Reflecting on Design Sketching: Implications for Problem-Framing and Solution-focused Conceptual Ideation

James Self [1] , Eujin Pei[2]

[1]School of Design and Human Engineering, UNIST, Ulsan, Korea

[2]School of Design, De Montfort University, Leicester, UK

Abstract

Background This investigation examines the role and use of sketching as tool of design representation during conceptual design activity. In particular we focus upon sketching's relationship with problem framing and solution-focused strategies and reasoning in the proposition, exploration and development of solution ideas. This research was conducted to contribute to furthering knowledge and understanding of sketching for use in design pedagogy and the development of conceptual design tools.

Methods In a qualitative content analysis (QCA) a coding frame based upon the constructs naming, framing, moving and reflecting is employed in the analysis of a concept design protocol using the think-aloud method. The protocol's transcriptions were segmented before being encoded through the concept-driven coding frame. The analysis and discussion of results proceeds through reference to the encoded protocol data and is supported by the synchronic charting of design activity.

Results Sketching activity during conceptual design provides opportunities for previous frames of reference to re-emerge and be re-engaged in new ways. The act of sketching appeared to facilitate frequent shifts of attention to and from sub-problems and sub-solutions. This thus provided opportunities to laterally explore different aspects of emergent solution ideas in a concurrent manner. These frequent shifting of attention may act as a catalyst for appositional reasoning across different aspects of the design problem. The participant's solution-focused thoughts appeared to both influence and be influenced by sketching activity, affording fresh insights and perspectives to emerge.

Conclusion The study of sketching and other tools of design representation provides opportunities to better understand the kinds of designerly ways of knowing, thinking and action required in practice. Findings have implications for design pedagogy and the development of conceptual design tools.

Keywords Design Sketching, Conceptual Design, Design Practice Research

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

*Corresponding author: James Self (jaself@unist.ac.kr)
This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2013S1A5A8021797)

Citation: Self, J., & Pei, E. (2014). Reflecting on Design Sketching: Implications for Problem-Framing and Solution-focused Conceptual Ideation. *Archives of Design Research, 27*(3), 65-87.

http://dx.doi.org/10.15187/adr.2014.08.111.3.65

Received Jul. 15. 2014 **reviewed :** Aug. 03. 2014 **Accepted :** Aug. 06. 2014
pISSN 1226-8046 **eISSN** 2288-2987

1. Introduction

Design representation through sketching is fundamental to conceptual design activity (Cross, 1990; Lawson, 2006; Visser, 2006), as often ill-defined design problems are framed (Cross, 2007; G Goldschmidt, 1997; Rittel & Webber, 1973), and solution-focused design intentions reflectively tested, explored and progressed (Cross, 1990; D. Schon, 1983). With a particular focus upon industrial design (IDSA, 2013), this study constitutes some of the findings from an investigation examining the influence of sketching during conceptual design. Here we focus upon the role and use of sketching as a tool of design representation (Self, Evans, & Dalke, 2014) used in support of both problem framing and solution-focused strategies and reasoning. As such, this paper presents a fine-grained examination of a case-study of design sketching during conceptual design activity. Similarly to other seminal works in the area of design practice research (Ho, 2001; D. A. Schon & Wiggins, 1992), our detailed, case-study analysis provides rich insights into the participant's design activity to well explicate the role and use of design sketching, both as means to facilitate problem exploration and in the solution-focused proposition, testing and development of conceptual design intent.

To date there has been much research to provide a better understanding of how sketching has the potential to influence seeing (G GOLDSCHMIDT, 1994, 1997), reflection-in-action (D. Schon, 1983; D. A. Schon & Wiggins, 1992), and reinterpretation (McGown, Green, & Rodgers, 1998) during conceptual design. However, there remains disagreement regarding the level of support that design sketching provides (Bilda, Gero, & Purcell, 2006; Jonson, 2005), in terms of both the framing of ill-defined design problems (Rittel & Webber, 1973) and solution-focused strategies of ideation (Cross, 1990). According to Rittel and Webber (ibid) designers, and other professionals, are often required to engage difficult, complex or ill-defined problems. That is, problems of multiple layers of complexity and many variables. When engaging these wicked problems, the practitioner may have no clear way to proceed and the nature of the final outcome or solution will also often be unclear or unknown. In order to engage these problems the designer must often take a solution-focused approach (Cross, ibid) to the exploration, testing and development of solution ideas.

In contrast to recent examinations of design sketching (Bilda et al., 2006; Tang, Lee, & Gero, 2011) we adopt the Schönian lens of reflection-in-action, employing the constructionalist and experiential epistemology of designerly ways-of-knowing (Cross, 2007) first proposed by Schön (1983, 1987; 1992) and further developed by Dorst and Dijkhuis (1995) and Valkenburg and Dorst (1998) as a means to better understand design activity. This

constructed account of design practice is used as a framework to examine sketching's influence upon the framing of ill-defined design problems and the designer's adoption of solution-focused strategies and reasoning during a conceptual design case-study. A fine-grained, qualitative examination of a sketching protocol indicates the ways in which sketching as media for design representation provides the necessary context for problem framing and acts as a catalyst for appositional and divergent, solution-focused conceptual design and development. Moreover, our study indicates the ways in which sketching appears to facilitate frequent shifts of attention between problem frames and solution conjectures, facilitating fresh insights and creative leaps towards more suitable solution ideas, in-line with the findings by Cross (2007).

1.1. Sketching as Tool of Design Representation

From loose thumbnail sketches to crisp renderings, digital CAD models to high-fidelity working prototypes (Cross, 2007; G. a. S. GOLDSCHMIDT, M, 2006; Pei, Evans, & Campbell, 2011; Visser, 2009), design representations are used for a wide variety of purposes, as means to support reflective activity (D. A. Schon & Wiggins, 1992), and as a way to communication design intentions to others (Cross, 2008; Self, Lee, & Bang, 2013). Considering its various and critical role in support of designerly work, studying design representation provide researchers, practitioners and educators an opportunity to extend their understanding of the nature of design practice and designerly ways of knowing and thinking (Cross, 2007; G Goldschmidt & Porter, 2004). For example. Pei et al. (2008) developed an extensive taxonomic classification of design representations as a means to clarify their role and to enhance communication between designers and engineers during new product development. An extension to Pei et al. (ibid) taxonomy has been proposed by Kim et al. (2013), who indicate the classification's limitations in terms of conceptual design representations. Considering the various types of representation used in the practice of design, perhaps the most prolific, and most often associated with designerly activity, is the designer's sketch (Bar-Eli, 2013; Goel, 1995). Due to its historic position as a critical non-verbal media through which design progresses and is communicated, a substantive body of knowledge now exists to extend an understanding of this most prolific and, arguably, most critical conceptual design tool.

