The Design Journal
An International Journal for All Aspects of Design

ISSN: 1460-6925 (Print) 1756-3062 (Online) Journal homepage: http://www.tandfonline.com/loi/rfdj20

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To cite this article: James Self (2017) Resolving Wicked Problems: Appositional Reasoning and Sketch Representation, The Design Journal, 20:3, 313-331, DOI: 10.1080/14606925.2017.1301070

To link to this article: http://dx.doi.org/10.1080/14606925.2017.1301070

Published online: 31 Mar 2017.

THE DESIGN JOURNAL
VOLUME 20, ISSUE 3
PP 313–331
REPRINTS AVAILABLE DIRECTLY FROM THE PUBLISHERS
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Resolving Wicked Problems: Appositional Reasoning and Sketch Representation

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ABSTRACT The influence of a design education upon reasoning in response to ill-defined design problems was examined through a comparative protocol study of design and non-design students. A statistical analysis compared distributions of and transitions between the activities naming, framing, moving, and reflecting. Design student protocols were characterized by significantly increased activity associated with reasoning between problem definition and solution ideation. In contrast, participants lacking any formal design education or experience indicated significantly increased reasoning towards problem definition, with little evidence of ideation. A subsequent qualitative comparison identifies sketching as a potential driver for both increased solution-focused activity and greater iteration between problem definition and

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solution ideation. Implications for design ability, sketching and appositional bridge-building between problem definition and solution ideation are discussed.

KEYWORDS: ill-defined problem, design sketching, appositional reasoning, design ideation

Introduction

A defining characteristic of conceptual design ideation is an ability to develop solutions to often ill-defined design problems (Rittel and Webber 1973). In engaging ill-defined problems, the designer relies upon past experience to judge the suitability of solution attempts (Nelson and Stolterman 2003). Within this process, sketching is frequently employed as a means with which to represent solution ideas and reflect upon their suitability given a developing understanding of the design problem (Schon and Wiggins 1992). Acting to support reasoning during initial resolution of ill-defined design problems (Goldschmidt 1997; Kim, Jung, and Self 2013), the designer's ability to express, explore and develop conceptual solutions through sketches of various levels of fidelity appears important (Pei, Campbell, and Evans 2011). This is because sketches and illustrations provide opportunities to approximate design solutions; and explore and develop their potential. Taking the epistemology of knowing-in-practice proposed by Schon (1983, 1987), this study examines the influence of design education upon the resolution of an ill-defined design problem during conceptual ideation. As first suggested by Rittel and Webber (1973), design problems may often be described as ill-defined in that the issues associated with a design problem, and the means through which they may be addressed, are unclear.

As indicated by Schon (1983, 1987), designers appear to employ reflective practice as a means to deal with the uncertainty of a design situation. As such, this study examines how design education may influence the frequency and duration of four design activities: naming, framing, moving and reflecting to contribute to an understanding of the relationship between design ability and the nature of reflective practice as design problems are undertaken and solutions sorted through sketching.

Qualitative analysis examines differences in the activity of design and non-design student participants and the study concludes with a discussion on the significance of results for understanding relationships between reasoning between problem definition and solution ideation and an ability to deploy design representation through sketching. The significance of external representation through sketching upon the ability to reflect-in-practice is highlighted.

Design Problems and Conceptual Ideation

Ill-defined design problems (Cross 2011; Rittel and Webber 1973) have attracted attention as a means with which to distinguish designerly problems (Dorst 1996) from those of the sciences (Archer 1979). Ill-defined problems may never definitively be solved, having instead a potentially infinite number of ways to proceed towards problem resolution. This is because the goal of problem resolution is the creation of the yet-to-be, as opposed to a definitive answer to explain the problem. Understanding the ill-defined problem depends upon, and is influenced by, attempts made towards its resolution: 'the problem can't be defined until the solution has been found' (Rittel and Webber 1973, 161). Although this is true to an extent, it is also the case that a design problem will never be truly defined in the sense of a single definitive solution. Instead, a best solution is generated based on the problem-solver's definition of the problem through their attempts towards its resolution.

