Three orientations of weaving design

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Abstract

This study investigated expertise in the process of professional-level weaving design. A working hypothesis of the study was that the weaving-design process is best considered as a dual-space search between the visual, composition space and the technical, construction space, subject to external (environmental, contextual) and internally generated constraints. The study analyses 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 participants were asked to solve the task while thinking aloud in two design sessions. 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-behavior graphs (PBGs). The present results indicate that weaving design shared many prototypical characteristics of design process. An examination of the nature of weaving design indicated that the participants, regardless of the level of expertise, focused on composition design in the first design session and construction design in the second design session. There were, however, substantial differences within the groups of participants concerning the role of different design spaces during their problem solving. An analysis of the relative importance of the composition, construction and constraints in the participants' designing indicated that they followed identifiable design orientations (i.e., composition orientation, composition-construction orientation, and constraint orientation).

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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. Generally, the design space is ill-defined in the sense that there are no definite criteria for testing whether a proposed solution is successful or not (Simon 1977; Akin 1986; Goel & Pirolli 1992). Moreover, the design space cannot be defined unambiguously. The designer has to structure and limit the huge design space by using external and internal constraints (Goel 1995). 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 1995).

In general, the design-task environment in the professional context of textile design is typically specified in a customer's brief. The design tasks provide information of both the design constraints and design elements (Seitamaa-Hakkarainen 2000). The design constraints specify the context 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 artifact to be designed and thus they constrain the design context (Goel & Pirolli 1992; Lawson 1991).

In the present study, it is proposed that the weaving design process may be characterized as a dual-space search through composition and construction spaces (Seitamaa-Hakkarainen 2000; Seitamaa-Hakkarainen & Hakkarainen 2001), like many other areas of problem solving (Goel & Pirolli 1992; Goel 1995; Goldschmidt 1997). *Composition space*, which is seen as a domain-independent design process, consists of the organization of the visual elements and principles selected and manipulated during design process. The visual elements consist of shape design, color design, and pattern design elements. *Construction space,* which is seen as a domain-specific design process, consists of organization and manipulation of the technical elements and principles. The technical elements include material design, structure design (e.g., weave and density) and design of production procedures (e.g., technique, yarn floats). Technical design strongly influences textiles' surface. The selection of the visual elements requires a search through the composition space, and the selection of technical elements requires search through the construction space. The pivotal aspect of the weaving 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 bringing the textile into the realm of the tangible (Seitamaa-Hakkarainen & Hakkarainen 2001).

Our previous analysis of the novices' design process by using problem-behavior graphs showed that novices started to design from the composition space and only occasionally manipulated visual and technical design elements in a parallel way (Seitamaa-Hakkarainen 1997; Seitamaa-Hakkarainen & Hakkarainen 2001). A very important feature of the novices' design process was the dominant role of the development of the composition of the textile. Due to the complexity of the weaving design problems and the many levels of detail that had to be considered, the novices' designing occurred mostly in the composition space; design of a composition was the novices' focus until the end of the design process. Due to the limits of the novices' domain-specific knowledge and lack of an iteratively developed understanding of the principles of weaves, they could not control the technical elements nor manipulate them together with visual elements. Unlike the novices, the experts did not start by considering one design element at time; rather, the experts connected many of the design elements together from the very beginning. In the middle of the process they did move back and forth between composition and construction spaces. By revising design elements cyclically and iteratively, the experts incrementally developed the design and effectively carried previous ideas into the other design space (Seitamaa-Hakkarainen 1997; Seitamaa-Hakkarainen & Hakkarainen 2001).

The dual-problem space model provides a plausible way to account for a variety of expert-novice differences (Bereiter & Scardamalia 1987; Klahr & Dunbar, 1988). Seitamaa-Hakkarainen & Hakkarainen (2001) made a corresponding prediction concerning the nature of expertise in weaving design. However, working with different spaces can also be seen to reflect on different design orientation. Given the rationale outlined above, the investigators pursued research objectives of the present study through the following approach, 1) analyze the role of the underlying design constraints and the relationship between composition and construction design elements; and 2) examine the different design orientations of the weaving design.