In a previous study, Cross (1999) investigated the nature of design problems through examining the act of sketching as the means by which problems are explored. In a seminal work, Goel (1995) investigates design representation through a comparison of digital and conventional sketching to suggest important cognitive insights that take place during the conceptual design activity. It is also important to recognize that the ambiguous nature of sketching, combined with the semantic density and ability to provide opportunities for transformations between and among ideas are presented as

distinctive characteristics during conceptual design. Using a notation system underpinned by Goel's (ibid) design transformations construct. Do et al. (2000) interpret the designer's thinking by investigating drawings to provide a greater understanding of the relationship between representation through drawing and its association with design practice. In further examples, McGown et al (1998) examine how computer-supported sketching tools can potentially improve design representation. However, Bilda et al (2006) employ the use of protocol analysis to suggest that there is no significant difference between the act of sketching and not sketching based on the design outcomes and the associated cognitive activities. In contrast, Bouchard et al's (2006) study indicates the importance of sketching as a tool for solution-focused, externalisation of thought through the use of design representation, reflection and the further iteration of design intent. Goldschmidt, in an influential series of design experiments (G GOLDSCHMIDT, 1994, 1997; Gabriela Goldschmidt & Weil, 1998) discusses sketching's importance as a means to facilitate visual thinking. They define the act of sketching as a 'clue' finding activity and the designer's germane of their own visual thinking 'on the fly' and 'in-situe'. Taking a step further, Menezes et al. (2006) explore the differences between novice and expert designers' perception of conceptual sketching activity to indicate the kinds of knowledge and thought engaged during the reinterpretation of sketches during the ideation process. More recent studies aim to extend knowledge related to conceptual design activity and its application, such as the development of computer-aided conceptual design tools (Aldoy & Evans, 2011; Contero, Naya, Company, Saorin, & Conesa, 2005; Dorta, Pérez, & Lesage, 2008; Plimmer & Apperley, 2002).

However, a review of the literature has found that there is a disagreement among scholars on the extent to which sketching as tool for design representation influences conceptualisation of design intent, both in the framing of ill-defined design problems and the solution-focused generation and progression of design ideas.

1.2. A Reflection–in–Action and Design Practice Research

The current study's examination of the role and use of sketching during conceptual design employs the discursive epistemology of ways-of-knowing in practice first proposed by Schön (1983, 1987), and Wiggen and Schön (1983, 1987; 1992) and extended as a means to investigate design practice by Dorst and Dijkhuis (1995) and Valkenburg and Dorst (1998).

A Schösian account of design practice provides an alternative to a more rational, scientific approach to understanding designerly activity (J. S. Gero & Mc Neill, 1998; Simon, 1996). Schön himself (op cit) discusses the rational problem solving paradigm's limitations in an inability to capture professional practice as it is experienced. Instead proposing the alternative of an epistemology of reflection-in-action, positioned as a means to explore

the kinds of experiential knowledge deployed in an artistry of professional practices. Reflection-in-action, then, may be best described as a constructed account of designerly activity (Dorst and Dijkhuis, 1995). Design is seen as a reflective conversation with the situation (Lawson, 2004; D. A. Schon & Wiggins, 1992) where unique problems in unique situations are framed and explored by the designer or design team (Nelson & Stolterman, 2012; Stolterman, 2008). Moves are made to test and reframe the design problem through a solution-focused, constructed reflection-upon-activity, often supported by sketching (Self et al., 2014). As a result of this reflective-practice, in response to often ill-defined design problems (Rittel & Webber, 1973), design work develops and is progressed.

Adopting a similar conceptual lens to existing design practice research (Bar-Eli, 2013; G. a. S. GOLDSCHMIDT, M, 2006; D. A. Schon & Wiggins, 1992; Valkenburg & Dorst, 1998) we employ reflection-in-action as the paradigm through which an analysis of design activity through sketching proceeds, and provide evidence to indicate sketching's influence when design practice research is based upon this constructionalist paradigm. The fact that our results may contradict those of others (Bilda et al., 2006; Jonson, 2005; Tang et al., 2011) provides further grounds for debate on the ways in which different approaches to the analysis of design practice may influence results.

2. Methods

This study employs the use of protocol analysis (Ericsson & Simon, 1993; Someren, Barnard, & Sandberg, 1994) as a means to examine the role and use of sketching during conceptual design (Cross, Christiaans, & Dorst, 1996; Dorst, 1995; Jiang, 2009). In this section, we outline the study's design, the protocol task, its set-up, the timing and methods of data collection and recording. Following this, we present the encoded process and an adapted, concept-driven coding frame as deployed by Valkenburg and Dorst (1997).

2.1. Participants

This paper reports upon the conceptual design activity of a participant from a population sample of 4th year undergraduate industrial design students at the researchers' institutions. The criteria for participant selection were as follows:

- Successfully completed design fundamental courses and sketching skills courses
- Enrolled as a full-time student in a 4 year ID degree program

Similarly to other seminal works examining design practice (D. Schon, 1983; D. A. Schon & Wiggins, 1992), and taking a depth first, fine-grained approach to the analysis of protocol data, here we present and discuss the

design activity of a single participant taken from the sample population.

In doing, we examine and assess the ways in which design representation through sketching may provide the necessary context for problem-framing and act as catalyst for appositional, solution-focused conceptual design and development.

Table 1 Participant's level of design expertise (Dreyfus & Dreyfus, 1980)

Level of Expertise	Knowledge	Coping with Complexity	Perception of Context
Novice Designer	Minimal, or 'textbook' knowledge without connecting it to practice	Little or no conception of dealing with complexity	Tends to see actions in isolation
Competent Designer*	Good working and background knowledge of area of practice	Copes with complex situations through deliberate analysis and planning	Sees actions at least partly in terms of longer–term goals
Expert Designer	Authoritative knowledge of discipline and deep tacit understanding across area of practice	Holistic grasp of complex situations, moves between intuitive and analytical approaches with ease	Sees overall 'picture' and alternative approaches; vision of what may be possible

The participant's design knowledge and skills may be described as competent according to the Dreyfus and Dreyfus (1980) model of skills acquisition (Table 1). The Dreyfus and Dreyfus model (ibid) derives stages of acquisition from the amount of experience an individual has had in practice. When applied to the criteria used in the selection of the participant, the model indicates the level of design competency. While not yet expert, the participant designer possesses a working knowledge of design practice, is able to cope with the complexities of design problems (Cross, 2007; Dorst, 1996; Rittel & Webber, 1973), and approaches design tasks with longer-term goals in mind (Dreyfus and Dreyfus op cit).

2.2. Task Environment

The participant's design activity and think-aloud responses to a given design problem were recorded through 3 video recorders as shown in Figure 1.