A defining characteristic of design problem resolution is a requirement to base resolution on an interpretation of the appropriateness of the proposed solution given a developing understanding of the original problem. Skills, knowledge and level of experience in addressing similarly ill-defined problems influence both the ways in which the problem is understood and judgements made towards the appropriateness of potential solution ideas. These judgements thus rest upon an interpretation of the solution's quality in its ability to meet the requirements of the design problem. Thus, the skilled use of external representation as sketches appears important in providing opportunities to both define the salient attributes of the design problem and concurrently assess the appropriateness of solution propositions (Visser 2006; Pei, Campbell, and Evans 2011).

However, design expertise, including practiced ability such as ideation sketching, appears to develop at a slower pace and over a longer period of time (Cross 2011; Lawson and Dorst 2009a). In the sciences, an ability to apply more prescribed methodologies to the analysis of the phenomena under observation appears more quickly developed compared to design. This is because an ability to both effectively define the design problem and explore appropriate solutions is founded upon the designer's more heuristic use of past experience and associated expertise. Although we do not disagree that experience of practice is important to facilitate generative conceptual ideation, the current study indicates how sketch ability can provide opportunities for less experienced designers to engage in the types of reasoning between problem and solution observed in the work of more seasoned professionals.

In a related way, Dorst (2011) describes abduction (Roozenburg 1993) as a type of reasoning often required in responding to ill-defined problems. In contrast with deductive reasoning, which may be used to reach a logically certain conclusion through a process of reduction and induction, described as reasoning based upon strong evidence of a conclusive truth, abductive reasoning is deployed when both the nature of the 'what' (the thing needing attention) and the 'how' (principles by which it may operate) are unknown. Only the required value of the result attained is understood. In order to address the design problem, the designer must both explore the problem in parallel to the use of this understanding in developing the strategy by which the problem may be resolved. As such, we see similarities between Dorst's (2011) description of abductive reasoning in design and Cross' (2011) notion of appositional reasoning between problem definition and solution proposition. In both cases, important considerations within the context of the problem are first named (Schon and Wiggins 1992). Partial solutions are then explored through conceptualization aimed at developing understanding of both problem and the appropriateness of propositional solution ideas.

Although the role of experience appears important in providing heuristic strategies by which design experts effectively ideate between problem definition and solution ideation, this study shows how students with limited design experience, but skill in the use of design representation through sketching, appear able to effectively engage in generative bridge building between problem and solution attempts. This indicates an ability to represent design intent through sketching, as opposed to extensive past experience of practice, provides opportunities for the kinds of appositional reasoning required to facilitate effective conceptual design.

Design Expertise and Design Representation

Together with studies describing the development of designerly ability (Cross 1990), design researchers have explored the relationship between expertise, design representation and design ideation. For example, Kavakli and Gero (2002) indicate how expert use of drawing afforded increased cognitive actions compared to novice designers. Casakin (2003) indicates how a lack of design expertise resulted in an inability to establish deep analogical structures between a source analogy and target. Likewise, Björklund (2013) shows how experts appear to see design problems as more difficult than novice designers, using analogies to connect mental and physical representation of the design problem. Dixon (2011) indicates the ways in which expert practice resulted in a greater depth of exploration compared to novice designers. Cross (2011) also observed that novice designers appear to substitute greater time in naming attributes of the design problem for actually engaging in solution ideation. In terms of implications for the quality of solution ideas, Cross, Christiaans, and Dorst (1994) report the ways in which problem-focused gathering of information resulted in poorer outcomes compared to solution-focused exploration.

An important aspect in reasoning between problem definition and solution ideation appears to be an ability to represent solution ideas at varying degrees of fidelity (Pei, Campbell, and Evans 2011). For example, Visser (2006) considers the importance of design representation as a means to define design activity itself. If expert design ability is 'founded on the resolution of ill-defined problems by adopting a solution-focusing strategy and *productive* (authors emphasis) or appositional styles of thinking' (Cross 1990, 132), an ability to represent design intent through sketching appears important to the resolution of ill-defined design problems.

