understood. An ability to engage in abductive reasoning during conceptual design ideation has also been described as akin to bridge building between problem and solution spaces [Dorst and Cross 2001]. To achieve effective bridging between design problem and solution ideas, important considerations within the problem space are first named and framed [Schon and Wiggins 1992]. Partial solution ideas are then tested and explored through the generation of iterative solution concepts as the designer moves between problem definition and solution ideation. Thus, the ability to reason between ill-defined design problems and their resolution requires experienced-based knowledge and techniques for problem solving towards an optimal solution, effectively bridging problem and solution spaces [Cross and Dorst 1994, op cit].

The relationship between design expertise and conceptual design ideation has attracted much attention as an object of study. For example, Kavakli and Gero [2002] indicate the ways in which expert use of drawing afforded many more cognitive actions compared to novice designers' more modest use of visual representation during conceptual ideation. Casakin [2003] indicates how a lack of design expertise can result in an inability to establish deep analogical structures between a source analogy and target solution idea. Likewise, Björklund [2013] shows how experts appear to see design problems as more difficult than novice designers, using analogies to connect mental and physical representations of the design problem. Dixon [2011] indicates the ways in which expert practice resulted in a greater depth of frame exploration compared to that of novices. The study illustrated how novice designers spent a greater amount of time and effort in problem definition, sequentially identifying, naming and listing problem specifications to address. This also agrees with Cross' [2011] observation that novice designers appear to substitute greater time in naming possible attributes of the design problem for actually engaging in solution ideation. Likewise, Cross et al. [1994] report on the ways in which novice, problem-focused gathering of information, at the expense of solution ideation, resulted in poor outcomes compared to the solution-focused, exploration observed in the work of more experienced designers.

The current comparative study illustrates how novice designers, with limited design experience, were nonetheless significantly more inclined to engage in activity that indicated the presence of abductive or appositional reasoning between definitions of the design problem and suitable solution ideas than those with no design ability.

2. Research aims

The study aimed to examine the effect of design ability upon responses to a typically ill-defined design problem during conceptual ideation. With these aims in mind the study addressed the following research question:

- RQ: What is the relationship between design ability and reasoning between an ill-defined problem and its resolution?

3. Methods

We employ protocol analysis [Ericsson and Simon 1993], [Someren et al. 1994] as method to address our research question. The following sections describe participants and criteria for selection, research design and instruments, study design and procedure, process of encoding and method of analysis.

3.1 Participants

The study drew a purposeful sample of twenty (n=20) participants from a sample population of 4th year undergraduates at the authors' higher education institution. In order to examine the influence of design ability in reasoning towards an ill-defined design problem, half the sample were taken from a cohort of 4th year undergraduate students majoring in Industrial Design. A further sample of ten participants was taken from a population of 4th year business management or material science majors. The ten industrial design students had completed fundamental undergraduate courses in design skills and knowledge as well as studio-based product design courses as part of their degree programme. The sample of management and science majors had no design education, ability or experience.

3.2 Research design

Due to the inclusion of equipment to gather protocol response data, an experimental approach to the study was adopted [Michel 2007]. Participants' response to a typically ill-defined design problem was captured through video recording. Both design and non-design students were provided with the same set of drawing materials: plain A3 drawing paper, lined A4 conference pad, pens, pencils, coloured markers, rubbers, sharpener and shape templates. Both were given the same design problem, requiring participants to develop a concept for a sports watch for young people aged between 18 and 30.

3.3 Task procedure

Participants were first provided instructions on the aims of the research and their role and obligations during the protocol before signing IRB approved informed consent forms. They were then given 25 minutes to respond to the design problem. In the case of the design students, immediately following the task, recorded design activity was played back to them during retrospective think-aloud sessions, where participants were asked to tell the researcher what they were thinking as they engaged the task [Someren et al. 1994]. During a pilot study it was discovered, in contrast to the design students, the non-design participants had difficulty retrospectively thinking aloud while viewing their own design activity immediately following the completion of the task. The reason for this appeared to be the more limited use they made of sketches and illustrations, meaning they were less able to employ these as memory aides in their retrospective think-aloud session. Due to their inability to retrospectively think aloud while viewing their own activity, a concurrent approach was adopted for sessions involving the ten non-design students.