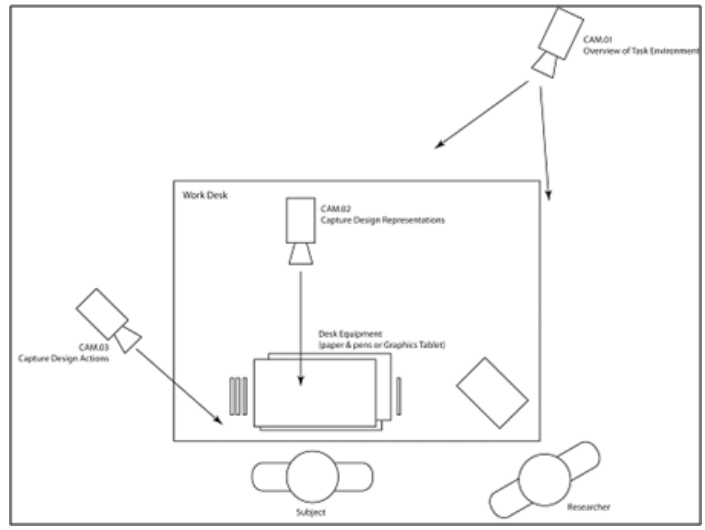


Figure 1 Study's task environment

The first camera (CAM.01) recorded an overview of the environment, the second camera (CAM.02), overlooked the participant, recorded the activity performed within the subject's working environment (sketching, drawing, writing, reading). A third camera (CAM.03) was positioned to record the participant's movements and body posture. The subject was provided with plain drawing paper, pens, pencils, coloured markers, shape templates and other analog tools commonly used as media during sketching activities.

2.3. Design Task

The participant was provided with the task of developing a concept for a sports watch (Appendix A). Due to limitations of time and the nature of the protocol analysis as research method, a moderate level of difficulty was sort in setting the design problem. As such, design specifications documents used in similar published protocol studies (Cross, Christiaans, & Dorst, 1994; Prats, Lim, Jowers, Garner, & Chase, 2009; Tang et al., 2011) were employed as benchmakes for the design brief's structure, composition and content. During the experiment, we identified the limitations of this approach, both in its inability to account for the rich context within which design practice is actually performed (Jonson, 2005), and facility to provide the designer with opportunities to develop understanding of the design problem through research and analysis such as leaving his "creative" environment to undertake user experience studies. As such, we acknowledge that such an experimental approach to understand the phenomena of design practice may in fact decontextualise what is in reality a highly collaborative and dynamically context-driven process as highlighted by Stolterman (2008). In defence of our methods, we suggest that conducting such an experimental methodology has its own merits such as providing a uniformly controlled environment for study, enabling a more focused understanding of the key aspects of the phenomena and also reducing unwanted noise that is often

associated with "in-the-wild" design research (Michel, 2007). Given our aims of a fine-grained examination of the role and use of sketching during conceptual design practice; its influence upon problem-framing and solution-focused design work, our study required the inclusion of equipment to gather controlled response data. In this regard, our approach mirrors the methodological approaches employed by Cross et al's Delft protocol workshops (1996) and Goel's (1995) analysis of sketching's association with cognition.

2.4. Design Task Procedure

The participant was given an introduction related to the aims and objectives of this research, their rights and obligations as a participant, the task procedure, methods of recording and time given to complete the task, after which the design problem was provided. An assistant researcher than withdrew from the environment, leaving the subject with 25 minutes to respond to the design problem. 20 minutes into the task, the participant was told 5 minutes remained. Immediately after the task, the subject's recorded sketching activity was played back on a screen as part of a retrospective think-aloud session. During this session, the participant was asked to tell the researcher what they were thinking as they engaged the design task (Someren et al., 1994).

The think-aloud method and protocol analysis are established technique for design practice research data collection (Chai & Xiao, 2012). However, the types of think-aloud experiments and variations in their format differ within the literature, from concurrent think-aloud to retrospective studies (Perry & Krippendorff, 2013) where the participants' design activity is played back to them after task completion. The length of time provided for a think aloud session can vary from a few hours to as little as fifteen minutes (Chai & Xiao, 2012; Jiang, 2009). As Perry and Krippendorff's (op cit) study suggests, concurrent think-aloud may have implications for the subject's ability to perform the design task as it has been found to be disruptive and may potentially affect the thinking process. As such, it was decided that the retrospective approach would be more suitable for this study.

2.5. Analysis: Reflection–in–Action

The transcribed protocol of the design task was encoded through a qualitative content analysis (QCA, (Miles, Huberman, & Johnny, 2013; Schreier, 2012)). The transcribed think-aloud session was segmented using a thematic criterion where two researchers, working as coders separately looked for phrases, sentences and discourse that appeared to hang together as a single idea, action or thought. The importance of having two coders working separately provided the opportunity to check the segmentation of the protocol. Following segmentation, differences in the length and division of segments were discussed and decision rules applied (Schreier, 2012). This

thereby limited the inherent subjectivity required in segmentation during QCA.

Following segmentation, coders assigned units of coding (segmented verbatim) to the dimensions of a coding frame adapted from Valkenburg and Dorst's (1998) encoding classification system (Figure 2).

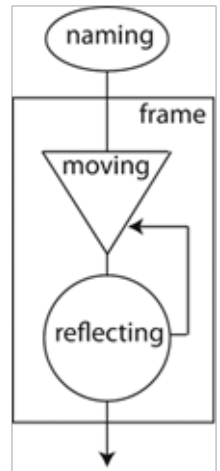


Figure 2 Five conceptual categories of coding frame (Valkenburg & Dorst, 1998)

The Valkenburg and Dorst's model (ibid, Figure 3) provides four theoretical constructs through which the segmented protocol was encoded. The four concepts (naming, framing, moving and reflecting) originate from Schon's (D. Schon, 1983; D. A. Schon & Wiggins, 1992) reflection-in-action epistemology of professional practice, with various studies having since extended their meaning (Bar-Eli, 2013; Dorst & Dijkhuis, 1995; J. Gero & Kannengiesser, 2008; Tang et al., 2011). A summative description of each concept is provided in Table 2.

Table 2 Four conceptual coding categories based upon reflection–in–action

Construct	Description
Naming (analyse)	When the designer is explicitly pointing to parts of the design task as being important, we code the activity as `naming'. 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)	When the designer frames a (sub)problem or (partial)solution to explore further on, then we code the context as a `frame'. The frame is a context for the next activities; something to hold on to and to focus on while designing. Therefore a frame is mostly only recognisable through the following activity. The essence was the `context for further activities'. Then a frame can best be visualised as a box in which other activities can occur. These named entities are put into context through framing, and an overall perspective on the design task is constructed.

Moving (simulate)	Experimental actions like generating ideas, making an inventory, sorting information, combining ideas, or comparing concepts are coded as 'moving'. During the '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 move is always characterized by a verb, identifying the activity, complemented with the content of the activity. The designer takes an experimental action based on the naming and framing of the design task.
Reflecting (evaluate)	An explicit reflection on earlier activities to know what to do next is coded as 'reflecting'. 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.