Likewise, Suwa, Purcell, and Gero (1998) emphasize the ability to represent design intentions, perceive and understand design issues requiring consideration, 'drawing sketches, representing the visual field in the sketches, perceiving visuo-spatial features in sketches, and conceiving of design issues or requirements are all dynamically coupled with each other' (Suwa, Purcell, and Gero 1998). Lawson and Dorst (2009b) suggest, due to a requirement to frame the design problem (Schon and Wiggins 1992) and test problem frames, that experience in problem ideation through representation implicates an ability to understand the design problem.

Although experience in design problem definition appears important to an ability to engage in appositional reasoning towards the resolution of ill-defined problems, we indicate how novice designers, of limited design experience are, nonetheless, significantly more inclined to engage in activity indicative of reasoning between problem definitions and the generation of and reflection upon solution ideas than those without sketch ability. Although design experience remains an important factor in effective conceptual ideation when engaging with ill-defined design problems, the ability to represent design intent through sketching is important in providing support for reasoning between problem definition and generative resolution ideation.

Methods

Following existing studies (Cross, Christiaans, and Dorst 1996; Dorst 1995; Jiang and Yen 2009), the current investigation employed protocol analysis (Ericsson and Simon 1993; Someren, Barnard, and Sandberg 1994) as means to examine design activity during conceptual ideation. The following sections describe criteria for participant selection, research design, research instrument and procedure, encoding and method of analysis.

Participants

The study drew a purposeful sample of 20 participants (n=20) from a population of fourth year undergraduates at Ulsan National Institute for Science and Technology, South Korea. To examine the influence of educational background on reasoning, half of the sample was taken from a cohort of fourth year BSc Industrial Design students. The remaining participants majored in Business Management or Material Sciences. The 10 Industrial Design students, although not experienced designers, had completed fundamental courses in design sketching as well as studio-based product design courses. The sample of management and science majors had no formal education in design.

Research Design

An experimental approach was taken that had the advantage of reducing the noise often associated with in-the-wild research (Michel 2007) and the subjects' responses to a design problem captured through three video recordings. The first camera recorded the participants' working environment; a second recorded activity performed within the participants' immediate working area (i.e. sketching, drawing, writing); and a third recorded body position, movement and posture during the protocols. Design and non-design participants were provided with the same set of drawing materials: plain A3 drawing paper, lined A4 conference pad, pens, pencils, coloured markers, erasers, pencil sharpener and drawing templates. Both were given the same problem, requiring participants to develop a design concept for a sports watch for young people aged 18 to 30.

Task Procedure

Participants were provided 25 minutes to respond to the design problem. In the case of the design students, immediately following the task the participants' recorded design activity was played back to them during a retrospective think-aloud session and participants asked to tell the researcher what they were thinking as they engaged in the task (Someren, Barnard, and Sandberg 1994). The think-aloud method is well established in design practice research (Chai and Xiao 2012) however, the types of think-aloud experiment and variations in format differ; from concurrent to retrospective studies (Perry and Krippendorff 2013). The length of time provided for protocol sessions also varies from several hours to 15 minutes (Chai and Xiao 2012; Jiang and Yen 2009). A pilot study discovered that the non-design participants had great difficulty in retrospectively thinking aloud while viewing their design activity immediately following completion of the task and a concurrent approach was therefore adopted. Participants were asked to think-aloud while engaging in the design task which proved to be more effective in providing opportunities for the subjects to retrospectively report think aloud as they engaged the design session.

Data Analysis

The 20 transcribed protocols were encoded through a Qualitative Content Analysis (QCA) and the think-aloud sessions first segmented using thematic criterion. Two coders worked separately to identify discourse that appeared to consolidate as a single idea or thought. Coders then assigned individual segments to the dimensions of a concept-driven coding frame adapted from Valkenburg and Dorst's (1998) classification system. Valkenburg and Dorst (1998) provide four theoretical constructs for the encoding of individual segments of activity (see Table 1) with the four concepts originating from Schon's (Schon and Wiggins 1992; Schon 1983) epistemology of reflective-practice.

In order to limit the inherent subjectivity required during QCA, a segmented transcription from a design and non-design student participant was encoded by two coders independently. Encoding was then compared for consistency, with disagreements examined and decision rules agreed upon and applied as required.