3.4 Data analysis

20 transcribed design protocols were encoded through a qualitative content analysis (QCA). To achieve this, following segmentation, coders assigned individual segments to the dimensions of a concept-driven coding frame adapted from Valkenburg and Dorst's [1998] classification system (Table 1). The frame provides four theoretical constructs for the encoding of individual segments. The four concepts originate from Schon's [1983], [Schon and Wiggins 1992] epistemology of reflective practice, with various studies having since employed variations on the original concepts [Dorst and Dijkhuis 1995], [Gero and Kannengiesser 2008], [Tang et al. 2011], [Bar-Eli 2013]. The first two, naming and framing are most often associated with problem definition, with moving and reflecting described as indicative of solution orientated work.

Table 1. Four conceptual coding categories based upon the reflection-in-action paradigm

Construct	Description
Naming (problem analyse)	Explicitly pointing to parts of the design task as being important. During naming-activity the designer is looking for relevant objects in the design task. The objects to be considered in the design situation are selected and named.
Framing (synthesise)	Framing a sub-problem or partial-solution to explore further on. The frame is a context for following activities; something to hold on to and to focus on while designing. The activity of naming entities is put into context through framing, and an overall perspective on the design task is constructed.
Moving (solution simulation)	Experimental actions like generating ideas, making an inventory, sorting information, combining ideas, or comparing concepts are coded as moving. During moving activity the designer not only tries to solve the sub-problem, but at the same time also explores the suitability of the frame. The designer takes an experimental action based on the naming and framing of the design task.
Reflecting (evaluation)	The reflecting activity contains a critical reflection of the designer on their earlier actions. Reflections on earlier actions lead to either satisfaction; the making of new moves, or the reframing of the problem. Reflection may also lead to a complete reconsideration of the

designer’s view of the design task, causing the designer to start naming new entities in the design situation.

In order to limit the inherent subjectivity required in any QCA, segmented transcriptions from a design and a non-design student participant were encoded by two coders separately, with encoding compared for consistency. Disagreements were then examined and decision rules agreed and applied as required. Thus, the reliability of the frame in its ability to define the activities indicated within the protocol sessions and validity, in its ability to describe the participants design activity, was examined through blind double-coding.

4. Results

In order to study the influence of design ability in response to a typically ill-defined design problem a statistical analysis was conducted using two different types of quantitative data from the encoded protocols. First, the absolute frequency of encoded items from each of the four encoding category (naming, framing, moving, reflecting) were identified. Following this, the number of transitions between two adjacent activities, indicating a transition from one design activity to another, was examined. A Chi-square test was run to examine whether the state of being a design student had an influence upon frequency distributions of the four design activities. A series of Mann-Whitney U tests were conducted to compare frequencies of each design activity and transitions between activities.

4.1 Comparing frequencies of design activity

Differences between the design and non-design student participants were first examined using absolute encoding frequencies of naming, framing, moving, and reflecting. Table 2 shows the absolute (f) and percentage (%f) frequencies of encoding across the four design activities for all 20 participants. Using the frequency data, a Chi-square test was run to investigate the effect of educational background upon the distribution of activities. The type of design activity and the educational background of participants were defined as independent variables, with the frequencies of the four activities defined as dependent variables. The results showed that there is a significant difference between the design and non-design student participants across the four design activities, $X2 = 103.987$, df = 3, $p<.001$. This indicated the state of being a design student had an influence on the frequencies to which each of the four design activities were engaged. In particular, mean scores for frequency of naming and moving activities appeared to indicate significant difference, (Table 2).