Method

Participants and experimental task

Eight participants, four professional weaving designers, and four advanced students of weaving design participated in the study. Each participant had quite similar educational backgrounds, specializing in weaving design having at least some professional working experience. However, the experts had extensive professional expertise, and two of them were highly regarded weaving designers in Finland. The participants were asked to solve an authentic, small-scale weaving-design task selected to represent general and stable features of the professional design tasks, but, it differs, however, in one respect from the characteristics of a full-scale design task and that difference was necessitated by the logistics of data collection. 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, both of which had time limits. They 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.

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 (1984) protocol-analysis technique. Accordingly, each participant was asked individually to think aloud from the beginning of the problem solving to the end of it. 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 as well as with notes and sketches produced during the design sessions. The systematic observations of the video protocol were coded manually in two-minute intervals.

We applied qualitative analysis of the contents to the protocols and used the data to construct problem-behavior graphs (PBGs). For the qualitative content analysis, the transcribed protocols were segmented into statements identifying single thoughts or main ideas, i.e., the meaning of the content (regarding segmentation of data for content analysis, Chi 1997). Each statement was coded along several independent dimensions. The focus of qualitative content analysis consisted of the design development phases, design activities, type of sketches, and design content variables.

The coding schemata consisted altogether of 29 variables but only design content variables will be reported here (for complete classification see Seitamaa-Hakkarainen 2000).

For each statement the nature of content was identified (a) *constraints*, (b) *composition* design or (c) *construction* design. The constraints of design form a general frame for the design, and they are identified or inferred from the external source or internal aspect of the design situation. The *constraints* can reflect some of more external issues about (a) *users*, i.e., aspects of the persons for whom the textile will be designed; (b) *environment* and atmosphere i.e., aspects of the local place and the atmosphere of the environment. In general, constraints involved consideration of desired aspects of the quality of the day-care center and its intended atmosphere. Nevertheless, the designer could generate more internal constraints during design, which were classified (d) *function* of the textile, which reflects desired properties for the textile. The function of textile may support certain purposes (hiding, function for touching and softness). Finally, the constraints may be connected to (d) *finishing*, installation, resources and maintenance aspects.

Each verbalized statement was further classified according to the elements of composition and construction design it contained. The elements of composition design were (a) *shape* or form; (b) *pattern*; (c) *color* or color scheme. On the other hand, each statement was coded on the basis of the elements of technical design. Construction design consisted of three elements: (a) *material*, including warp and weft or figure shot; (b) *structure*, including weave, profile draft/motif, long draft, density; and (c) *production procedure*, i.e., finger-manipulated techniques, yarn floats, Finnish *ryjy* rya pile, thread grouping, weaving plan etc. 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 for constraints, .94 for composition and .96 in the case of the construction design elements.

After completing the qualitative content analysis, problem-behavior graphs (PBGs) were constructed for each participant. The analysis of the problem-behavior graphs generally captures well temporal aspects of a subject's design activity and domain content and helps to examine the interaction between composition and construction designing in each participant's design process (see also Chi 1997; Suwa & Tversky 1997). Design elements were described graphically as a set of moves from one knowledge state to another (i.e., propositions connected with particular design elements). It also represents unsuccessful attempts at reaching a solution, i.e., dead-ends. Following the segmentation of the protocols into statements (i.e., the unit of analysis reminded the same), each subject's solution process was analyzed by using special problem-behavior graphs developed by one of the present authors (Seitamaa-Hakkarainen 1997; 2000). Every design element considered during that episode was represented as a trace of moves in the graphs. Each of a given participant's verbalized statements was coded according to the design element or their relationship represented. This method made it possible to analyze whether the participants were processing design elements serially or in a parallel way i.e., within and between design spaces.

Results

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 1986 statements produced in the first session, and 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. The number of participants' protocol statements varied from less than 200 to over 250 in the first design session, and from less than 90 to about 250 in the second session.