Results

Quantitative Comparison

After encoding, two types of quantitative data were obtained from the encoded protocols. First, the frequencies of the four design activities (see Table 1) through the absolute number of encoded segments of each coding category were identified (*f*) along with the number of transitions between two adjacent activities, thereby indicating a transition from one design activity to another. A *Chi-square* test was then run to examine whether educational background had any influence on the distribution of and transitions between activities. A series of *Mann-Whitney U* tests were then conducted to compare differences in frequencies of and transitions between activities. Results indicated the significant influence of having a design education on the four activities of naming, framing, moving and reflecting.

Frequencies of Design Activity

Table 2 shows the absolute (*f*) and percentage (*%f*) frequencies of encoding across the four design activities for 20 participants. A *Chi-square* test investigated the effect of educational background upon the distribution of activities. The type of design activity and the participants' background were defined as independent variables, with the frequencies of the four activities defined as dependent variables. Results showed that there was 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 at which each of the four design activities were engaged. In particular, mean

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

Construct	*Description*
Naming (problem definition)	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 (problem definition)	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 ideation)	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 (solution ideation)	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.

scores for frequency of naming and moving activities appeared to indicate significant difference (see Table 2, bold font).

To explore if different frequencies and distributions of activities were statistically significant, *Mann-Whitney U* tests were conducted for the individual activities of naming, framing, moving and reflecting, with the frequencies with which the design and non-design students engaged in each activity compared (see Table 3).

The frequency of naming were significantly reduced among the design students (*Mdn* = 25.50) compared to non-design students (*Mdn* = 41.00); U=16.50, $p < .05$), indicating that exposure to design

Table 2. Frequencies of encoding for 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

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

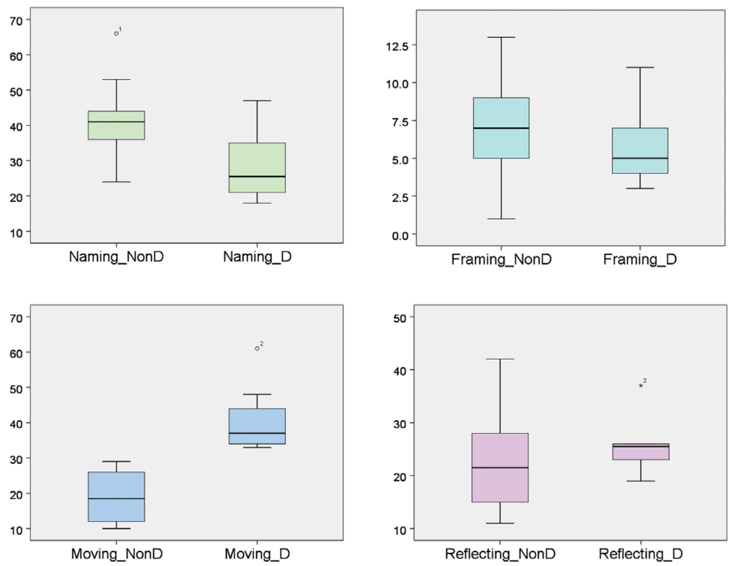

Figure 1.
Box plots of the frequencies of four design activities.

education significantly reduced the frequency of naming events compared to non-design student participants. Contrary to this, frequencies of moving activity were significantly increased among design educated participants (*Mdn* = 37.00) compared to the non-designers (*Mdn* = 18.50); $U = 0.00$, $p < .05$). This showed that design students engaged in significantly increased moving activity compared to non-design participants. Results also indicate that the design student participants had increased frequencies of reflecting activity, although this was not found to be significant. Figure 1 compares frequencies of the four design activities between non-design (NonD) and design (D) student participants.

Examining the distribution of frequencies of naming and moving (see Figure 1), a wide distribution of naming activity across both design and non-design students was identified. In contrast, moving activity showed a narrow distribution for both sets of participants (see Figure 1, Moving_NonD and Moving_D).

As moving is associated with solution ideation and naming with problem definition, findings indicated how the non-design participants focused their attention upon problem definition, with little time spent in solution proposition or development. In contrast, the design students' protocols were characterized by significantly more moving activity, indicating a focus upon generative solution ideation.

Transitions Between Activities

We examined activity transitions in order to test for any differences in the way in which participants moved between activities. The greatest differences in transition rates were identified between *naming* to *naming*, *naming* to *reflecting*, *moving* to *moving* and *moving* to *reflecting*.