Table 2. Frequencies of encoding for all participants across coding frame dimensions

Education	Participants	Naming	Framing	Moving	Reflecting
Non Design Students	A	66 (45%)	13 (9%)	26 (18%)	42 (29%)
	B	33 (39%)	10 (12%)	19 (23%)	22 (26%)
	C	41 (55%)	7 (9%)	15 (20%)	12 (16%)
	D	24 (39%)	1 (2%)	10 (16%)	26 (42%)
	E	38 (37%)	7 (7%)	29 (28%)	28 (27%)
	F	41 (51%)	8 (10%)	10 (12%)	21 (26%)
	G	36 (41%)	9 (10%)	28 (32%)	15 (17%)
	H	41 (51%)	5 (6%)	24 (30%)	11 (14%)
	I	54 (61%)	7 (8%)	12 (13%)	15 (17%)
	J	44 (45%)	4 (4%)	18 (18%)	32 (33%)
Design Students	A	23 (27%)	4 (5%)	34 (40%)	25 (29%)
	B	47 (30%)	11 (7%)	61 (39%)	37 (24%)
	C	35 (31%)	9 (8%)	44 (39%)	25 (22%)

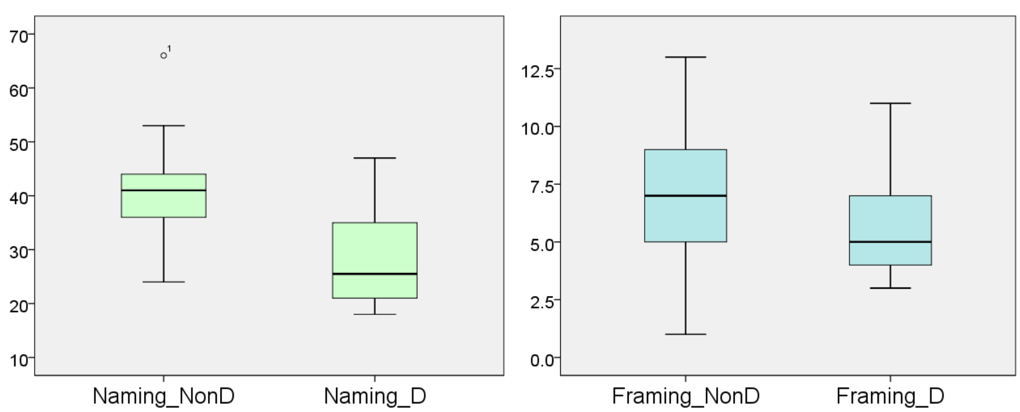
	D	27 (31%)	6 (7%)	33 (38%)	21 (24%)
	E	40 (37%)	5 (5%)	36 (34%)	26 (24%)
	F	24 (26%)	5 (5%)	36 (40%)	26 (29%)
	G	18 (23%)	4 (5%)	38 (48%)	19 (24%)
	H	18 (22%)	3 (4%)	34 (42%)	26 (32%)
	I	28 (26%)	7 (7%)	48 (45%)	23 (22%)
	J	21 (22%)	4 (4%)	44 (46%)	26 (27%)
Non Design Students	Mean	41.80	7.10	19.10	22.40
	SD	11.47	3.31	7.32	9.83
Design Students	Mean	28.10	5.80	40.80	25.40
	SD	9.69	2.53	8.74	4.74

To explore if differences in the frequency and distribution of activities during the design task were statistically significant, Mann-Whitney U tests were conducted for encoding of naming, framing, moving and reflecting activities individually. The frequencies with which the design and non-design student participants engaged each activity were compared. As indicated in Table 2 and shown in Table 3, differences between design and no-design student frequencies of naming and moving activity were found to be statistically significant.

Table 3. Results of Mann-Whitney U tests for encoding frequencies of four design activities

	Naming	Framing	Moving	Reflecting
U-value	16.50	34.50	0.00	38.50
Sig.	.01	.24	.00	.38

As Table 3 illustrates, the frequency of naming activity were significantly reduced among the design students (Mdn = 25.50) compared to the non-design student participants (Mdn = 41.00); U=16.50, $p < .05$). This result showed exposure to design education significantly reduced the frequency of naming activity compared to the non-design student participants. Contrary to reduced frequencies of naming, frequencies of moving activity were observed to be significantly increased among design educated participants (Mdn = 37.00) compared to the non-design students (Mdn = 18.50); U=0.00, $p < .05$). This showed the design student participants engaged in moving activity more often than the non-design educated participants and that this was statistically significant. Figure 1 compares frequencies of the four design activities between non-design (NonD) and design (D) student participants.



