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DRAFT OF VISUALIZATION AND SKETCHING IN DESIGN PROCESS

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VISUALIZATION AND SKETCHING IN THE DESIGN PROCESS

ABSTRACT

The study analyzes expertise in weaving design by examining how professionally experienced designers (n=4) and advanced students (n=4) of weaving design solved a professional weaving-design task. The data consisted of (1) verbal protocols, (2) video protocols, and (3) written and drawn material produced by the participants. We analyzed the data through qualitative content analysis and problem-behaviour graphs (PBGs). The results of the analysis indicated that the advanced students produced a number of thinking sketches by moving very quickly from one design idea to another without articulating their design ideas in depth. Although strategies of visualization varied within the expert group, most experts according to the evidence, considered only a few design ideas and focused on developing and articulating their design ideas in depth.

1 INTRODUCTION

Any design task requires a very complicated process of searching for a workable (i.e., aesthetic as well as functional) solution that can be reached in a practical and effective way. Designing involves various elements that must be considered and related to each other, within the constraints in order to create a functional and aesthetic solution (Goel & Pirolli, 1992; Goel, 1995). According to Goel and Pirolli's (1992) analysis, the design process consists of two basic types of activity: problem structuring and problem solving. They argued that the ill-structured nature of the design-task environment influences the extensive use of problem structuring during design. Problem structuring is the phase in which a problem solver constructs and reconstructs the problem-space. The analyses of the ill-structured design tasks suggest that design is an iterative process. De-
sign solutions emerge gradually as a process of structuring and restructuring, composing and decomposing the problem.

In general, the design-task environment in the professional context of textile design is typically specified in a customer's brief. The brief, however, does not completely specify all the requirements for the desired textile. The aspects presented in the design tasks can be divided into the design constraints and design elements. The design constraints have more abstract relations to the artefact to be designed, rather than any clear visual or technical aspects to be modified. The design constraints specify the context or the framework of the textile by answering questions: what kind of textile, to whom, where and for what purpose the textile is going to be designed. In other words, user, place, function (i.e., purpose) of the textile and resources available (time, money, equipment or legislation) define the context of the entire artefact to be designed and thus they constrain the design context (Chan, 1990; Goel & Pirolli, 1992; Lawson, 1991).

Sketching is an integral part of the design activity, and drawing is the most important “thinking tool” for the designer (Eisentraunt & Günther, 1997; Ferguson, 1992; Goel, 1995; Suwa & Tversky, 1997). The visual representation of a product and the role of visualization have recently become a central issue in design research, because much of design is concerned with concrete qualities of the design elements to be designed, and effective ways to achieve plausible solutions. A designer examines their designs in several overlapping ways i.e., including different types of the sketches, notes, and models of various sorts (Goel, 1995). Using several visual representations (i.e., thinking sketches, prescriptive and final sketches) a designer generates alternative solutions and tests them before bringing the designed product to production (Goel, 1995). Different kinds
Visualization and sketching play important roles in the design process (Fergusson, 1992; Goel, 1995). Yet, the way a designer modifies and adapts visual representation through sketching and re-sketching is still one of the least understood phenomena in design research.

Weaving design is seen as a complex problem-solving process requiring domain-specific knowledge of principles of weaving as well as more domain-general knowledge of visual design. The pivotal aspect of the design process is the gathering and utilisation of domain-specific knowledge, in conjunction with the visual and technical characteristics of the desired textile. Thus the main problem of weaving design is the concretizing and realizing of visual ideas. Given this as a starting point, the knowledge of traditional weaves, models and techniques of weaving, the study of materials and their interrelationships and the organisation of visual elements then become crucial in bringing the textile into the realm of the tangible (Seitamaa-Hakkarainen, 1997).