The statistical significance of these differences was further examined using a *Chi-square* test. Results showed there was a statistically significant difference between design and non-design student participants in the distributions of transitions during naming, framing, moving and reflecting ($X2 = 223.393$, $df = 15$, $p < .05$). Using a nonparametric *Mann-Whitney U* test, differences were further examined for each type of transition (see Table 4).

As illustrated in Table 4, non-design students showed a statistically significant transition rate from *naming* to *naming* ($U = 7.50$, $p < .05$) and *naming* to *reflecting* ($U = 15.00$, $p < .05$) compared to the design students. The analysis also showed the non-design students performed significantly less transitions from *naming* to *moving* ($U = 20.00$, $p < .05$). These results further indicated how non-design students appeared to spend more time in both naming issues to consider within the problem and reflecting upon their importance. In contrast, the design educated participants spent significantly less time transitioning between naming activities and more time transitioning from naming to moving. A summative account of results is provided in Table 5.

Qualitative Comparison

The follow section examines how statistically significant differences in frequencies and transitions between the activities of *naming* and *moving* influenced the participants' reasoning between problem definition and solution ideation. Figure 2 illustrates the distribution of activities encoded as naming (N), moving (M), reflecting (R) and framing (F) across the design protocols of design student (DE.1) and non-design student (NE.2).

DE.1 engaged in significantly increased moving activity (see Figure 2, Design Educated Participant [DE.1], M: second set of bars from top). His work was also characterized by increased transitions from moving to naming and moving to reflecting. In contrast, NE.2's work was characterized by increased naming activity (see Figure 2, NE.2 N: orange bars), with fewer transitions between naming and moving. The first five minutes of DE.1's work consisted of transitions between moving (see Figure 2, DE.1, M) and naming (DE.1, N). These transitions appear to provide DE.1 opportunities to test and refine his own understanding of the design problem, while at the same time moving quickly to explore possible solution ideas through sketching. An example of his use of sketching appears as early as 00:27 when he names form as an important concept to consider, 'So I think first I think about the shape, sporty. A sports shape can make watches look sporty.' He then immediately start to draw, 'so at first I draw the round shape of a watch'. The beginning of DE.1's protocol also included two framing events (see Figure 2, F), before his work shifts to a solution focus. In doing this he appears to hit upon the idea of a banded watch design, 'And this watch is … looks like a band, a wrist band, so a banded watch.' This then serves as catalyst for DE.1's subsequent solution ideation, re-emerging at various stages in the protocol.

Table 4. 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

Table 5. 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 were 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. Design students engaged in significantly more moving activity compared to non-design students, indicating a greater focus upon solution ideation.
Transitions	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 ideation.

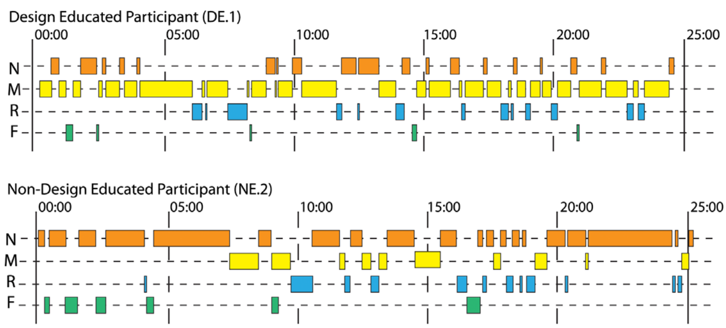

Figure 2.
Distribution of *naming*, *moving*, *reflecting* and *framing* activity across the protocols of DE.1 and NE.2.

DE.1's transitions between naming and moving, and its stimulation of iterative problem understanding, contrasted with NE.2's naming dominated activity at the beginning of their protocol (see Figure 1, NE.1, 00:00–05:00) as they continue to list things to consider within the problem space. In the period between 00:00 and 05:00, NE.2 makes four transitions between naming and framing. These framing events include a flexible strap design idea, 'I'm thinking about a flexible strap; Velcro as fixing material, maybe Velcro or something that can be easy to put on and take it off.' However, unlike DE.1's application of his banded-watch idea, NE.2's problem framing appears to have little impact in moving his focus away from problem definition. NE.2's use of written text appears only to compound an inability to transition from the naming of attributes within the design problem, to the generative proposition of conceptual solution ideas.

