
DRAFT OF COMPOSITION AND CONSTRUCTION IN EXPERTS’ AND NOVICES’ WEAVING DESIGN

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ABSTRACT

The purpose of this study was to analyze qualitative differences between novices' and experts' design processes and investigate the relationships between visual and technical designing in depth. Four participants, two professional weaving designers, and two graduate students of textiles participated in the protocol-analysis study. The results of the study indicated that the basic difference between experts and novices in their approach to weaving design is the novices' tendency to structure the process in a serial fashion around the visual elements of the task whereas experts were able to continuously consider the visual and technical elements of weaving in a parallel way during the design process.

Keywords: design cognition, design knowledge, design process, problem solving, generic design
INTRODUCTION

Weaving design is a complicated long-term creative process; while working with open-ended, ill-defined problems, a designer often applies general heuristic strategies based on domain-specific knowledge in order to narrow the search in a huge problem space\textsuperscript{1,2}. The pivotal aspect of the design process is the gathering and utilization of domain-specific knowledge, in conjunction with the visual and technical characteristics of the desired textile. 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 organization of visual elements then become crucial in producing a textile. An analysis of the elements of weaving design, i.e., those general aspects of design that necessarily characterize all weaving-design tasks, is an important condition for conceptualizing the process of weaving design.

In the present study, it is proposed that the weaving design process may be characterized as a dual-space search like many other areas of problem-solving\textsuperscript{3,4,5}. Accordingly, weaving design may be divided into two problem spaces: composition space, which represents visual designing; and construction space, which represents technical designing. The former space represents more domain-general knowledge of visual composition while the latter requires the domain-specific knowledge of production of woven textiles.

The principles of visual design are guidelines used in visual composition. Composition refers to how visual elements are arranged with each other, i.e., contrast, movement, direction, figure, and background. The composition space consists of the organization of the visual design elements selected and manipulated during design process. The visual elements consist of four types; shape design, color design, material design, and pattern design. These elements are considered in different levels of detail during the process of weaving design. The elements and principles of visual design are fundamental in every field of visual arts as well as general for all areas of design as opposed with technical knowledge that is particular for each design area.

The construction space consists of technical elements and principles of weaving. The construction space consists of the technical design elements that give a concrete form for the visual design, i.e., guidelines that direct possibilities of producing such a textile. The technical elements can be divided to two different categories; texture design and production procedure design. The former elements consist of weave design, draft and warp setting (density) design while the latter category consists mainly of technique design and produc-

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tion procedures. Each weaving technique has its own special equipment, methods of planning and order of progressing (for example make profile draft before long drafting). The present study focused on loom-controlled (i.e., harness-controlled) weaves that create geometric patterns (blocks, stripes) through a mechanical repetition of interlacements, which are governed by the weaving loom.

A close interaction between the two design spaces appears to be a necessary prerequisite for successful weaving design. The design process may be characterized as a serial processing or as a parallel processing within and between those two design problem spaces. "Serial processing" means that designing is carried out by considering only one problem space at a time, i.e., a designer first tries to solve a visual problem, and after that moves to the problem of construction of visual ideas. "Parallel processing" means that a designer considers both visual and technical aspects of a design problem in a given period of time; these aspects of design are more integrated.

The hypothesis of the present study is that the basic difference between experts and novices in their approach to weaving design is the novices' tendency to structure the process in a serial, single-focused manner around the visual elements of the task whereas experts integrate both the visual and technical elements of weaving and routinely consider them in a parallel way during the design process. This hypothesis is examined through analyzing the interaction and relationship between visual and technical elements of weaving design in novices' and experts' processes.