Each participant differed in her design proceeding and producing different types of sketches, notes, and working instructions with varying degrees of completeness. Furthermore, each participant processed her design problem in an individual way, and subsequently, designed a unique plan for a weavable textile. Participant 1 designed a Finnish ryjy (i.e., rya rug) during her design sessions by relying on finger manipulation technique. While analyzing the design task, she rapidly produced many different design ideas, generating five thinking sketches, one prescriptive sketch and three final alternatives in the first design session. Participant 2 relied on more complex weave techniques, and her design was based on a loom-controlled technique (weft-faced compound type of summer and winter weave) with Finnish rya technique in the middle area. She constructed five thinking sketches, two prescriptive sketches, and one final alternative during the first 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.

Participants	**First Design Session**			**Second Design Session**			**Type of Production**
	Time (min)	State-ments*	Design Episodes	Time (min)	State-ments*	Design Episodes	
Students							
Participant 1	68	234	12	32	133	8	FM
Participant 2	64	260	18	44	228	14	LC
Participant 3	63	228	13	52	241	14	FM
Participant 4	66	275	7	29	105	6	FM
Experts							
Participant 5	62	236	13	29	134	7	LC
Participant 6	53	191	13	18	94	5	FM
Participant 7	58	286	16	22	100	7	LC
Participant 8	57	276	12	28	164	8	LC

Note: Total number of statements (propositions) verbalized includes silence statements. Type of production of textile (LC = Loom controlled; FM = finger manipulated)

Table 1: Individual weaving design projects in the first and second design sessions

Participant 3 designed a textile in which the ground consisted of weft-faced compound weave and half rya rug piles. During the first design session, participant 3 produced five thinking sketches, one prescriptive sketch together with a small demonstration, and one final alternative. Participant 4's design theme was based on an abstract colored-surface design of the Finnish rya (i.e., half-rya) and she produced four thinking sketches, one prescriptive sketch and one final alternative in the first design session.

Participant 5's design was based on weft-faced compound weave (loom controlled), although certain color areas required pick-up. She used 15 minutes to structure the design task and the design brief, and ended up with an idea of an abstract form of colored-surface design. She produced two sets of thinking sketches, prescriptive sketches, and final alternatives. Participant 6's design process in the first session took 53 minutes and consisted of 13 episodes. She, like some of the others, designed a textile with a complex type of weft-faced compound weave, in which the pattern and color areas (i.e., figures) are to be done by pick-up between the shed. Because the ground consisted of different weave structures (tabby, twill, and rep, for example), this kind of textile requires extensive use of the pick-up technique. The participant 6 produced two very complex and detailed alternatives in the first design session that differed substantially from one another. Participant 7's design was also based on weft-faced compound weave, although certain color areas required pick-up. Her design was based on abstract color and pattern designs. She produced only one thinking sketch, one prescriptive sketch and a final alternative. Participant 8 designed a weft-patterned textile, completely based on a loom-controlled technique. Her design theme comprised abstract colored areas and patterns. Participant 8's design output consisted of a thinking sketch, a prescriptive sketch, a final alternative, and a demo drawing, along with some extra copies of sketches of the shape related to them.

Analysis of the frequency distribution of the contents of the participants' design process showed that composition design was a very important part of the first design session regardless of the level of expertise. C*onstraint* represented aspects to be used to define the design context. These constraints limit designing, but they are not the focus of designing. While c*omposition space* referred to the principal meaning of the visual design, the *construction space* referred to the technical aspects of the design. By selecting and manipulating these composition and construction elements the designer actually constructs the artifact to be designed. Table 2 presents the proportions of design statements representing these three design aspects in the first and second design sessions.