The analysis indicated how DE.1's exploration of solution ideas resulted in both positive and negative assessment of the solution's suitability in addressing the design problem. At 06:14 (see Figure 3), when reflecting upon his own sketch work, DE.1 announces, 'At the end of the sketch I think I failed.' However, recalling an earlier idea of a more unique form, DE.1 continues his solution-focused moving, 'so I think some

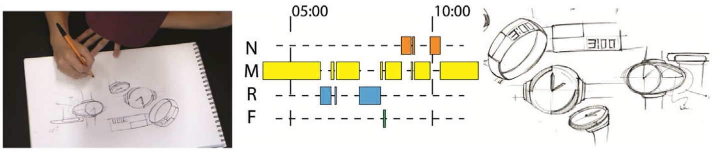

Figure 3.
DE.1's design work and protocol activity, 05:00 to 10:00.

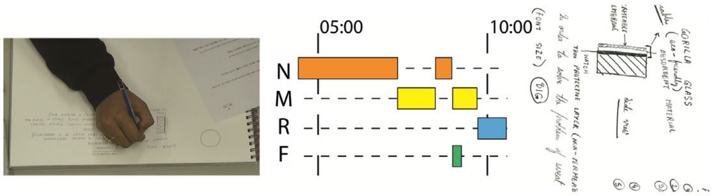

Figure 4.
NE.2's design work and protocol activity, 05:00 to 10:00.

other special shapes are, would make some sports feeling'. Although DE.1's moves to progress solution ideas fail his assessment of suitability in terms of a developing definition of the design problem, his ubiquitous sketching appears to facilitate a continuation of solution focused activity.

During the 7th minute of NE.2's task, he appears to move to consideration of solution ideas (see Figure 4, naming to moving). However, rather than exploring the suitability of initial solution candidates through sketching, NE.2 attempts to think through the appropriateness of ideas rather than embody them as sketches, 'And at the same time since some people do their involvement in sports and they are above 20, around thirties, sometimes they want something just not flashy.' This strategy appears to fail as NE.2 transitions back to problem definition, 'Usually we see that because of exercising we sweat a lot and the salt comes out of the body usually tends to spoil the watch.'

In contrast, 10:00 to 13:23 of DE.1's protocol continues to be characterized by solution-focused moving through the expression of design intent as sketches, as at 13:05 a reflection upon progress prompts a shift in attention back to the design problem, 'This watch has a new function because … and at this time I think a sports watch, if a sports watch has this'. This is followed by 10 minutes of increasingly transitional work between periods of moving fragmented by shorter iterations of naming and reflecting activities. As seen previously, DE.1's ability to sketch appears to support transitions between problem definition and solution-focused ideation. Although a similar period of NE.2's protocol appears equally fragmented (see Figure 5, 15:00–20:00), a larger proportion of activity continues to be spent engaging in naming.

At 15:43, NE.2 names uniqueness as an important consideration of a future design solution, 'we need to have something unique'. He then frames a moving screen as a possible solution candidate followed by an extended period naming existing problems around the use of smart devices, 'say in a smart watch we have the application … but at the same time if we are trying to compare two performances or something'. As before, NE.2 attempts to explore the moving screen idea though thinking about its appropriateness, 'I'm trying to think if we can have

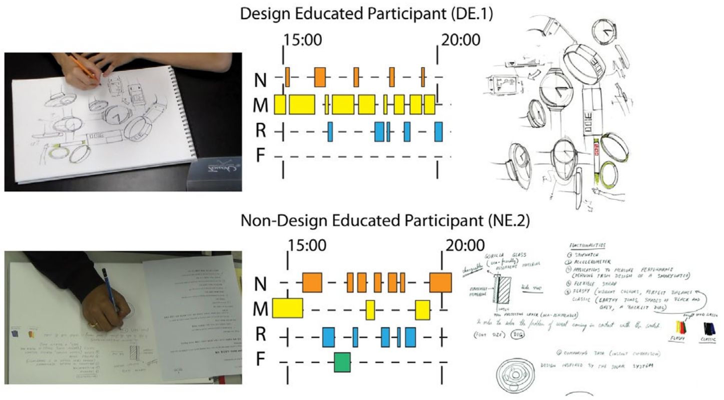

Figure 5.
Comparison of DE.1 and NE.2's design work and protocol activity, 15:00 to 20:00.