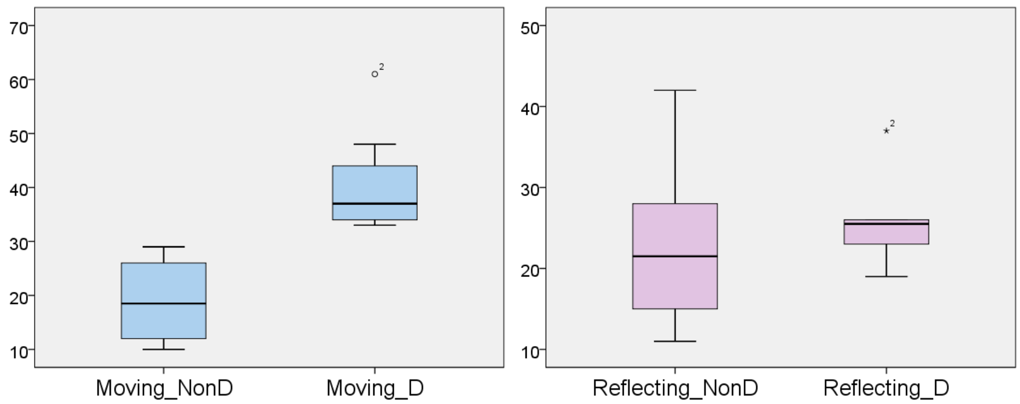


Figure 1. Box plots of the frequencies of four design activities

Together with statistically significant difference in the frequency of moving activity, Figure 1 also illustrates how instances of naming activity were significantly reduced in the protocols of the design students compared to the non-designers. This was in contrast to moving, which was significantly increased in the design student participant protocols compared to the non-designers. Examining the distribution of frequencies of naming and moving indicates a wider distribution of naming activity across both design and non-design students. In contrast, moving activity shows a narrower distribution for both design and non-design educated participants (Figure 1, Moving_NonD & Moving_D). Figure 1 also indicates differences in frequencies of reflecting and framing activities, although these differences were not found to be statistically significant. However, in the case of reflecting, deviation within the non-design student participants was relatively wide compared to the design students (Figure 1 Reflecting_NonD and Reflecting_D). This may indicate design ability did influence frequencies of reflection, but that some individuals with no design education reached the higher frequencies of reflection indicated in the work of the design educated participants.

4.2 Comparing transitions between activities

After examining the significance of differences in the absolute frequency with which each of the four design activities were engaged, we then examined transitions between activities. The four design activities encoded resulted in a total of sixteen types of transitions. Table 4 illustrates the frequencies of transitions between the four design activities for all 20 participants.

Table 4. Number of transitions between four activities for all 20 participants

Participant		Naming to				Framing to				Moving to				Reflecting to			
		N	F	M	R	N	F	M	R	N	F	M	R	N	F	M	R
Non-Design	A	38	4	9	14	3	0	7	3	9	4	4	9	15	5	6	16
	B	17	3	4	8	1	1	6	2	3	3	7	6	11	3	2	6
	C	19	6	10	6	4	0	3	0	9	0	1	4	8	1	1	2
	D	7	0	3	14	0	0	1	0	3	0	5	2	14	1	1	9
	E	15	2	15	6	0	0	4	3	12	2	5	9	11	2	5	10
	F	16	8	4	12	4	0	1	3	7	0	2	1	13	0	3	5
	G	19	4	6	7	3	1	4	1	8	3	8	6	5	1	7	1
	H	19	2	16	3	3	0	0	2	13	3	3	5	5	0	5	1
	I	34	4	6	9	5	1	1	0	6	0	2	4	8	2	3	2
	J	19	2	10	12	1	1	1	1	7	0	2	9	17	1	5	9
	Avg	20.30	3.50	8.30	9.10	2.40	0.40	2.80	1.50	7.70	1.50	3.90	5.50	10.70	1.60	3.80	6.10
Design	A	4	2	12	4	0	0	4	0	8	2	9	14	9	0	9	7