2. METHOD

2.1. Participants and Experimental Tasks

Four participants, two professional weaving designers, and two graduate students of textiles were used in the study. The novices had specialized in textiles in general, whereas the experts were specialists in weaving design in particular. The extensive education of the novices in the field of the textiles (including all textile techniques and teaching practicing) was based on four to six years’ studies; however, they did not have any working experience in weaving design. The experts’ education was based on five years’ studies specialization in weaving. The experts’ working experience ranged from 5 to 10 years in the area of weaving design. Thus, both the experts and the novices were somewhat familiar with weaving design, but their working experience in weaving differed considerably.

In the experiment, participants were asked to complete an already started weaving design idea of his or her own. They were asked initially to think what product they would like to design or develop during the session a day before the experimental session. The design objects varied from summer-and-winter weave (i.e., bound weave) rug (the participants 1 and 2, both of the novices) to wall hanging textile (circule weave; the Participant 3) and men's jacket fabric (applied honeycomb weave; the the Participant 4). All the design pro-
jects were quite challenging, relied on loom-controlled techniques, and required integration of visual and technical designing. The participants were at about the same stage in their design work: they had thought of an idea, but had not yet found visual and technical ways of producing it and, in addition, had not yet found detailed solutions for any of the design elements.

2.2. Method and Data Analysis

The study was carried out by using the thinking-aloud method, i.e., protocol analysis, following closely to Ericsson and Simon’s protocol-analysis technique. The experiment was arranged individually for each of the participants following a similar procedure. A participant was allowed to use all design materials (drawing equipment, samples of materials, and a textbook of weaves) needed in the design work. To aid in the documentation of these processes, sessions with the participants were recorded on videotape to enable a comparison of the verbal report with observed activity.

Result analysis was based on qualitative analysis of the contents of the protocols as well as a construction of problem-behavior graphs (PBGs). Participants' verbalized thoughts were divided into statements identifying single thoughts or main ideas, i.e., the meaning of the content (regarding segmentation of data for content analysis, see 7). Further, in order to increase the reliability and validity of protocol analysis the protocols were cross-referenced with the observed activities seen in the videorecording (divided into five-minute segments) as well as with the notes and sketches produced during the experiment.

The coding scheme employed in the present study focused on analyzing the nature of the participants’ designing process. Each verbalized statement was classified according to the use of a visual design element. The design activities that referred to the use of a visual design element were classified into the following categories. 1) **Shape** referred to designing of the form and the width or height of the woven textile: “This will be a very big textile … about 5 meters” 2) **Pattern** (i.e. figure and background) meant that the designer considered the background and figure on the design area or of one single pattern (e.g., stripe), or repetition of the same pattern or figure. “This is getting too striped”; “Some kind of clear divisions of patterns”, 3) **Color** comprised selecting colors for the product (colors for a warp, a weft or a figure shot), combining different colors, determining a color scheme, or evaluating color quality and the properties of the colors. “I would like to use quite bright colors… maybe red and orange…”, 4) **Material** referred to selection or evaluation of materials used for the woven textile as well as designing of warp, weft or figure shot materials.” Warp could be cotton and weft could be mixed materials … cotton, linen …”


The design statement referring to the use of technical design element were classified into the following categories: 1) **Structure** (i.e., weave/draft/warp setting) referred to the selection of weave structure to be used for a woven textile. “*I need at least eight harnesses to make the pattern part*”. The weave often consisted of the draft design, which was more detailed, and which included threading, treadling, tie-up and draw-down. Structure included also the selection of warp-setting (i.e., density, warp ends per centimeter) for the weave as well as more general references to the density of the fabric (loose or firm). 2) **Production procedure** comprised the technical design activity connected to considerations of finger-manipulated techniques, or the properties of the particular technique. “*Rya rug piles was one thing that came to my mind and how it will be produced...*” It also included the construction of the rya pile. Plans for experimenting at the beginning of the warp, or sampling weave structures in order to test warp set, warp or weft floats were regarded to represent this category. In addition, consideration of prevention of excessively long thread floats was a part of the designing of production procedure. ”*There will be too long floats... how could I prevent that...*”.