Subsequent to the encoding of the protocol, coding was compared for consistency and inter-coder reliability. To achieve this, the same two coders worked seperatly in the encoding of the segmented protocol. Encoding was then compared for inconsistancies in the application of the coding frame when encoding of protocol segments (Schreier, 2012). Where inconsistancies were found, decision rules were then applied and segments recoded.

Although there will always be an element of subjectivite interpretation required in any QCA (Miles et al., 2013), through a process of encoding, comparison and revision, consideration for the reliability of the coding frame (its ability to classify the segmented protocol transcriptions) and validity (its ability to describe the participant's design activity while sketching) was achieved.

3. Results

In this section, we present the results of a fine-grained, qualitative analysis of the subject's encoded design protocol supported with reference to an illustrative flow-diagram of design activity while sketching (Figure 3). In deploying this approach we provide a rich analysis to well explicate the role and influence of sketching for both the framing of the design problem and solution-focused strategies and reasoning towards the generation and development of design intent. For the purposes of the analyasis, the participant is refered to as subject A.

3.1. The Design Task

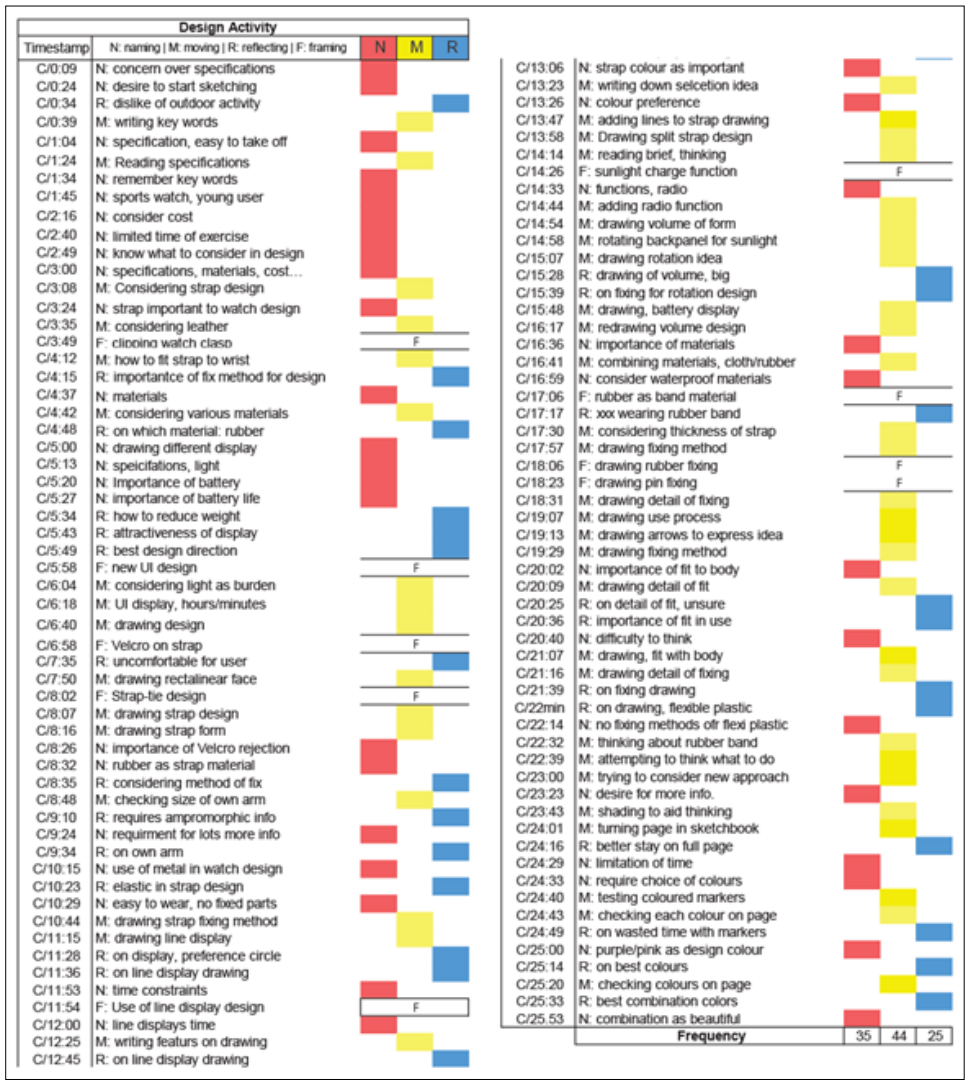
Figure 3 illustrates subject A's design activity from the beginning to the protocol's end. The encoding of protocol segments as naming, moving and reflecting (see Table 2) are represented as red, yellow and blue respectively.

Framing events are illustrated as rectangular boxes cutting across these three. In the left most column time stamps indicate the timing of each activity. To the right of this, notations provide an indication of what the subject was actually doing at each encoded segment. Absolute frequency counts (f) of encoded at naming (f=35) moving (f=44) and reflecting (f=25)

indicate the amount of time spent on each activity.

From the flow-illustration we see that subject A commences the design task with a series of naming events (C/1:24-3:00, Figure 3). That is, she names the things she feels she must pay attention to within her task environment, 'I have to consider all these things' ([C/0:09min] N: concern over specifications, Figure 3)

Figure 3 Diagrammatic flow–illustration of subject A's design activity



After an extended period of naming, subject A starts to sketch, whereupon her sketching moves appear to act as stimuli to further developing understanding of the strap design, *'It will be a strap, kind of a strap. What could be the best for this design, proper for this design?'* (C/3:08, M: considering strap design, Figure 3). At this point the idea of a clasp design emerges as a possible partial-solution frame to address the sub-problem

of strap design (C/3:49, F: clipping watch clasp). Subject A then engages in sustained sketching activity to test the frame's suitability in light of her own emerging understanding of the design problem. Figure 4 illustrates subject A's design work by the end of the protocol's 4th minute.