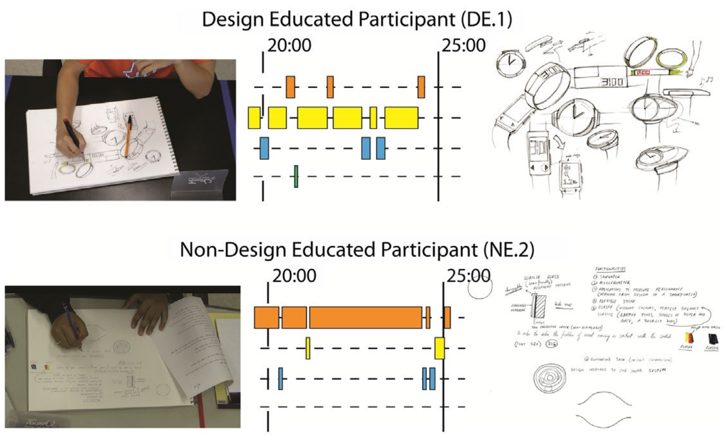

Figure 6.
Comparison of DE.1 and NE.2's design work and protocol activity, 20:00 to 25:00.

the function to overlap the graphs'. At 18:44 he appears to make one of a limited number of transitions from problem to solution ideation, 'We need to have distinct numbers, sports people always want to have big letters'. However, at 19:30 NE.2's attention again transitions back to problem definition, 'Right now I'm just trying to look at the requirements again.' For the remainder of the protocol, NE.2 engages in an inventory of things to consider in defining the problem; naming each item in a list of requirements (see Figure 6, NE.2 20:00–25:00). This is broken by a final transition from naming to moving as detail is added to one of only two of their sketch representations, 'So something at the center may be the most important function'. In contrast, DE.1's final section of the protocol (see Figure 6, 20:00–25:00) indicates a continued focus upon the refinement of solution intent through sketch representation.

DE.1's work is characterized by solution-focused moving through the generation, development and reflection upon ideas to test their suitability against an interpretation of key considerations within the design problem. As if to highlight the significance of the solution-focused sketching activity, DE.1's protocol concludes with a final framing event, 'so finally I can see a new type of watch, not a band or on the wrist, just a clip watch' (see Figure 6, 20:00–25:00, F). In contrast with NE.2's problem-focused activity, the final moments of DE.1's protocol are employed in work towards generative solution ideation supported by ubiquitous use of sketching.

Discussion

The statistical analysis of 20 design protocols demonstrated that design student participants spent a significantly greater amount of time engaged in moving activities and transitioned between moving and other activities significantly more often. This indicated the design students' ability to more effectively move between problem definition and the generation of solution ideas.

In contrast, the non-design educated participants spent significantly more time naming and transitioning into and out of naming activities. This result suggested that the non-design students spent significantly less time in solution ideation and transitioned significantly less often between problem definition and idea generation.

The design students' orientation towards solution ideation and ability to transition more effectively between problem and solution were reflected in the comparative qualitative analysis, with DE.1 (design student) engaging significantly more often in moving activity while NE.2's (non-design student) protocol was characterized by naming events. These findings agree with Cross (2011) and Cross, Christiaans, and Dorst (1994) who report the novice's substitution of solution ideation for problem-focused information gathering.

The effect of the non-design students' problem-focused approach on an ability to engage appositional reasoning was evident in the qualitative comparison of design protocols. NE.2's naming focus resulted in continuous attempts to define the nature of the problem with little work towards generative solution proposition and development. Moreover, within the limited attempts made to adopt a solution-focus, as seen in moving activity during 07:00 to 09:00 of NE.2's protocol, ideas were not well developed. In contrast, DE.1's significantly increased time spent in moving activity was a defining characteristic of the protocol.