Visual and technical design were not regarded as mutually exclusive categories; i.e., a single design statement could represent both the visual and technical elements as well as only one or another of these categories. A design statement was, however, regarded to contain only one visual (or one technical) design element at a time. In the case of statements that contained references to two visual (or two technical) elements (e.g., pattern and color), the coder were guided to categorize the statement according to the most important visual (or technical) element. In order to examine relations between composition and construction design, it was examined whether a design statement included both the visual and the technical elements. **Type of processing** category was used to analyze how different aspects and elements are related to each other. 1) **Serial design** means that the design elements are processed one by one. These statements contained only a single design element representing either composition or construction space. “*Such patterns would be better in a sense*” 2) **Parallel design** means that the design elements are connected to each other, and are solved more or less simultaneously. Parallel design statements contained two different design elements representing both the composition and construction space. “*How do I get that color there... if it were a weft-faced weave ...by using yellow... it could be quite possible*”.

A sample of one protocol set (175 statements) was selected for analysis of the reliability of classification. The agreement coefficient between the two independent raters was as high as 82% in the case of the visual design elements and 92% in the case of the technical design elements.

After qualitative content analysis, each participant's design process was analyzed using **problem-behavior graphs** in order to examine the relationships between composition and construction spaces in novice and expert designs in depth. Design elements were described graphically as a set of moves from one knowledge state to another (i.e., propositions connected with particular design elements). The starting point of the analysis for each par-
participant was an identification of design episodes on the basis of the participant’s verbalized intentions ("I will ...", "I have to ...").

A design episode was defined as an identifiable segment of problem-solving process associated with attaining a goal, i.e., solving a design element. The episode started when the participant verbalized a specific goal (e.g., pattern design) and continued until a new goal was set. Every design element considered during that episode was represented as a trace of moves in the graphs. Each design episode consisted of 5-25 statements arising in the search for a solution for a design element or interaction between design elements.

A further partitioning was made by separating alternative designs. An alternative can be defined as a set of design elements which together constitute a sketch. A significant change in the viewpoint of design moves a participant from one alternative to another. Each participant produced several alternative designs during the experiment, usually two or three. Each alternative consisted of several episodes, the number of which varied substantially. A new alternative emerged when development of an old one was interrupted or abandoned.

3. RESULTS

3.1. General Nature of Weaving Design Process

The participants used from 45 to 67 minutes to solve the task (average 60 minutes). The four participants produced altogether 538 statements during the first task; the novices produced 257 statements, and the experts 281 statements. Individual differences concerning verbalization during task 1 were considerable; Participant 1 and Participant 4 produced twice as many statements as Participant 2 and Participant 3. An average statement consisted of 19 words.

Analysis of the frequency distribution of the contents of the participants' design process showed that visual design was a very important part of the overall design process regardless of the level of expertise. As many as 435 protocol statements out of all 538 statements produced in the experiment were related to visual design. Shape and pattern design consisted 56% (f=242) of all visual design statements (f=435). Color and material design were equally important, consisting respectively of 25% (f=107) and 20% (f=86) of design statements. Individual differences in emphasis on the elements of visual design mainly stemmed from the projects the participants were working on.

More systematic and salient differences between the novices and experts were, however, found when the participants’ technical design process was analyzed. The analysis indicated that the novices generally did not focus on technical design as much as the experts; only about 25% (101 out of 257) of statements produced by the novices considered technical elements, while 67% (205 out of 281) of statements produced by the experts represented technical elements. The experts produced twice as many statements associated with technical design than the novices.
Out of all technical design statements \( (f=306) \), 57% \( (f=175) \) were focused on texture design and 43% \( (f=131) \) on production procedure design. The relative importance of technical elements, however, varied between the novices' and experts' design process. The elements of technical design addressed by the novices were associated with texture of the product in approximately 79% \( (f=80) \) of the cases and with production procedure in only 21% \( (f=21) \) of their technical statements \( (f=101) \). However, in the experts' design, the relative importance of production procedure design \( (54\%, \ f=110) \) was almost equal to texture design \( (46\%, \ f=95) \). These expert-novice differences concerning technical design elements may be explained by the fact that the novices did not control their visual design process by developing production procedure and vice versa. The novices’ texture design process consisted mainly of direct copying of the structure of weaves (motif) and drafting from the textbook. The experts, on the contrary, controlled their visual design process by articulating production procedure at a very detailed level.