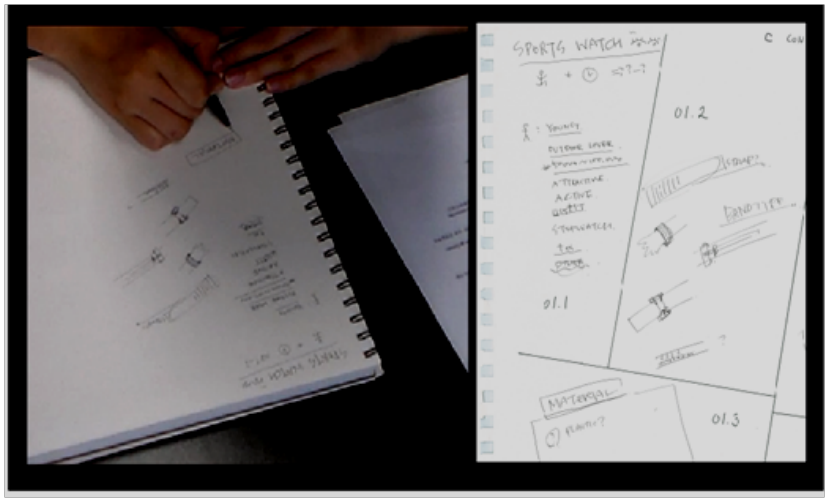


Figure 4 Working environment, 4th minute of protocol

Following a further period of exploration and reflection (C.4:12, M: how to fit strap to wrist , C/4:15, R: importance of fix method for design, Figure 3), Subject A abruptly writes in capital letters, *'Materials'* before enclosing the word within a dark boarder to signify its importance as something requiring her attention. She then proceeds to write, *'rubber'* underneath, and reflects upon its suitability in light of her developing understanding of the design problem, *'I think maybe rubber can be the best material for this design'* (C/4:48 R: on which material: rubber). Following this, subject A's attention shifts as she draws a large rectangle at the top of her page and writes within it the digits, *'9:00'*, *'Err, this was kind of the display, digital or analog method'* (C/5:00 M: drawing different display). Following this, subject A continues to name design requirements, before proceeding to explore options for the design of the display ([C/5:27 N: importance of battery life; C/5:34 R: how to reduce weight; C/5.43 R: attractiveness of display).

At this point it appears that subject A's attention towards important considerations within a future design proposition provide the necessary conditions for the frame of a new user interface to emerge, *'So I started to think about a new UI maybe'* (C/5:58 F: new UI design, Figure 3). After the identification of this new frame of reference, subject A appears to immediately explore its suitability as a possible solution candidate through a period of sketching moves, *'Err, that is my design, a new UI so that the display above will display the numbers for checking the hours. And for the bottom part for checking the minutes'* (C/6:18 M:UI display, hours/minutes). By the 5th minute of the design task, subject A has generated a sheet of

sketch work, notes and schematic drawings (Figure 5).

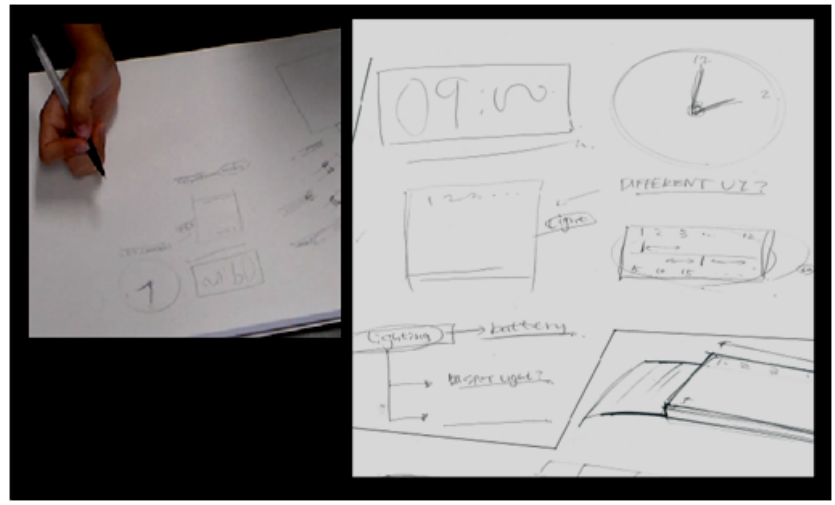


Figure 5 Working environment, 5th minute of conventional sketching

At this point subject A continues her moves to explore solution ideas through a 3D sketch, notably including an indication of where the watch display interfaces with strap design. From exploring the new UI frame's suitability to address the design sub-problem of display (C5/5:58 F: new UI design, Figure 3), subject A shifts her attention to the watch's strap, as indicated by a new, emergent frame of reference, *'Velcro I see. A sticking method. Yeah. Yeah a fixing method for Velcro.'* (C/6:58, F: Velcro on strap). It appears moves made in the testing of the UI display frame have included an incidental representation of the watch's strap (Figure 6), prompting the reemergence of a focus upon strap design. This incidental sketch representation appears to have provided the stimuli through which subject A reengages the strap sub-solution, through which the Velcro insight emerges as a new frame worthy of exploration.

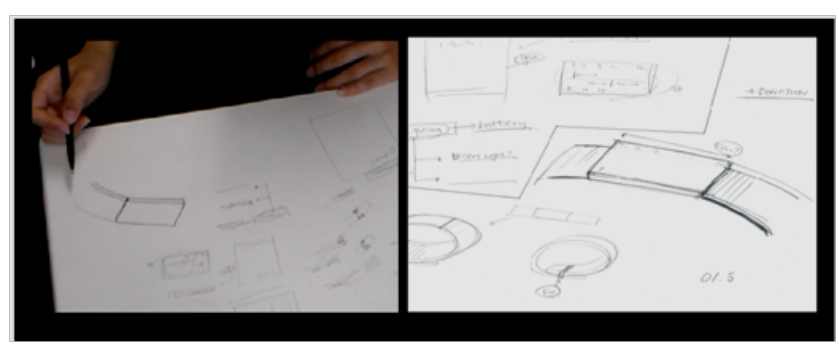


Figure 6 Incidental sketch, watch strap, 7th minute

At this point a further frame emerges, *'because...just I thought a strap-tie would be good"* (C/8:02 F: Strap-tie design). It appears that by the time

subject A's sketching move is complete her preference for Velcro has been replaced. As before, the strap-tie design appears to have emerged from the testing of the previous frame through sketch representation, which, itself, has been retrieved through an exploration of the UI display frame. That is, upon exploring the suitability of her frame through design orientated representation as sketching, her focus of attention has shifted back to a previous frame of reference. This has then provided a means to further develop the previous frame through reflection upon the current one, supported by subject A's sketchwork. The act of sketching has provided the context through which previous frames may reemerge, be reevaluated combined and revised. Thus subject A's sketch activity acts as a stimuli through which both the framing of the design problem, and its exploration, through solution propositions embodied as design-orientated sketch representations, has proceeded.

By the end of the protocol's 10th minute, subject A continues to test and explore the detail of her solution frames, *'Yeah, the fixing method. Maybe mainly I'm thinking and considering the...fixing part as a very important issue...'* (C/10:44 M: drawing strap fixing method, Figure 3). Having completing her sketch of the watch-strap fixing, subject A returns to her previous frame of a new UI display. After some hesitation, she frames the display element of her design, *'so I just decided to use that display.'* (C/11:54 F: Use of line display design), and proceeds to name the importance of clarity in the display of time (C/12:00 N: line displays time), before moving to explore the frame through sketching. However, after reflection upon the sketch representation of her intentions towards the new UI display, subject A abruptly names strap colour as an important consideration, *'When people are purchasing the watch, they can select their own watch. So they can select this colour, this colour, this plain colour and strap colour'* (C/13:06 N: strap colour as important). Her reflections upon time and the telling of time indicate uncertainty towards the suitability of her UI display concept solution, *'Most people consider, say about time, they just say about up or down, the numbers of the time. So, just five o'clock or five fifteen. They rather love to speak about time like that'* (C/12:45 R: on line display drawing). It appears her work in the testing and development of her initial line-display frame has resulted in some uncertainty in the evaluation of the solution's suitability. And that her sketching work appears to be critical in her solution-focused conceptual development and evaluation.