2 METHOD

2.1 PARTICIPANTS AND EXPERIMENTAL TASK

The present study analyzes how professionally experienced designers and advanced students solved professional weaving design-tasks and how they work with different kinds of visual representations during designing. Eight participants, four professional weaving designers, and four advanced students of weaving design participated in the study. All participants had similar educational background; they had already completed an extensive education in weaving design and acquired some professional experience. However, the experts had extensive professional expertise, being highly regarded weaving designers.
The participants were asked to solve an authentic weaving-design task selected to represent general and stable features of the professional, design tasks. In particular, it was essential (1) that the design task could be solved in a relatively short time; (2) that it could be approached from different perspectives (3) that it resembled kinds of tasks with which the participants were familiar; and (4) that it was representative of a professional weaving-design assignment. The task was to design a wall-hanging textile for a planned day-care centre called ‘Little Prince’. The participants were given a design brief containing some background information and an architectural plan including some information about the intended location of the textile to be designed. They took part in two design sessions. The participants were allowed to use one-and-a-half hours for designing the textile in the first session and one hour in the second session. In the second design session, the participants were asked to continue their previous design at a more detailed level and produce working instructions for the weaver.

2.2 METHOD AND DATA ANALYSIS

The investigation employed a thinking-aloud method, i.e., protocol analysis. Accordingly, the participants were asked to think aloud from the beginning of the problem solving to the end of it. The experiment was arranged individually for each of the participants following a similar procedure. The data were from (1) verbal protocols, (2) video protocols, and (3) written and drawn material produced by the participants during design sessions. Following data collection, the recorded protocols were transcribed according to the audiotapes. Further, in order to increase the reliability and validity of analysis, the verbal protocols were cross-referenced with the observed activities seen in the video recording (divided into two-minute segments) as well as with notes and sketches produced
during the design sessions. We applied qualitative analysis of the contents to the protocols and used the data to construct problem-behaviour graphs (PBGs). For the qualitative analysis, the verbal protocols were segmented according to a single thought or main idea, i.e., the meaning of the content (regarding segmentation of data for content analysis, see Chi, 1997).

The advancement of the design process was analyzed by distinguishing three basic phases of the design process; problem structuring, problem solving and decision. Each protocol statement was considered to represent just one of these categories. Problem-structuring statements generated the information that further refined the problem, identified constraints and constraints concerning particular design elements, and clarified the general organisation of the problem or generation of the goals or subgoals. Problem solving refers to processing of particular design elements and their combination; it refers to an active process of finding a solution for the design. Problem-solving statements were further classified according to the following categories: (a) statements representing preliminary design refer to an initial specification of design ideas, design elements or other solutions; (b) statements representing refinement design elaborate or modify already developed design ideas, elements or other solutions, and (c) statements representing detail design focus on determining design ideas or design elements. The final phase of the design development was categorized as decision. Decision statements refer to a solution made about particular design sketches or group of design elements, not single, design element (compare Akin & Lin, 1995).

Design activity statements indicated participants’ mode of designing; mode of bookkeeping and type of sketching. The mode of designing refers to the nature design
activity, seen on the videotape, associated with each protocol statement. The mode of design consisted of four categories: verbal, verbal and written, verbal and drawn, and silence. **Verbal designing** refers to plain verbalized statements without any other activities. **Verbal and written designing** refers to a process in which a participant was writing something down and simultaneously thinking aloud. A participant engaged in producing sketches or other visual representations was considered to represent **verbal and drawn designing**. **Silence** refers to the pauses in the thinking aloud protocols. Writing is focused on producing symbolic and conceptual representations; drawing produces visual representations.

The **mode of bookkeeping** variable indexed whether the designer recorded and updated the design by producing either **visual sketches** or **written ideas** (i.e., notes). The participants’ strategies of visualization were analyzed by distinguishing different types of sketches produced by the participant. **Type of sketching** refers to following categories of external representation produced by a designer during the process:

(a) **thinking sketch** representing an initial unarticulated design idea that is based only on a few design elements;

(b) **prescriptive sketch** representing a further articulated and detailed design including consideration of several design elements and, frequently, an initial scaling;

(c) **alternative** representing a detailed and fully articulated design that could, in principle, be produced.

**Type of sketching** appears to represent explicitness and completeness of design ideas produced by designer (Goel, 1995; Eisentraut & Günther, 1997). In principle, the processes of working from thinking sketches to prescriptive sketches, and, finally, to an
alternative help produce a sufficiently determined design so that the detailed scale drawings and work instructions could be produced.