Analysis of relationships and interaction between visual and technical design was one of the most important objectives of the present study. The relationship between serial and parallel processing of the visual and the technical elements according to level of expertise is presented in Table 1, which depicts the parallel nature of the design elements in the experts’ processing. Out of all design statements produced by the participants \( (f = 538) \), as many as 62% \( (f=335) \) were serial in nature, i.e., related to visual or technical design, not both. The remaining 38% \( (f=203) \) of statements represented parallel design, i.e., the participants, at the same time considered both visual and technical design. Only 20% \( (f=53) \) of the novices design statements represented parallel designing whereas the proportion of the experts’ parallel design statements was 53% \( (f=150) \).

Successful design for weaving appears to require interaction between visual and technical aspects of the design, and novices to some degree were able to consider the two problem spaces simultaneously. Analysis of the frequency of parallel design statements, however, suggested that there were remarkable differences between the experts and the novices; the former group produced three times more parallel statements and two times more technical statements than the latter group. However, an analysis of frequency distribution of different categories of the participants' design does not provide detailed information about the nature of participants design process. Therefore, a deeper analysis of the participants’ design process was conducted by using problem-behavior graphs.

### 3.2 Process Analysis of Weaving Design

The problem-behavior graphs (PBG) were constructed to analyze the relationships between technical and visual design in the experts' and the novices' process of weaving design. The result analysis was conducted at several levels by analyzing design alternatives developed by the participants, design episodes processed as well as relationships between technical and visual designing.
The analysis indicated that there was a great deal of within-group homogeneity in relation to experts’ and novices’ practices of designing. Therefore, we will present the report results of analyzing PBGs by describing, in a detailed way, one novice's and one expert's weaving design process. These cases provide representative information of expert-novice differences in weaving designing as well as illustrate the detailed methods of process analysis used in the study.

3.2.1. A Novice's Weaving Design Process

Participant 1's design process consisted of 12 episodes of designing a summer and winter weave. Summer and winter is a reversible weft-faced (e.g., bound weave) weave with the same design on both sides but with colors reversed. In this kind of weft-faced weave the weft is dominant and gives the colors, texture and dimensions to the whole look. Development of Participant 1's whole design at the level of design alternatives is presented in Figure 1. The figure displays design alternatives activated during the design process as well as episodes processed during each alternative. An additional parallel design element which affected the process of achieving of a solution for a specific goal is also represented in the picture.

For Participant 1's design project it was characteristic that she always made the reversed side of the carpet to each of the alternatives. Further, the participant often considered pattern and color elements together. She started her design process by considering the shape of the textile making a preliminary decision on the shape of the carpet in the first episode. Shape was only implicitly considered during the following stages of designing and while developing subsequent alternatives. From shape (S) the participant moved on to considering pattern (P) and color (C) of Alternative 1.

The summer-and-winter weave has a usable reverse side, and, therefore, Participant 1 started to develop the other side of the product (positive-negative effect) as Alternative 1a by changing the colors of Alternative 1. During Alternative 1a's color episode the pattern was also solved following a previously made decision. Thus, at the end of Alternative 1a both sides get a patterned surface (Alt 1 and Alt 1a). Consideration of color of the textile (Alternative 1a) led the participant to contemplate more detailed patterns in Alternative 2, and the process moved to a new stage. Pattern and color were again solved together in Alternative 2. The original color considered in Alternative 1a remained, however, mainly unchanged even though color was a active element during the subsequent Alternative 2.