After reflecting upon her sketch activity, subject A's attention shifts to representing a battery detail, *'...oh...battery, yeah...The same things, displaying it...and'* (C/15:48 M: drawing, battery display), before exploring the size and form of the design through a second sketch, *'Um, I just wanted to find the better line that I wanted to draw'* (C:16:17 M: redrawing volume

design). At this point subject A's think-aloud statements point towards concerns over the practicality of her emerging solution concept, concerns she attempts to resolve through further moves to explore ideas supported by her sketching work. Thus she returns to the naming of materials as an important consideration, exploring ideas towards material combinations (C/16:41 M: combining materials, cloth/rubber). It is at this point that subject A's 5th framing event is recorded as a decision to use rubber for the watch's band material, *'So, I think I finally decided the material as rubber.'* (C/17:03] F: rubber as band material). subject A again enters a period of moving activity immediately preceding this frame, sketching a strap concept and fixing mechanism, *'And, again, I wanted to find a more fancy fixing method…So, just continue to think…'* (C.17:57 M: drawing fixing method, Figure 3).

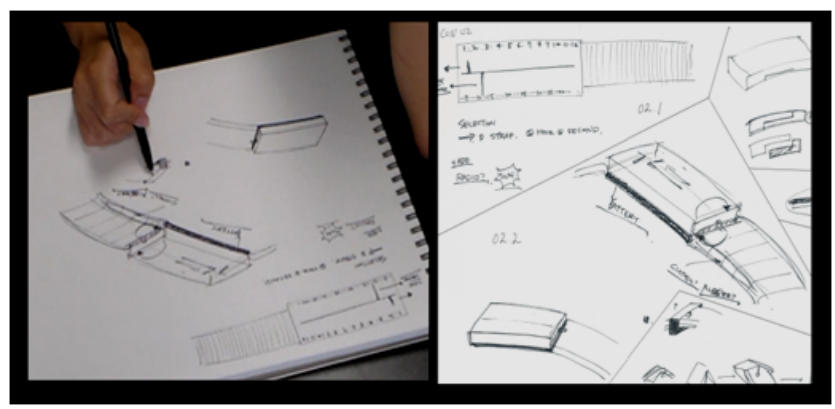


Figure 7 Exploring fixing mechanism, 17th minute of conventional sketching protocol

It is during these sketching moves that two final problem frames emerge, *'How about using some, like, pin-shape with rubber, not metal.'* (C/18:23 F: pin fixing). As seen earlier in the protocol, this latest framing event emerges as a direct result of subject A's exploration through sketch representation. That is, the representation of design intent through sketching acts as a stimuli for an emerging understanding of the design problem through framing, as well as providing the necessary conditions for her solution-focused conceptual development work.

While continuing to explore her current understanding of the fixing method through further sketch activity, subject A's attention shifts to ergonomic considerations as she writes the word *'FIT'* next to her sketch, *'Yeah, I think the most important thing is the fit to the body – it fits very well.'* (C/20:02 N: importance of fit to body). It appears subject A's thoughts have shifted again from an exploration of strap-fixing to the notion of fit, previously encountered earlier on in the protocol. Her exploration of a currently focused aspect of her conceptual design work appears to provide opportunities to emerge related to previously explored frames. These moves, aimed at exploring solution conjectures under current consideration, act as a kind

of catalyst for reengagement with previous frames in new ways. This thus results in shifts of attention between aspects of her design work. As such, the frame of current focus is explored in terms of the notion of fit through a sideelevation of her watch concept (Figure 8).

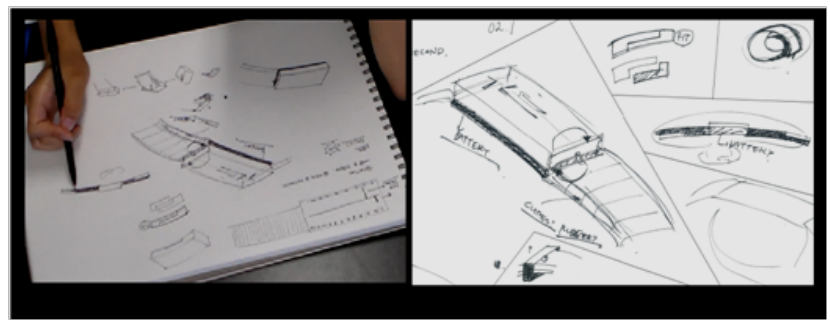


Figure 8 Exploration of current frame through sketching, 20th minute of conventional sketching

At the end of the 20th minute of the design task, subject A names a difficulty to know what to do next, (C/20:40 N: difficulty to think) and indicates a focus towards her drawing work, *'so I draw it below this thing. And I keep drawing it. It will be better for it.'* (C/21:07 M: drawing, fit with body).

After further sketching moves to explore the suitability of a flexible plastic material, she rejects the idea to reaffirm fixing method as the frame through which her design work must now proceed, *'Yeah. It would be better I think, but it doesn't have the fixing method.'* (C/22:00] N: no fixing methods of flexi plastic). As indicated in the think-aloud protocol, subject A's current focus upon her sketchwork is less about improving the quality of her sketches, and more a means to consider her next design move, *'wanting to refresh myself and wanting to think about a new method...'* (C.23:00 M: trying to consider new approach). This is unsuccessful, however, and appears to instead trigger frustration as she names a desire for more information (C/23.23 N: desire for more info.). subject A then continues to shade as an aid for her thinking, *'So just keep shadowing and thinking and err more ideas I need yeah.'* (C/23:43 M: shading to aid thinking). It is interesting to note the ways in which this apparently, somewhat undirected drawing activity is used as a means to facilitate thinking towards design intent. However, it appears to fail as stimuli, evidenced by subject A's distraction as she considers starting a new page, *'No, nothing, just thinking, will it be okay to go over there?'* (C/24:01 M: turning page in sketchbook).

In the final stages of the protocol, subject A is told that 3 minutes of time remain. This appears to change her focus from activity related to the development and testing of design intent to the clearer communication of her existing ideas, *'So, I'm thinking that I have to choose the colour combination.'* (C/24.33 N: require choice of colours). At this point subject A opens a pack of markers and proceeds to create colour swatches for each (Figure 9),

subsequently announcing her choice of colour (C.25:00 N: purple/pink as design colour). These final actions mark the end of the design protocol.