The comparison also indicated sketch ability as significant driver for the increased solution-focused moving activity identified in the statistical analysis of the design educated participants. For example, in the first five minutes of the design student's protocol, transitions between naming and sketch-driven moving provided opportunities for the establishment of a banded strap design. An ability to transition between naming and moving activity and, thereby, frame the problem in a particular way while testing the problem-frame through solution-focused moves, appeared to be dependent upon the design student's ability to sketch. In contrast, iteration between problem definition and solution ideation was absent in the work of the non-design student. An inability to deploy sketch representation as a means by which to explore solution ideas appeared to inhibit the application of problem understanding in solution-driven design ideation.

The findings indicate how participants with limited experience of practice were more able to define the design problem (albeit with a limited previous experience on which to draw) and, through sketching, turn to identify the principles through which a resolution may be achieved. In contrast, participants lacking sketching ability were less able to move between problem definition and generative solution ideation as reflected in significantly reduced moving and increased naming activity.

Conclusion

We have presented results of a protocol analysis in order to examine the influence of an educational background in design on response to a design problem. Statistical analysis indicated that design student participant protocols' were characterized by significantly increased solution focused activity. In contrast, the protocols of non-design student participants were shown to be defined by significantly increased activity aimed at problem definition. While all participants lacked extensive design experience, a qualitative comparison indicated sketching ability as driver for increased solution-focused work. These results indicate that sketching ability, as opposed to extensive experience of practice, provided the means through which participants were able to engage in the kinds of abductive (Roozenburg 1993) or appositional reasoning (Dorst and Cross 2001) often required in response to ill-defined design problems (Rittel and Webber 1973) during conceptual design.

Although the current study has indicated how participants with sketching ability appeared to more readily engage appositional reasoning towards an ill-defined design problem, caution is required in the generalization of results. Participants possessing a design education, while not yet expert designers, had experience of internship and engaging in practice-based studio design courses. The influence of this upon an ability to engage in iterative problem definition and solution ideation was not measured. How this experience related to their significantly increased solution-focused activities or predisposition to sketch was not examined. Future studies may wish to explore what we see as an important interaction between design experience, solution-focused activity and sketching ability.

A statistical analysis showed individual differences in the rates at which the non-design students engaged in problem identification (naming activity) and solution ideation (moving activity). The influence of idiosyncratic approaches to the resolution of the design problem was also not explored. Future research may wish to explore differences in approach, character traits and their influence upon solution-focused work through, for example, profiling participant characteristics and/or experience.

The findings provide evidence to suggest the important role that the ability to represent design intent through sketching plays in providing less experienced designers the necessary means to move from problem definition to the development of solution intent during conceptual design. Further studies are now required. For example, how do other designerly skills, knowledge and abilities influence a predisposition to sketch in response to ill-defined problems? How might the nature of the problem itself influence both the use of sketching and engagement in reasoning during design ideation?

Although it is beyond the scope of the current study to address these questions, we provide evidence to illustrate the importance of sketching as means to represent design intent, thereby providing less experienced designers opportunities to engage solution ideation. This then has the potential to provide the foundations for a theory of design sketching which may be used to inform the development of pedagogic methods and strategies to explicitly define the benefits of sketch ability as they relate to the requirements of conceptual design. Such a theoretical foundation for explaining the role and use of sketching also has the potential to benefit other fields and disciplines that face the challenges of wicked problem resolution.

Disclosure Statement

No potential conflict of interest was reported by the author.

Funding

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2013S1A5A8021797).

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Biography

James Self is associate professor of industrial design and director of the Design Practice Research Lab, School of Design and Human Engineering, UNIST. He holds a doctorate in industrial design practice and worked for several years within the design industry in London and Sydney, Australia. Dr Self also holds degrees and diplomas in 3D Design (ND) Model Design (BA) and Digital Modelling with Rapid Prototyping (MA). Dr Self is a design commentator for Core77, peer reviewer for numerous international publications and currently holds associate editorships and committee positions for a number of international journals and conferences. His design works and research contributions include numerous peer reviewed publications, international design awards, patents, design articles, exhibitions, invited seminars and workshops. Current and past research and design projects include a broad field of interests, from design-driven innovation to sketching and its role in conceptual ideation, to interdisciplinarity in design education.

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