From Participant 1’s design process can be seen that pattern and color design interacted strongly. A solution in Alternative 2 led to development of design by experimenting with color and pattern design in Demonstration 2a (Demo 2a) which was based on consideration of the mirror image of the previous color and pattern (Alternative 2). On the basis of this experimentation (Demo 2a) the participant decided to elaborate Alternative 3. Alternative 3 was articulated in a more detailed way, and the one side of the carpet was solved. The re-
versed patterns and colors were solved to Alternative 3a based on previous solutions in Alternative 3. Thus, both sides of the carpet were solved in a more detailed way. Further, the size and shape of the product were determined, materials selected and draft of weave finished.

It was typical of Participant 1’s design process that the design solutions were developed incrementally; as the initial design idea was generated in first alternatives (shape, color, pattern), design elements were retained and manipulated many times until the final form was reached. Figure 1 shows clearly that, in alternatives (1) shape, pattern and color were defined; from Alternative 1a to Alternative 3 only pattern and color episodes were activated until Alternative 3a needed more specification of the texture design. Alternative 3a, the last one, included shape, material and texture solving, and design achieved a produceable form.

In the following, excerpts are presented from Participant 1’s thinking-aloud protocols during parallel designing. At the beginning of the design process, the connections between the visual and technical elements were rather isolated comments on the nature of the weave and how it may affect the pattern or colors. However, in later stages of the design process, the parallel consideration of pattern and weave created longer chains of parallel processing of design elements. These examples showed that the novices' technical designing was based on simple production rules such as "if X is the case, then Y follows".

Alternative 2a

Pattern/Weave #92: If I will make a summer and winter weave ... then it is always opposite on the other side.

#99: No, No, then comes only ... like becomes on this black background. Yes, comes these white points ... so it's same like here ... so So if I will have white background then I have black points..white background black points.

An abstract analysis of interaction between the elements of technical and visual designing in Participant 1’s weaving design is presented in Figure 2a and 2b. Each design episode as well as activated elements within and between the composition space and the construction space are represented.

The analysis presented in Figure 2a and 2b shows that the participant's visual (composition) and technical (construction) design were more serial and isolated than parallel in nature. Figure 2a and 2b also illustrates clearly how visual design dominated Participant 1's weaving design process. However, when Participant 1 moved to develop Alternative 1a for her reversible summer-and-winter weave, she connected pattern design to positive-negative nature of the weave (the back side of the weave is a reversed image of the front side). Consideration of this construction guided her to develop an opposite color alternative to the previous one. These pieces of parallel design inside the composition space were quite separated, individual comments on the nature of the weave without consideration of the produc-
tion procedure. In the middle of the design process, when Participant 1 made a demonstration (Alternative 2a), the interaction between visual and technical design increased, i.e., half of the statements were connected, and later when considering colors of Alternative 3a, she also handled texture and colors together in half of the statements of the episode. In the end of her designing, Participant 1 made mistakes by trying to solve the draft (motif) for the weave from the size of the product. In the last episode, Participant 1 solved the motif for the weave correctly and thus moved to the construction space.

3.2.2. An Expert’s Weaving Design Process

Participant 4 verbalized as many design statements as Participant 1, and her design process took a little bit longer than that of the other participants. Participant 4 began her design process by considering the texture of the textile together with the properties of the materials. These considerations were further connected with exploration of the possibilities of producing a desired kind of pattern. Before starting the actual drawings, Participant 4 analyzed the texture of an old fabric sample (Sample Demo) and explored the possibilities of varying the sample in order to produce different kinds of patterns. Further, she expressed her concerns about how the selected material affects the surface of the textile in the following statements:

# 2: "I know the properties of the fabric [Rag material], they are already tested and exists, but I want here something else, because Rag material [Finnish "poppana"] creates a smooth velvet-like surface when it has been weaved by using one color"