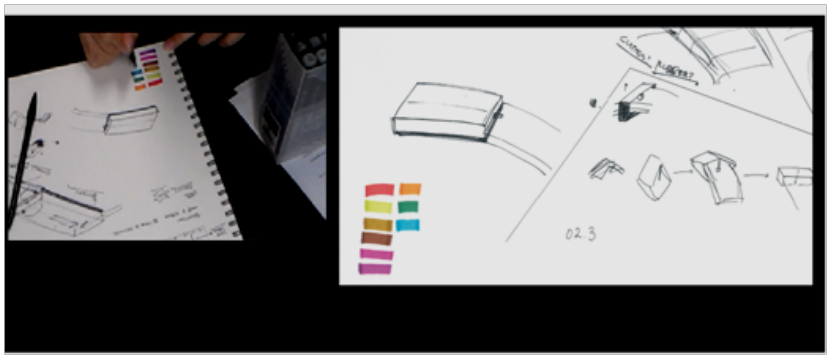


Figure 9 Choosing colour variations, 24th minute of protocol

4. Discussion

4.1. Problem Framing

An analysis of results indicates the ability of the sketching activity itself to provide the necessary conditions for framing and re-framing of the existing design problem. The study also indicated the way in which incidental representation (such as the strap design in Figure 6) made during sketching activity has the potential to prompt the reemergence of previous frames of reference. These Incidental representations appeared to provide the stimuli through which re-engagement with a sub-solution was achieved. That is, according to our qualitative analysis, it appears the activity of sketching provided the context through which previous problem frames re-emerged, were re-evaluated, combined and revised. It appeared that the designer's sketching acts as a critical stimuli through which the framing and re-framing of the design problem is achieved. The act of sketching thus provides stimulus for the re-emergence of new problem frames. This then appears to provide the necessary condition for the propagation and progression of solution ideas, based upon a clearer framing of the design problem.

4.2. Solution–focused Strategies and Reasoning

An analysis of the participant's design orientated sketching work indicates the ways in which sketching acts as stimuli for solution-focused strategies aimed at the proposition and development of conceptual design ideas.

Following framing events related to developing an understanding of the design problem, the subject's design-focused sketching work appeared to provide the necessary catalyst for the development and testing of the frame's suitability to address an emerging understanding of the design problem.

That is, the participant's sketching activity provided a means through which new problem frames were tested and refined through propositional solution candidates as sketches.

Moreover, results indicate it is through the use of design representation as sketches that design moves were self-interpreted in various ways to both explore a current focus of attention and provide emergent insights often related to previous frames of reference and previously proposed solution ideas. These insights were observed to be further tested and explored through further framing of different aspects of the design problem. That is, the expression and testing of a currently focused aspect of conceptual design work through sketching provided opportunities to emerge which relate to previously explored frames. Sketching moves that were aimed at exploring solution conjectures under current consideration, thus acted as a kind of catalyst for reengagement with previous frames through new solution-focused insights emergent from the participant's sketching activity.

These were then progressed through further moves and reflections. This thus resulted in repeated shifts of attention between aspects of design work. Results indicate that these shifts, also identified by others (Cross 1990, Cross 2007, Lawson and Dorst 2009) as an indicator of expertise in design practice, are critically facilitated and enhanced through sketching activity.

5. Conclusions

This study adopted a qualitative approach to the exploration of the role and use of sketching as a tool of design representation during conceptual ideation. Design activity was empirically investigated through a think-aloud protocol analysis of sketching during conceptual design. In contrast to other studies of design sketching (J. S. Gero & Mc Neill, 1998; Tang et al., 2011), the current investigation employed the use of reflection-in-action (Dorst & Dijkhuis, 1995; D. A. Schon & Wiggins, 1992) as the bases of a concept-driven coding frame. A qualitative content analysis indicated how sketching activity both provided the necessary context for the framing of the design problem and acted as a catalyst to support solution-focused testing and development of problem frames. Moreover, sketching activity during conceptual design also appeared to provide opportunities for previous frames of reference to re-emerge and be re-engaged in new ways. The act of sketching appeared to facilitate frequent shifts of attention to and from sub-problems and sub-solutions. This thus provided opportunities to laterally explore different aspects of emergent solution ideas in a concurrent manner. This frequent shifting of attention also appeared to act as a catalyst for appositional reasoning (Cross 1990, 2007). The subject's solution-focused thoughts appeared to both influence and be influenced by sketching activity, affording

fresh insights and perspectives to emerge. This both reaffirms an ability to move between problem and solution as an important designerly ability and indicates sketching's critical role in providing a context and catalyst for this to happen.

Our results have started to indicate the ways in which sketching may facilitate solution-focused, appositional reasoning providing a necessary catalyst for creative leaps of insight (Cross, 2007) towards more appropriate or desirable solution ideas. Building upon the findings of this study, future work is required to examine, for example, the ways in which sketching is used to address design problems of different levels of complexity, by designers of varying degrees of experience and expertise. As indicated here, examining the role and use of sketching provides opportunities to understand the cognitive strategies employed by designers during conceptual design practice, thus developing and extending an understanding of designerly ways of knowing, thinking and doing.

REFERENCES

1 Aldoy, N., & Evans, M. (2011). A Review of Digital Industrial and Product Design Methods in UK Higher Education. *The Design Journal, 14*(3), 343–368.

2 Bar-Eli, S. (2013). Sketching profiles: Awareness to individual differences in sketching as a means of enhancing design solution development. *Design Studies, 34*(4), 472–493.

3 Bilda, Z., Gero, J. & Purcell, T. (2006). To sketch or not to sketch? That is the question. *Design Studies, 27*(5), 587–613.

4 Bouchard, C., Aoussat, A., & Duchamp, R. (2006). Role of sketching in conceptual design of car styling. *Journal of Design Research, 5*(1), 116–148.

5 Chai, K., H., & Xiao, X. (2012). Understanding design research: A bibliometric analysis of Design Studies (1996–2010). *Design Studies, 33*(1), 24–43.

6 Contero, M., et 4. (2005). Improving Visualisation Skills in Engineering Education. *Computer Graphics in Education, September/October,* 24–31.

7 Cross, N. (1999). Design Research: A Disciplined Conversation. *Design Issues, 15*(2), 5–10.

8 Cross, N. (2007). *Designerly Ways of Knowing.* Basel: Birkhauser.

9 Cross, N. (2008). *Engineering Design Methods: Strategies for product design* (4 ed.). Chichester: Wiley.

10 Cross, N., Christiaans, Henri., & Dorst, Kees. (1996). *Analysing Design Activity.* Chichester: Wiley.

11 Cross, N. (1990). The nature and nurture of design ability. *Design Studies, 11*(3), 127–140.

12 Cross, N., Christiaans, H., & Dorst, K. (1994). Design Expertise Amongst Student Designers. *Journal of Art & Design Education, 13*(1), 39–56.