B	16	2	20	9	1	3	6	1	13	3	24	21	16	3	11	6
C	11	2	15	6	2	1	4	2	9	5	19	11	12	1	6	6
D	6	3	14	4	1	0	2	3	14	2	7	9	6	1	9	5
E	16	2	14	7	1	0	2	2	10	2	11	13	12	1	9	4
F	10	1	9	4	0	2	3	0	9	0	12	15	5	2	11	7
G	4	3	10	1	0	0	4	0	6	1	13	17	7	0	11	1
H	3	0	10	5	1	1	1	0	8	0	12	14	5	2	11	7
I	7	3	15	2	0	0	7	0	16	4	16	12	5	0	9	9
J	3	0	16	2	0	0	2	2	9	2	18	15	8	2	8	7
Avg	8.00	1.80	13.50	4.40	0.60	0.70	3.50	1.00	10.20	2.10	14.10	14.10	8.50	1.20	9.40	5.90

As Table 4 illustrates, wide differences in transition rates between the design and non-design student participants were identified for transitions between naming to other activities and moving to other activities. The statistical significance of these identified differences was further examined using Chi-square tests. The test explored the influence of design ability upon the distribution of the sixteen types of transitions during the entire design protocols. Results showed that there was a statistically significant difference between design and non-design student participants in the distributions of transitions during naming, framing, moving and reflecting (X2 = 223.393, df = 15, $p < .05$).

Employing the nonparametric Mann-Whitney U test, the identified differences were further examined for each type of transition. The results indicated that the design students' transition rates were significantly different for seven types of transition: N-N (naming to naming), N-M (naming to moving), N-R (naming to reflecting), F-N (framing to naming), M-M (moving to moving), M-R (moving to reflecting) and R-M (reflecting to moving). Table 5 summarizes the results of the Mann-Whitney U tests with the Median for both participants group.

Table 5. Results of Mann-Whitney U test comparing transitions between participants

Types of transitions	Naming to				Framing to				Moving to				Reflecting to			
	N	F	M	R	N	F	M	R	N	F	M	R	N	F	M	R
Non-D (Mdn)	19.00	3.50	7.50	8.50	3.00	.00	2.00	1.50	7.50	1.00	3.50	5.50	11.00	1.00	4.00	5.50
Design (Mdn)	6.50	2.00	14.00	4.00	.50	.00	3.50	.50	9.00	2.00	12.50	14.00	7.50	1.00	9.00	6.50
U value	7.50	25.50	20.00	15.00	21.00	46.00	37.50	38.00	28.00	41.00	1.50	1.50	35.00	44.50	1.50	48.50
Sig.	.00	.06	.02	.00	.02	.73	.34	.34	.09	.48	.00	.00	.25	.67	.00	.91

As shown in the Table 5, non-design students showed a statistically significant increased rate of transition from N-N ($U = 7.50$, $p < .05$) and N-R ($U = 15.00$, $p < .05$) compared to the design student participants. The analysis also showed the non-design students (Table 5, Non-D) performed significantly less transitions from N-M ($U = 20.00$, $p < .05$) compared to the design students. This supported the results of the design frequency analysis (Table 3), further indicating how the non-design student participants appeared to spend more time and effort in both naming important issues to consider within the problem space and reflecting upon these naming events. In contrast, the design educated participants spent significantly less time transitioning between naming activities and significantly more time transitioning from naming to moving. These results thus indicated how the design students appeared to spend more time and effort both exploring solution ideas, through increased moving activity, and bridge building between the design problem (naming) and possible solution attempts (moving). A summative account of results is presented in Table 6.

Table 6. Results of statistical analysis, comparison of frequencies and transition rates between samples

Comparison	Results
Frequencies	The overall distribution of four design activities – naming, framing, moving and reflecting – is significantly different. 1. Non-design student participants engaged in significantly more naming activity compared to the design students, indicating a focus upon problem definition. 2. The design students engaged in significantly more moving activity compared to non-design students, indicating a greater focus upon solution ideation.
Transitions	The overall distribution of sixteen types of transition among four design activities – naming, framing, moving and reflecting – is significantly different. 1. Non-design students transitioned significantly more often from framing to reflecting from naming, framing and reflecting to naming, indicating limited appositional reasoning or bridge building between problem and solution 2. Design student participants performed significantly more transitions between moving and reflecting and from naming to moving and reflecting to moving; indicating increased appositional bridge building between problem definition and solution attempts.