#10: "My idea is to create this [rag material] fabric by using thin weft or supplied weft and shotting here and there small coloured stripes beside the weft, which do not go through the whole fabric but instead make stripes here and there either regularly or irregularly"

She started by making the pattern for Alternative 1 and Alternative 2 and 2a, and by testing the influence of the material and colors on the pattern. She selected the pattern design as developed in Alternative 3 as the starting point for further design. The whole design process consisted of ten design episodes. The problem-behavior graph indicates that Participant 4 abandoned both of the first two alternatives and began the development of Alternative 3. The pattern for Alternative 3 was effectively developed together with construction of the elements of the technical design.

An abstract reconstruction of Participant 4's whole design process is presented in Figure 3. During the first design episode Participant 4 structured the problem and tried to map all the constraints for the desired product. She did not have any initial sketches other than old sample of woven fabric. The fabric sample based on the honeycomb weave, guided the image of the desired patterns for the men's jacket fabric like a drawing sketch of the patterned surface (checked pattern). After exploring the constraints of the textile, she moved to design the pattern of the textile in a parallel way with production-procedure design in Alternative 1. Alternative 1 as well as subsequently developed Alternatives 2 and 2a (in
which she analyzed relationships between pattern and color from the viewpoint of production procedure) led to rejection of these alternatives because the properties of the warp, weft and texture of designed textile would not have produced the desired surface. The development of Alternative 3 included the colored and patterned drawings, a very detailed drafting (draw-down, treading, readling, tie-ups) and wrapping sample in which were used actual materials and simulation of the solved pattern. The participant succeeded in solving all of the above mentioned problems in this detailed and deeply developed Alternative 3 (see Figure 3).

A dominating role of the technical design elements was characteristics of the whole design process. Figure 3 reveals how consideration of the technical design elements was used to control the process of visual sketching during Participant 4's design process. This kind of control structure was totally missing from the novices' design process.

An abstract description of Participant 4's design process from the viewpoint of the composition space and the construction space is presented in Figure 4. In the figure is represented each of the design episodes and elements processed as well as their interaction in Participant 4's design process. Figure 4 demonstrates very clearly how an expert weaving designer continuously moves from technical to visual design space and vice versa, and how parallel consideration of design elements is the key to a successful design.

Like Participant 3, Participant 4 started her design process from the construction space, moving onto the composition space toward the middle of the designing. Participant 4's design process was parallel in nature from the very beginning, but the relative proportion of parallel design statements increased considerably toward the end of design process. Excerpts from Participant 4's verbalized statements highlighting parallel design are presented below. These excerpts were selected from the record of the design process to illustrate how there was a continuing connection between visual and technical designing.

Pattern/Procedure #35: I will try to get some sort of small stripes,... and in any case the end result will be cross-striped in the direction of the weft.

Weave/ Pattern    #65: But here we came again to the very same problem that in the lace weave ... there where the stripe does not show [cannot be seen] on the right side ... it still is there [still exists] making floats to the other side [of the textile].

4. DISCUSSION

The experiment indicated that the thinking aloud method can be productively applied to research in the area of weaving design. The participants produced verbalized thoughts very fluently, and the thinking aloud protocols provided very important information about weaving design processes. Construction of each participant's problem-behavior graph was
based on a detailed qualitative analysis of the elements of visual and technical design and their relationships. These procedures made it possible to assure that verbal protocols were highly relevant to the task, corresponded to activity seen in the videotapes and were consistent with the previous verbalized thoughts, i.e. the protocols progressed in a meaningful order.4

A methodological limitation of the study was that the experimental task captured only a part of a long-standing weaving-design process; transition from the first design idea to the production may take several weeks, whereas this study, of necessity, focused only on two hours of intensive designing. However, the weaving design task used in the study correspond to important aspects of meaningful, real-world tasks of weaving design.8

The hypothesis of the study was that the basic difference between the experts' and the novices' weaving design is that the experts are able in a parallel way to consider both the construction and the composition spaces whereas the novices' design process is serial in nature, focusing on visual design. The analysis of problem-behavior graph provided detailed evidence of the development of each participant's design process and confirmed the parallel nature of the experts' design process. However, the fact that the participants' were designing different kinds of woven textiles suggests a necessity for extra caution in generalizing the results.