13 Do, Y., et 3. (2000). Intentions in and relations among design drawings. *Design Studies, 21*(5), 483–503.

14 Dorst, K. (1995). Analysing design activity: new directions in protocol analysis. *Design Studies, 16*(2), 139–142.

15 Dorst, K. (1996). The Design Problem and its Structure. In N. CROSS, CHRISTIAANS, H. and DORST, K (Ed.), *Analysing Design Activity.* Chichester: Wiley.

16 Dorst, C. H. (1997). *Describing Design: A comparison of paradigms.* (Doctoral dissertation), TU Delft.
17 Dorst, K., & Dijkhuis, J. (1995). Comparing paradigms for describing design activity. *Design Studies, 16*(2), 261–274.
18 Dorta, T., Pérez, E., & Lesage, A. (2008). The ideation gap:: hybrid tools, design flow and practice. *Design Studies, 29*(2), 121–141.
19 Dreyfus, S., & Dreyfus, H. (1980). A five-stage Model of the Mental Activities Involved in Directed Skill Acquisition: University of California, Berkeley.
20 Ericsson, A., & Simon, H. (1993). *Protocol Analysis.* London: The MIT Press.
21 Gero, J., & Kannengiesser, U. (2008). An ontological account of Donald Schön's reflection in designing. *International Journal of Design Sciences and Technology, 15*(2), 77–90.
22 Gero, J., & Mc Neill, T. (1998). An approach to the analysis of design protocols. *Design Studies, 19*(1), 21–61.
23 Goel, V. (1995). *Sketches of Thought.* London: MIT Press.
24 Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture *Design studies, 15*(2), 158–174.
25 Goldschmidt, G. (1997). Capturing indeterminism: representation in the design problem space. *Design Studies, 18*(4), 441–455.
26 Goldschmidt, G., & Porter, W. (2004). *Design Representation.* London: Springer.
27 Goldschmidt, G., & Smolkov, M. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies, 27*(5), 549–569.
28 Goldschmidt, G., & Weil, M. (1998). Contents and structure in design reasoning. *Design Issues, 14*(3), 85.
29 Ho, C., H. (2001). Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts. *Design Studies, 22*(1), 27–45.
30 IDSA. (2013). *What is Industrial Design?.* Retrieved from IDSA website: http://www.idsa.org/what-is-industrial-design.
31 Jiang, H., & Yen, C. (2009). *Protocol analysis in design research: a review.* Paper presented at the Relevence and rigour: IASDR09, Seoul, Korea.
32 Jonson, B. (2005). Design ideation: the conceptual sketch in the digital age. *Design Studies, 26*(6), 613–624.
33 Kim, S., Jung, S., & Self, J. (2013). *Investigating Design Representation: Implications for an Understanding of Design Practice.* Paper presented at the IASDR13 Consilience and Innovation in Design, Tokyo.
34 Lawson, B. (2004). *What Designers Know.* Oxford: Architectural Press.
35 Lawson, B. (2006). *How designers think: the design. process demystified* (4 ed.). Oxford: Oxford University Press.
36 McGown, A., Green, G., & Rodgers, P., A. (1998). Visible ideas: information patterns of conceptual sketch activity. *Design Studies, 19*(4), 431–453.
37 Menezes, A., & Lawson, B. (2006). How designers perceive sketches. *Design Studies, 27*(5), 571–585.
38 Michel, R (Ed). (2007). *Design Research Now* (Michel, R ed.). Berlin: Birkhäuser Verlag AG.
39 Miles, M., B., Huberman, M., A., & Saldana, J. (2013). *Qualitative Data Analysis: A Methods Sourcebook* (Third Edition ed.). London: SAGE Publications.
40 Nelson, G., & Stolterman, E. (2012). *The Design Way: Intentional change in an unpredictable world.* London: MIT Press.
41 Pei, E., Campbell, R., & Evans, M. (2008). *Building a Common Ground: The Use of Design Representation Cards for Enhancing Collaboration between Industrial*

Designers and Engineering Designers. Paper presented at the DRS2008 Undisciplined, Sheffield, UK.

42 Pei, E., Evans, M., & Campbell, R. (2011). A Taxonomic Classification of Visual Design Representations Used by Industrial Designers and Engineering Designers. *The Design Journal, 14*(1), 64–91.

43 Perry, G., T., & Krippendorff, K. (2013). On the reliability of identifying design moves in protocol analysis. *Design Studies 34*(5), 612–635.

44 Plimmer, B., & Apperley, M. (2002). Computer-aided sketching to capture preliminary design. *Proceedings of the Third Australasian Conference on User Interfaces, 7,* 9–12.

45 Prats, M., et. 4 (2009). Transforming shape in design: observations from studies of sketching. *Design Studies, 30*(5), 503–520.

46 Rittel, H., & Webber, M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences, 4,* 155–169.

47 Schon, D. (1983). *The Reflective Practitioner.* London: Ashgate.

48 Schon, D. (1987). *Educating the Reflective Practitioner.* New York: Jossey-Bass.

49 Schon, Donald A., & Wiggins, Glenn. (1992). Kinds of seeing and their functions in designing. *Design Studies, 13*(2), 135–156.

50 Schreier, M. (2012). *Qualitative Content Analysis in Practice.* London: SAGE Publications.

51 Self, J., Evans, M., & Dalke, H. (2014). The Influence of Expertise upon the Designer's Approach to Studio Practice and Tool Use. *The Design Journal, 17*(2), 169–193.

52 Self, J., Lee, S., & Bang, H. (2013). *Understanding the Complexities of Design Representation.* Paper presented at the 2013 Ancient Futures: Design and/or Happiness, Seoul, Korea.

53 Simon, H. (1996). *The Science of the Artificial* (3rd ed.). London: MIT Press.

54 Someren, M., Barnard, Y., & Sandberg, J. (1994). *The Think Aloud Method.* London: Academic Press.

55 Stolterman, E. (2008). The Nature of Design Practice and Implications for Interaction Design Research. *International Journal of Design, 2*(1), 55–65.

56 Tang, H. H., Lee, Y. Y., & Gero, J. S. (2011). 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, 32*(1), 1–29.

57 Valkenburg, R., & Dorst, K. (1998). The reflective practice of design teams. *Design Studies, 19*(3), 249–271.

58 Visser, W. (2006). *The Cognitive Artifacts of Designing. new* York: Routledge.

59 Visser, W. (2009). Design: one, but in different forms. *Design Studies, 30*(3), 187–223.

Appendix A (Design Problem and Task)

Sports Watch

Design a sports watch that can be worn while playing sports and is suitable for use while exercising.

Target User

- Young people or students between 18 and 30 years old
- A male or female user
- Should be priced affordably for the target market (50 to 100US).

Form and Style

- The form and style of the sports watch should be attractive to the target user: male or female students who enjoy sports and exercise.
- The form and style should create a feeling of sportiness, health and/or an active life.

Function & Use

- Must be lightweight
- Should be hardwearing and resistant to knocks and scratches.
- Should be quick and easy to put on and take off.
- Must display the time clearly even in low light conditions