Participants	**Design Space in the First Design Session**				**Design Space in the Second Design Session**			
	Con-straints	Compo-sition	Con-struction	Total	Con-straints	Compo-sition	Con-struction	Total
Participant1	.17	.77	.06	1.00	.11	.37	.53	1.00
Participant 2	.14	.57	.29	1.00	.08	.48	.44	1.00
Participant 3	.38	.34	.28	1.00	.02	.30	.68	1.00
Participant 4	.13	.82	.05	1.00	.13	.03	.84	1.00
Students Total	**.21**	**.63**	**.17**	**1.00**	**.09**	**.29**	**.62**	**1.00**
Participant 5	.27	.61	.12	1.00	.11	.17	.72	1.00
Participant 6	.15	.47	.36	1.00	.05	.00	.95	1.00
Participant 7	.29	.42	.29	1.00	.13	.32	.55	1.00
Participant 8	.36	.31	.33	1.00	.19	.19	.62	1.00
Experts Total	**.26**	**.46**	**.28**	**1.00**	**.12**	**.17**	**.71**	**1.00**

Table 2: Proportion of design statements representing the three design aspects in the first and second design sessions

The analysis suggests that the designing related to constraints played an important role in the first design session. Both the advanced students' (*M*= .09; *SD*= .05) and the experts' (*M*= .12; *SD*= .06) dealt with constraints designing, which reduced substantially towards the second design session. Further, out of all verbalized protocol statements produced during the first session (*f*=1686), a substantial proportion (.53, *f*=893) were focused on composition space. The composition elements consisted of shape, pattern, and color design. The mean proportion of the advanced students' protocol statements representing composition design (*M*= .63, *SD*= .22) was higher than that of the experts (*M*= .46, *SD*=.12) in the first design session. In the second design session, however, the mean proportion of composition design decreased substantially in the advanced students' design process (*M* =.29; *SD*=.19), and even more in the experts' (*M*=.17; *SD*=.12) designing. The proportion of protocol statements representing construction design was somewhat higher in experts' than the advanced students' designing, in the first design session. In the first design session, construction design did not play a dominant role in the subjects' verbalized protocol statements. The mean proportion of construction space design increased in both of the groups from the first design session to the second.

Participants 7 and 8 from the expert's group appeared to equally consider all of the design spaces in the first design session, whereas participant 5 considered composition space relatively more in the first design session than did the other experts. Moreover, participant 6 appeared to consider to a greater degree construction design space, moving more and more towards the construction design space as the main aspects of designing in the second design session. We can conclude that while the subjects considered both design spaces (composition and construction spaces) and related aspects of designing i.e., design constraints, nevertheless, within-group differences were relative larger than the differences between the groups of advanced students and experts. Since both of the groups have extensive backgrounds in weaving design, the differences between the groups were, in fact, smaller than differences between the sessions. Even starting with the same motif, all unique art and craft works differ in style due to the craft person's individual perspective, interpretation and the characteristics of the technique used. Moreover, each artist or craft person has his/her individual style and sources of inspiration. Such diversity of approaches extends to all areas of art and has been well documented (von der Wert & Frankenberger 1995; Eisentraunt & Günther 1997). Thus, one possible explanation for the observed patterns of designing may be found in the different design orientations, which reflect an individual's design style.

To better understand the processes of design that the different subjects engaged in, the present investigators decided to carry out a further analysis focused on examining how the designers' personal orientations affected the relative importance of the composition, construction, and constraint design spaces. Thus, the next step was to construct a group of characteristic variables that might specify a designer's way of working. In order to examine whether the subjects' designing represented an identifiable design orientation beyond the level of expertise, a K-means cluster analysis (see Aldenderfer & Blashfield 1984) was conducted by using SPSS for Windows (7.5). Through cluster analysis the researchers were able to form homogenous groups and identify highly similar cases by analyzing patterns of relationship between the design elements. Variables used in the cluster analysis were the proportions of constraint, composition and construction statements in the first design session. The analysis focused on the first design session because it was hypothesized that the design orientation would have the strongest effect when the designer begins to develop his or her design ideas and begins to structure the problem space. Table 3 presents the final cluster centers that emerged from the analysis.