Analysis of the novices' design process using problem-behavior graphs showed that novices organized their weaving process around the composition space at the beginning of the designing and only occasionally jumped to the construction space to explore how visual ideas could be realized by weaving. However, noted toward the end of designing was the novices increased concern for construction problems, though in many cases technical design still remained a segregated aspect of the process. In the end of the design process, both novices moved to the construction space to update their previous visual solutions and to give them a more operational form. The problem-behavior graphs indicated that it was typical for both of the novices to handle the elements of technical and visual design serially.

Further, analysis of the novices' visual design suggested that designing of visual elements did not progress monotonically or linearly, rather the novices' visual design was cyclical (or iterative) in nature; i.e., consideration of a design elements was repeated many times as its relation to other elements changed and its design was continuously revised and developed. In the case of visual design even if the designing was internal to an episode, there was a considerable carryover and parallel development of visual design elements (color and pattern and visa versa) reflecting the incremental development of design. In the construction space most of the design elements considered by the novices occurred inside of an episode, and usually there was no carryover from previous visits to the composition space.

Without cyclical (repetitive) revising and iterative processing the solving of technical elements remained at a rather superficial and general level in the novices’ weaving design.

The experts were able to integrate both the visual and technical elements of weaving and generally consider them in a parallel way during design process. After exploring technical possibilities, the experts moved onto the visual design. The iteration between the composition space and construction space is a very salient character of the experts' design processes. The experts' not only processed visual and technical design elements in a parallel way, but also continuously moved from one design space to another to carry out very detailed processes of search for design solutions. In addition, when experts started their design process from technical design elements, considered them in parallel with visual design, and further moved to composition space; all the previous considerations were carried over to the next episode as well as manipulated and updated many times. In the experts' designing, transfer to visual design was always related with technical production of the textile and the visual ideas were carried back to the construction space. The experts' design processing was iterative and cyclical in nature in both of the design spaces. By revising different design elements cyclically and iteratively, the experts incrementally developed the design and effectively carried previous ideas over another design episode or more significantly onto the other design space. For example, they often simultaneously reflected on the components of visual design (pattern) and its technical realization (weave). The search in the construction space effectively constrained the search in the composition space by giving information about how a particular weave would influence the pattern or be related to materials.

The domain-general aspects of the designing have been insightfully investigated by many researchers but the critically important interaction between domain-general and domain-specific knowledge has not been analyzed in detail. Thus far, design studies have relied on analysis of domain general aspects of designing, such as methods of heuristic search. These weak methods can, however, be effectively utilized only by the means of strong domain-specific knowledge and methods. Analysis of the design process from the viewpoint of the two problem spaces appears to give new insight for analyzing interaction between domain-general and domain-specific knowledge in design processes in general and

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9 This finding corresponds closely to the idea of generic design space, see Goel V and Pirolli P The structure of design problem space Cognitive Science, Vol 16 (1992) pp 395-429