The development of each participant’s sketches was further analyzed by examining how sketches produced by a participant changed or progressed in the course of designing. From the material, we abstracted two contrasting strategies of sketch development. The first strategy, labelled horizontal sketch development, is to move from one design idea to another a more-or-less different idea. In other words, horizontal sketch development indicates that the participant goes over several design ideas without articulating anyone in depth. The second strategy, labelled vertical sketch development, is to move from a design idea to a more articulated and detailed version of the same idea. Horizontal sketch development means that the sketches produced are not, we will say, syntactically or semantically connected to each other, and the degree of details or complexity of the sketch do not increase (see Goel, 1995). Vertical sketch development means that the produced drawings are syntactically and semantically closely connected to each other; sketches being developed become more and more detailed and complex, consisting of an increasing number of design elements. In order to analyze the role of sketching in the design process, the present investigators examined the relative importance of the two strategies in each participant’s designing.

To analyze the reliability of the classification, two independent coders classified a sample of the participants’ transcribed protocol statements \((f=268)\) together with corresponding videotapes. The agreement coefficient between ratings given by two independent raters was as high as .92 in the case of main content, .85 constraints, .94 composition and, .96 in the case of the construction design elements. In order to test the reli-
ability of the sketch development, two independent coders arranged all participants’ sketches according to horizontal and vertical sketch development. The reliability of classifying the sketch development was .85.

3 RESULTS

3.1 NATURE OF THE DESIGN PROCESS

The nature of the experts’ and the advanced students’ design protocols was studied qualitatively, using qualitative content analysis. Data from the protocols were examined by analyzing frequencies of the participants’ design statements. The total number of protocol statements produced by the participants was 3185, which consists in almost two thousand (\(\bar{f} = 1986\)) statements produced in the first session, and more than one thousand (\(\bar{f} = 1199\)) in the second session. The mean number of words in a statement was ten (\(M = 10.3, SD = 7.4\)) in the first session and nine (\(M = 9.0, SD = 6.5\)) in the second session. Table 1 illustrates the participants’ individual weaving design projects in the first and second design sessions, the number of protocol statements, the time they used, the episodes and the type of the textile being designed.

<table>
<thead>
<tr>
<th>Participants</th>
<th>First Design Session</th>
<th>Second Design Session</th>
<th>Type of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (min)</td>
<td>Statements*</td>
<td>Design Episodes</td>
</tr>
<tr>
<td>Students</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 1</td>
<td>68</td>
<td>234</td>
<td>12</td>
</tr>
<tr>
<td>Participant 2</td>
<td>64</td>
<td>260</td>
<td>18</td>
</tr>
<tr>
<td>Participant 3</td>
<td>63</td>
<td>228</td>
<td>13</td>
</tr>
<tr>
<td>Participant 4</td>
<td>66</td>
<td>275</td>
<td>7</td>
</tr>
<tr>
<td>Experts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 5</td>
<td>62</td>
<td>236</td>
<td>13</td>
</tr>
<tr>
<td>Participant 6</td>
<td>53</td>
<td>191</td>
<td>13</td>
</tr>
<tr>
<td>Participant 7</td>
<td>58</td>
<td>286</td>
<td>16</td>
</tr>
<tr>
<td>Participant 8</td>
<td>57</td>
<td>276</td>
<td>12</td>
</tr>
</tbody>
</table>
From Table 1 one can infer that there were considerable individual differences in the number of design episodes. Further, the number of episodes appeared generally to be smaller in the second than in the first session though there were some exceptions. The number of episodes varied from 7 to 18 in the first design session and from 5 to 14 in the second session. It should be noted that the number of statements in one episode varied considerably from 3 statements to more than 100 statements. For example, Participant 4 operated with fewer different design episodes; however, these episodes were quite long. In other words, all participants handled certain, core, design elements (e.g., shape and colours, weave structure) aimed at reaching a specific goal, but the number of statements representing each design episode varied considerably.