First Design Session	**Cluster centers**		
	1	2	3
Composition	.80	.55	.36
Constraints	.15	.18	.34
Construction	.05	.26	.30

Table 3: Final cluster centers in the first design session

Cluster 1 refers to as *composition orientation*; cluster 2 is *composition-construction* orientation; and cluster 3 is as *constraint orientation*. The first cluster emphasized the composition orientation as the main content of design. In addition to composition design, construction design was also emphasized in the second cluster. This second cluster is therefore called composition-construction orientation. Characteristic of the third cluster was a rather equal emphasis on all of the design spaces. The emphasis on the constraint design was substantially stronger in the third orientation than in the other two orientations, therefore it was termed constraint orientation. Table 4 presents the cluster memberships of each participant.

Participants	Level of expertise	Orientation Cluster	Distance from the cluster center
1	Advanced student	Composition	.04
2	Advanced student	Composition-Construction	.05
3	Advanced student	Constraint	.05
4	Advanced student	Composition	.04
5	Expert	Composition-Construction	.16
6	Expert	Composition-Construction	.13
7	Expert	Constraint	.08
8	Expert	Constraint	.06

Table 4: Cluster membership of the participants

Participants 1 and 4 represented the *composition orientation,* and both of them were advanced students designing a Finnish rya rug and relied on finger-manipulation techniques. The second orientation type was called *composition-construction orientation* indicating that both composition and construction design elements were emphasized. Participant 2 from the advanced students' group, as well as the experts 5 and 6 represented composition-construction orientation. All of these participants relied on more complex weave techniques than did the composition-oriented participants; the designs were mainly intended to be produced by loom-controlled techniques.

Design Orientations		
Composition	**Composition construction**	**Constraints**
• There was a very short period of problem structuring (about 2 minutes) in the very beginning of the first design session. • There was an immediate production of a number of thinking sketches. • Composition design was the main focus of the whole first design session, and color design was the main composition element. • The construction design and construction elements are not considered in separate design episodes. • There was a short consideration of the production procedure which implicitly direct the development of design idea but does not refer to weave structures. • The design process was mainly serial in nature	• All participants had a separate problem-structuring phase lasting 5 to 15 minutes. • External design constraints were considered in a relational way i.e., through connecting design constraints with design elements. • After the beginning of the design session the external design constraints were not considered very intensively. • Composition design was the main aspect of designing from the beginning of the session but, somewhere in the middle of the session, the process started to move between composition and construction design spaces. • Moving between composition and construction spaces transformed the designing towards a parallel process.	• All participants had a long separate problem-structuring phase lasting almost 20 minutes. • The constraints related to the environment and the users were investigated extremely carefully. • After the beginning of the design session, the external design constraints were also considered once and a while. • The composition and construction design were given an equal consideration, and participants started continuously to jump between the composition and construction design spaces somewhere in the middle of this session. • The design process was parallel in nature.

Table 5: Typical features of three different orientation

Participant 3 from the advanced student group, and the experts 7 and 8, represented the constraint orientation and their design processes appeared to represent a more equal processing of all the aspects of design. These *constraint-oriented* participants typically proceeded through the design spaces in a balanced way; i.e., they focused equally on all aspects of designing. Yet their design process focused more on the external constraints than that of the participants representing composition orientation or composition-construction orientation. Both expert participants' designs relied on complex weaving techniques, which were mainly produced by loom-controlled methods. In participant 7's design, some pattern areas were designed for finger-manipulated pick-up techniques. Participant 3's design was based on finger-manipulated technique (i.e., half rya rug), and the ground of the textile consisted of summer and winter weave. Table 5 present typical characteristics of design of participants representing each of the three orientations. The problem-behavior graphs had important role in the emergence of these orientations.

Discussion

In the present study four advanced students and four professional weaving designers participated, and they solved a representative professional weaving design task by thinking aloud. 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.