5. Discussion & conclusions

The statistical analysis showed design student participants spent a significantly greater amount of time engaged in moving activities and transitioned significantly more often between naming and moving. In contrast the non-design educated students spent significantly more time in naming activity and transitioning between naming & framing and naming & naming significantly more often. As naming activity is associated with problem definition [Cross et al. 1994] and moving with solution ideation [Valkenburg and Dorst 1998], our findings support the notion that design ability provides opportunities for appositional or abductive modes of reasoning between problem definition and more generative ideation work.

Although we did not examine the effect an ability to move between problem and solution attempts had upon the quality of design work, a speculative assessment of design student output suggested improved productivity and quality of solution attempts compared to the non-designers (Figure 2). That is, the non-design student participants' significantly greater time spent in attempts to define the design problem (as indicated in both significantly increased naming and transitions rates in and around naming activity) resulted in limited solution proposition or development. These findings agree with Cross [2011] and Cross et al. [1994] who report that novices tended to substitute problem-focused information gathering for work aimed at solution ideation.

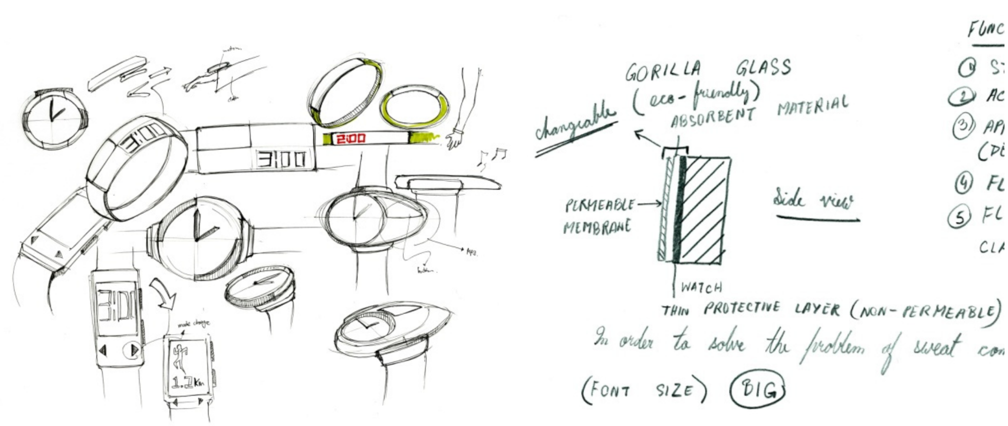


Figure 2. Design student's conceptual output (left) compared to non-design student (right)

Returning to our earlier discussion of reasoning during conceptual design in response to ill-defined design problems, it appears the non-design student participants were less able to engage in the kinds of

abductive reasoning [Roozenburg 1993], [Dorst 2011] often required during conceptual design. This also relates to an inability to bridge-build between design problem and solution; the required appositional reasoning to provide conditions for bridging problem and solution spaces [Dorst and Cross 2001]. How the experiential skill and knowledge required to drive an ability to potentiate reasoning between design problem and solution attempts is developed and how this is then applied to the resolution of design problems is still unclear. We note the design students' ability to express intent through sketching and illustration appeared to provide opportunities for transition between problem definition and solution ideation (Figure 2). In contrast, the non-design students' inability or unwillingness to sketch appeared to frustrate attempts to move between definition and conceptual ideation. In following publications the authors will continue to explore this possibility.
Although the current study has indicated how design students appeared to more readily engage abductive reasoning when engaging a typically ill-defined design problem, caution is required in the generalisation of results. The statistical analysis showed considerable individual differences in the rates at which the non-design student participants engaged in problem identification (naming activity) and solution ideation (moving activity). The influence of individual or idiosyncratic approaches within the sample for ability to reason between problem and solution was not explored further in the current investigation. However, our findings do provide evidence to support the important role design ability has in potentiating transitions between problem definition and solution ideation during conceptual design. Further work is now required to continue to build an understanding of how experience in practice and/or experiential design knowledge and ability is able to support the kinds of appositional reasoning required in response to ill-defined design problems. This then has the potential to provide greater understanding of how design knowledge and ability may be appropriated and applied as driver for the successful resolution of complex designerly problems.