3.2 MODE OF DESIGNING

One important aspect of design protocol studies has been an analysis of the relation between the verbal-conceptual and visual-graphic mode of designing. It has become increasingly clear that the designer’s activity relies on the use of external aids and tools, such as notes and drawings (Akin & Lin, 1995; Goel, 1995). In order to fully understand expertise in designing, one should include in the analysis not only verbal transcripts but also visual and graphical representations used in the process of designing. In order to analyze the role of different design representations processed by the participants, we analyzed the mode of designing, i.e., to what extent the participants relied on verbal, written or graphical forms of designing.
The independent-sample *t* test was performed in order to test whether the proportion of the plain verbal designing differed between the groups of the advanced students and the experts in the first and second design session. There was statistically significant (*t* = -2.92, *df* = 6, *p* < .027) difference between the groups in the proportion of the plain verbal statements in the first design session. The experts used more verbal mode of designing (*M* = .53, *SD* = .01) than the advanced students (*M* = .36, *SD* = .05) in the first design session. This was probably connected with the fact that in the beginning of the first design session the experts used more time to structure the design task than the advanced students did. Apparently, experts used more time for searching the problem space than the advanced students; the former did not start immediately to produce sketches. The experts appeared to prefer processing the task conceptually. There were, however, no statistically significant differences between the advanced students and the experts in plain verbal designing in the second design session.

The analysis of the mean proportion of statements in which the participants were simultaneously verbalizing and drawing in the first design session revealed that the advanced students engaged relatively more often in verbal and drawn design (*M* = .42, *SD* = .03) than the experts (*M* = .28, *SD* = .04) (*t* = 5.54, *df* = 6, *p* < .001). A corresponding difference was not, however, found in the analysis of the second design session. The analysis revealed that the mean proportion of the verbal and written design did not differ between the groups in either of the design sessions.

Mode of designing associated with proportion of statements in each design development phase is presented in Table 3 across both of the groups and the design sessions. A higher number of verbal-only statements were generated during problem structuring than problem-solving phase. The phases of preliminary and refinement design
were mainly associated with verbal and drawn mode whereas detail design and decision making were associated with verbal-only, and verbal and written mode of designing. These results support corresponding findings of Goel and Pirolli (1992; Goel, 1995) and indicate that drawing and writing play a substantial part in the design process. There appeared to be a steady increase in the number of verbalisations associated with writings as participant progresses from a preliminary design to a detailed design.

Table 3.
Mode of Designing and Design Phase

<table>
<thead>
<tr>
<th>Design Phases</th>
<th>Mode of designing</th>
<th>Verbal</th>
<th>Verbal &amp; written</th>
<th>Verbal &amp; drawn</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td>Problem structuring</td>
<td></td>
<td>607</td>
<td>81%</td>
<td>70</td>
<td>9%</td>
</tr>
<tr>
<td>Preliminary</td>
<td></td>
<td>158</td>
<td>40%</td>
<td>22</td>
<td>5%</td>
</tr>
<tr>
<td>Refinement</td>
<td></td>
<td>93</td>
<td>31%</td>
<td>14</td>
<td>5%</td>
</tr>
<tr>
<td>Detail Design</td>
<td></td>
<td>520</td>
<td>50%</td>
<td>236</td>
<td>23%</td>
</tr>
<tr>
<td>Decision</td>
<td></td>
<td>119</td>
<td>51%</td>
<td>88</td>
<td>38%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1497</td>
<td>55%</td>
<td>430</td>
<td>16%</td>
</tr>
</tbody>
</table>

Note: In the table are included designing statements representing both of the groups and the two design sessions. The silence statements were excluded from the table.

As stated earlier, the advanced students engaged more often in verbal and drawn mode of designing than the experts. Further, there were substantial differences between the design session and, moreover, considerable differences between participants. Some participants (for example, Participants 5 and 8) engaged in extensive writing. All participants produced sketches in their preliminary and refinement design whereas decision making appeared mainly to happen by verbal-only statements. The nature of the design instruction of the second design session, as stated earlier, guided the participants to make more notes than sketches.
3.3 MODE OF BOOKKEEPING

All participants produced sketches in their problem solving. In order to examine how the participants’ relied on external representations in their designing, we constructed a variable labelled the mode of bookkeeping. The variable was designed to distinguish between visual (sketching) and conceptual (note making) representations used by the designers. The analysis revealed that the number of the different types of sketches produced varied, and there were considerable individual differences within the groups of participants. All advanced students produced many thinking sketches whereas the experts showed considerable within-group differences. Table 4 presents the number of different types of the sketches constructed by the participants.