12 Chan C-S Cognitive processes in architectural design problem solving Design Studies Vol 11 No 2 (1990) pp 60-79

weaving design in particular. All areas of handicraft, for instance, deal with composition design and problems of technical constructions although the nature of technical processes or the way those direct and control design processes and construction of compositions vary. The dual-space model of designing probably appears to have implications over or above the study of weaving design; explanation of interaction between domain-general and domain-specific designing on the basis of the two problem spaces would be applicable for a large class of design domains and design tasks.
### Table 1.
**Coding of Technical and Visual Design Elements in Problem-behavior Graphs**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Type of Visual Design Element</th>
<th>Token of Visual Design Element</th>
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</thead>
<tbody>
<tr>
<td>VCS</td>
<td>Visual Composition of <strong>Shape</strong></td>
<td>Size</td>
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<tr>
<td></td>
<td></td>
<td>Height</td>
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<tr>
<td></td>
<td></td>
<td>Width</td>
</tr>
<tr>
<td>VCP</td>
<td>Visual Composition of <strong>Pattern</strong></td>
<td>Figures/shapes/stripes</td>
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<td></td>
<td></td>
<td>Motif</td>
</tr>
<tr>
<td></td>
<td>Visual Composition of <strong>Color</strong></td>
<td>Pattern repeat</td>
</tr>
<tr>
<td>VCC</td>
<td></td>
<td>Color combination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Color Scheme</td>
</tr>
<tr>
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<td>Visual Composition of <strong>Material</strong></td>
<td>Color quality</td>
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<td>Warp</td>
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<td>Figure shot</td>
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<tr>
<td></td>
<td><strong>Type of Technical Design Element</strong></td>
<td><strong>Token of Technical Design Element</strong></td>
</tr>
<tr>
<td>COT</td>
<td>Construction of <strong>Texture</strong></td>
<td>Weave</td>
</tr>
<tr>
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<td>Profile Draft / Motif</td>
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<td>Long Draft (drawdown;</td>
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<tr>
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<td>Drafting</td>
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<tr>
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<td>Density</td>
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<td>COP</td>
<td>Construction of <strong>Production Procedure</strong></td>
<td>Technique</td>
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<td>Yarn floats</td>
</tr>
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<td>Tread grouping</td>
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<td>Weaving plan</td>
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Table 2.
Type of Processing and the Level of Expertise

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<tr>
<th>TYPE OF PROCESSING</th>
<th>LEVEL OF EXPERTISE</th>
<th>SERIAL PROCESSING</th>
<th>PARALLEL PROCESSING</th>
<th>TOTAL</th>
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<tr>
<td></td>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
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<tr>
<td>NOVICES</td>
<td>Participant 1</td>
<td>133 76.0%</td>
<td>42 24.0%</td>
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<tr>
<td></td>
<td>Participant 2</td>
<td>71 86.6%</td>
<td>11 13.4%</td>
<td>82 100%</td>
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<td>Subtotal</td>
<td>204 79.4%</td>
<td>53 20.6%</td>
<td>257 100%</td>
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<tr>
<td>TOTAL</td>
<td></td>
<td>335 62.3%</td>
<td>203 37.7%</td>
<td>538 100%</td>
</tr>
<tr>
<td>EXPERTS</td>
<td>Participant 3</td>
<td>47 52.8%</td>
<td>42 47.2%</td>
<td>89 100%</td>
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<tr>
<td></td>
<td>Participant 4</td>
<td>84 43.8%</td>
<td>108 56.3%</td>
<td>192 100%</td>
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<tr>
<td></td>
<td>Subtotal</td>
<td>131 46.6%</td>
<td>150 53.4%</td>
<td>281 100%</td>
</tr>
<tr>
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<td>TOTAL</td>
<td>335 62.3%</td>
<td>203 37.7%</td>
<td>538 100%</td>
</tr>
</tbody>
</table>
Figure 1.
Relationships between weave structure, materials, production procedure and woven textile.
Figure 2.
Participant 1's design process as development of alternatives and activated episodes within each alternative.
Figure 3.
Design elements between composition space and construction space in Participant 1's weaving designing.
Figure 3B
Figure 4.
Participant 4's design process as development of alternatives and activated episodes within each alternative.
Figure 5.
The interaction between composition space and construction space in Participant 4’s design process.
Appendix.
Samples of Participant 1's and Participant 4's problem-behavior graphs
(ALT=alternative, EVA=evaluation, demo=demonstration)