Goel and Pirolli (1992) argued that the structure of "design problem space" and task environment is similar across various prototypical design areas. Although there are general features that are common for all design processes, there are, however, also substantial differences concerning domain-specific knowledge and design elements used within a particular field of design.
The interaction between domain-general and domain-specific aspects of designing was specifically addressed in the present investigation. Design research indicates that there is a great deal of variation between individual designers in their ways of approaching and solving design tasks, not only between different disciplines but also within the same one (see, for example, Eisentraunt & Günther 1997; see also Akin 1986). However, the special nature of the prototypical design tasks, design processes and the role of the visualization in the design process represent the prototypical aspects of the all design fields.

The present investigators provisionally identified two fundamental problem spaces of designing: composition space, and construction space. However, while designing composition and construction design elements one must always deal with external and internal constraints, which frame the entire task environment. As stated in the previous section, the designing related to the constraint space played an important role in the first design session but, apparently, decreased in the second design session. The overall analysis of the role of the design spaces suggests that the participants focused strongly on the composition design during the first design session. The composition space had a more dominant role in the advanced students' designing than that of the experts, in the first design session. In the second design session, construction design was generally more emphasized in both groups' design process. To conclude, in general, the participants' design process apparently started by identifying design constraints, continued through developing a visual design idea, and ended by considering the technical possibilities of giving the visual idea a more concrete form.

Our expectation had been that subjects having an extensive background in specializing weaving would not differ substantially from each other in terms of working with the composition or construction spaces and dealing with design constraints. Therefore, it appears to be understandable that differences between the groups of advanced students and experts were not statistically significant. It was proposed that designers might represent different types of design orientations according to relative importance, for them as individuals, of processes related to the composition, construction and constraint spaces, which is to say, their design orientation. The significance of design orientation appears to arise from the fact that all participants had a large amount of specialized weaving design knowledge, skills, and experiences. Designers who are familiar with the same professional content still often have entirely different ways of solving design tasks, and their solutions can be of a very different quality as well. Moreover, the course of reaching solutions can also vary in different design tasks. In other words, it was expected that, beyond the level of expertise, each participant would approach the solution of the textile-design task in their own way. Three prototypical design orientations were found. The first orientation emphasized composition designing (participant 1 and 4), the second orientation focused on composition and construction design (participants 2, 5 and 6), whereas the third orientation (participant 3, 7 and 8) emphasized design constraints equally with the two other design spaces in their designing. However, more empirical study on the individual design orientations and their relation to the visual representations and problem structuring phases may be needed, in order to explain satisfactorily individual differences in the design process.

There are multiple ways of expressing one's own design ideas but the choice of medium, such as materials or techniques, constrains one's way through the multitude of possibilities. All design elements are needed for producing a woven textile and, in this sense, equally important (although the relative importance may vary from one to another design). Further, the analysis indicated that the type of production did not completely control how design elements are used; rather, individual characteristics of the designer appeared to have effects, as well as his or her design orientation and expertise. However, the analysis does not indicate that design orientations would represent a permanent propensity to approach design tasks in any particular way: the present study focused on only one design task, thus the results cannot be generalized to other tasks. It is possible that the design orientations emerged from situation-specific or task-related factors, and that the participants would follow different orientations in different kinds of situations. Therefore, the design orientations may be regarded as descriptive categorizations that, in the context of the present study, would help to understand the differences and similarities of the participants. Nonetheless, the skills of the experts in weaving design evidently involved interactive and parallel processing between domain-specific knowledge and domain-general knowledge. The dual-space model of weaving design developed in this study appears to have implications over or above the present study.

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Contributions made by the authors

This study is based on professor Pirita Seitamaa-Hakkarainen’s doctoral thesis. She designed the study, collected the material, and developed methods used in analysis of the data. Dr. Hakkarainen provided theoretical and methodological guidance during the process and participated in writing of the present article. Grants provided by the Academy of Finland for both of the contributors made finishing of this manuscript possible.

Durling D. & Shackleton J. (Eds.) *Common Ground : Design Research Society International Conference 2002*, UK. ISBN 1-904133-11-8