Table 4. Different Types of Sketches Constructed by the Participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>FIRST DESIGN SESSION</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thinking Sketch (f)</td>
<td>Prescriptive Sketch (f)</td>
</tr>
<tr>
<td>Students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Participant 2</td>
<td>5</td>
<td>2+1</td>
</tr>
<tr>
<td>Participant 3</td>
<td>5</td>
<td>2+1</td>
</tr>
<tr>
<td>Participant 4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Experts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Participant 6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Participant 7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Participant 8</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: * demo pictures

An independent-samples t test was performed to analyze whether, in the design sessions, the proportion of protocol statements representing sketching differed between the groups of advanced students and experts. The analysis indicated that the proportion of sketching statements was higher in the case of the advanced students (M= .55, SD=...
that the experts ($M = .35$, $SD = .05$) in the first design session ($t = 6.20$, $df = 6$, $p < .001$). There were not, however, significant differences between the groups in the second design session. The results indicated that in the beginning of the first design session, the advanced students’ sketch development consisted mainly of the shape designing whereas the experts focused more on the pattern designing in their sketching.

There were considerable individual differences concerning how the participants produced notes in the first design session. In the second design session, participants were asked to produce working instruction for the weaver, and, therefore, completed more detailed notes than in the first design session. Apparently, note making was closely connected with solving the technical design elements.

3.4 PARTICIPANTS’ SKETCH DEVELOPMENT PROCESS

The number of the different type of sketches produced by the participants varied, and there were considerable individual differences between the participants. All advanced students produced many thinking sketches whereas, the experts’ showed considerable within-group differences. Figure 1 and Figure 2 present abstract descriptions of the advanced students’ and experts’ sketch development. As explained in the method section, each participant’s sketch development was analyzed distinguishing between horizontal and vertical sketch development. The advanced students produced many different kind of thinking sketches, and they extended their design ideas by producing a number of thinking sketches. However, as seen in Figure 1, the advanced students appeared to develop their sketches in the horizontal way, moving very quickly from one thinking sketch to another. Only toward the end of the process, did they start to develop
their design ideas in depth by working with prescriptive sketches and alternatives in a vertical manner.

Participant 1 produced many different design ideas by generating several thinking sketches. She elaborated different kinds of figurative and concrete forms and a nature theme in her, first, four thinking sketches. In her final thinking sketch, however, she ended up to a more abstract form of coloured-surface design. After finding the desired design idea, the participant produced a more detailed version (i.e., prescriptive sketch) of the same idea. The three alternatives she produced were coloured versions of the prescriptive sketch.

Insert Figure 1 about here

Participant 2’s process of sketching was very similar in spirit to that of Participant 1; she quickly produced two completely different thinking sketches. The third thinking sketch resembled the first, but the subsequent thinking sketches diverged substantially from the previous ones. The prescriptive sketches and alternatives were detailed variations of the fifth thinking sketch.

Participant 3’s drawings were connected to the nature like Participant 1 but she ended up to the more abstract version of that theme with abstract colour areas. Participant 3 produced two thinking sketches representing the external environment of the designed textile. The third thinking sketch differed from the previous ones, but the subsequent two sketches slightly resembled each other. Just as in the case of Participants 1 and 2, the final form of the textile emerged through generating a prescriptive sketch and two alternatives.
Participant 4’s design theme was based on an abstract coloured-surface design. Her process of sketch development progressed in a horizontal manner. The first two sketches produced in the beginning of designing resembled each other. However, the subsequent thinking sketches were based on a different design idea. She articulated the last thinking sketch further by producing a prescriptive sketch. However, she rejected the prescriptive sketch and produced a final alternative by returning to her original design idea (the first thinking sketch).