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References
Archer, L. B., "The three Rs", Design Studies, Vol.1, No.1, 1979, pp. 195-201.
Bar-Eli, S., "Sketching profiles: Awareness to individual differences in sketching as a means of enhancing design solution development", Design Studies, Vol.34, No.4, 2013, pp. 472-493.
Björklund, T. A., "Initial mental representations of design problems: Differences between experts and novices", Design Studies, Vol.34, No.2, 2013, pp. 135-160.
Casakin, H., "Visual Analogy as a Cognitive Strategy in the Design Process: Expert Versus Novice Performance Expertise in Design", Design Thinking Research Symposium 6 University of Technology, Sydney, Australia Creativity and Cognition Studios Press, 2003.
Cross, N., "Design Expertise", Design Thinking, Oxford, Berg, 2001.
Cross, N., Christiaans, H., Dorst, K., "Design Expertise Amongst Student Designers", Journal of Art & Design Education Vol.13, No.1, 1994, pp. 39-56.
Dixon, R. A., "Selected Core Thinking Skills and Cognitive Strategy of an Expert and Novice Engineer", Journal of sTEm Teacher Education Vol.48, No.1, 2011, pp. 36-67.
Dorst, K., "The Design Problem and its Structure. Analysing Design Activity", N. Cross, Christiaans, H., Dorst, K. Chichester, Wiley, 1996.
Dorst, K., "The core of 'design thinking' and its application", Design Studies Vol.32, No.6, 2011, pp. 521-532.
Dorst, K., Cross, N., "Creativity in the design process: co-evolution of problem–solution", Design Studies Vol.22, No.5, 2001, pp. 425-437.
Dorst, K., Dijkhuis, J., "Comparing paradigms for describing design activity", Design Studies Vol.16, No.2, 1995, pp. 261-274.
Ericsson, A., Simon, H., "Protocol Analysis", London, The MIT Press, 1993.
Gero, J., Kannengiesser, U., "An ontological account of Donald Schön's reflection in designing", International Journal of Design Sciences and Technology Vol.15, No.2, 2008, pp. 77-90.

Kavakli, M., Gero, J. S., "The structure of concurrent cognitive actions: a case study on novice and expert designers", Design Studies, Vol.23, No.1, 2002, pp. 25-40.

Lawson, B., Dorst, K., "Design Expertise", Oxford, Architectural Press, 2009.

Michel, R. E., "Design Research Now", Birkhäuser Verlag AG, Berlin, 2007.

Nelson, H. G., Stolterman, E., "Design Judgement: Decision-Making in the 'Real' World", The Design Journal - Vol.6, No.1, 2003, pp. 23-31.

Rittel, H., Webber, M., "Dilemmas in a General Theory of Planning", Policy Sciences, 1973, pp. 155-169.

Roozenburg, N. F. M., "On the pattern of reasoning in innovative design", Design Studies, Vol.14, No.1, 1993, pp. 4-18.

Schon, D., "The Reflective Practitioner", London, Ashgate, 1983.

Schon, D., "Educating the Reflective Practitioner", New York, Jossey-Bass, 1987.

Schon, D., Wiggins, G., "Kinds of seeing and their functions in designing", Design Studies, Vol.13, No.2, 1992, pp. 135-156.

Simon, H., "The Science of the Artificial", London, MIT Press, 1996.

Someren, M., Barnard, Y., Sandberg, J., "The Think Aloud Method", London, Academic Press, 1994.

Tang, H. H., Lee, Y. Y., Gero, J. S., "Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function–behaviour–structure coding scheme", Design Studies, Vol.32, No.1, 2011, pp. 1-29.

Valkenburg, R., Dorst, K., "The reflective practice of design teams", Design Studies, Vol.19, No.3, 1998, pp. 249-271.

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