The experts’ sketch development was very different from that of the advanced students and, further, varied considerably between the experts. Figure 2 presents an abstract depiction of the experts’ horizontal and vertical sketch development. The figure indicates that the experts did not try as many different design ideas as the advanced students did in the first design session. They generated only a few design ideas and developed their ideas in depth, engaging in vertical sketch development. Further, the process of sketching appeared to vary considerably between the experts.

Participant 5 advanced in a stepwise manner and produced two thinking sketches that represented the same kind of an abstract colour and pattern design but varied in details. The variations were well constrained, and she quickly produced a set of modifications, apparently within one thinking sketch. She selected one of the thinking sketches, then developed an identical, but a more detailed prescriptive sketch, and an alternative. After that, she drew a new set of quick thinking sketches, selected one and made a prescriptive sketch and a final alternative. However, all sketches represented different versions of the same colour and pattern theme and resembled each other very closely.
Participant 7’s and Participant 8’s processes of sketch development resembled each other. Both participants’ design themes were based on abstract colour and pattern designs. Both participants produced only one thinking sketch, prescriptive sketch, and alternative. They remained in the first thinking sketch and completed that in more detail level.

Participant 6’s practices of sketch development differed substantially from that of the other participants. She produced two very complex and detailed alternatives that differed substantially from each other. The alternatives represented figurative depictions of nature. She rejected the first alternative that was based on a theme of four seasons and moved to the second alternative that represented different provincial flowers.

4 DISCUSSION

The process of weaving design was analyzed using a thinking-aloud method. The participants were four advanced students and four professional weaving designers, and they solved a representative professional weaving design task. The design task, however, took only 1-2 hours to solve so that it may not represent all aspects of real-life weaving design assignment. Further, the participants were allowed to select the type of production (e.g., finger-manipulated or loom-controlled) themselves so that the types of designed, woven textiles varied between the participants. Regardless of these methodological limitations, the study material provided content-rich and detailed information about advanced students’ and professional experts’ weaving design process.

The results of the study suggest strongly that design is an iterative process. Design solutions emerge gradually as a process of structuring and restructuring, composing
and decomposing the problem, defining and redefining constraints of designing and
generating and testing design solutions. Visualization guides the design process in each
stage of design, making the process move forward and backward. The iterative nature of
design makes construction of completely new and creative design solutions possible. An
important aspect of iterative design is visualization and sketching which provides feed-
back from testing of design ideas.

Sketching played an important role in the advanced students’ and experts’ weav-
ing-design process. The results of the study indicate that the advanced students produced
more visual sketches than experienced designers, moving very quickly from one design
idea to another. After exploring the problem space by producing a series of thinking
sketches, the advanced students turned their attention toward specifying their design in
detail by constructing prescriptive sketches or alternatives. Although the advanced stu-
dents did not develop their design ideas in depth, the experts worked with only a few
design ideas that were further articulated through constructing prescriptive sketches and
alternatives. Perhaps, the different types of sketches also represent different levels of
commitment of the designer. The thinking sketches, which were produced quickly and
later interrupted or rejected, represented a lower-level commitment while the prescrip-
tive sketches and final alternatives represented a higher level of commitment (cf., Goel,
1995).

To conclude, the results suggest that weaving design represents many general
characteristics of the design process as revealed by design research (e.g., Goel & Pirolli,
1992) including the importance of visualization and sketching in designing. We may
summarize the role of visualization and sketching in weaving design as follows:
• By relying on various kinds of external representations, particularly sketching and note keeping, the designers are able to reduce cognitive processing load during designing. Visual sketches and notes provide a mechanism of testing and exploring developing design ideas.

• Through the process of sketching, the first vague design ideas are transformed into further articulated and more determined ideas and, finally, to the explicit design alternatives.

• Design sketches are developed by moving from one idea to slightly different ideas or from one idea to a deepen level of the same idea. The former represents horizontal sketch development while the later represents vertical sketch development.

• Production and assessment of external representations (drawings, notes) enable the designer to evaluate whether the current goal has been achieved and whether the solution satisfies constraints of the intended design.

• Less-experienced designers tend to examine their design ideas by producing a number of thinking sketches; more experienced designers may articulate their designs mentally, and focus on examining a few design ideas in depth.
REFERENCES


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