# General Strategic Knowledge Models Connections and Expertise Development in Product Design

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This paper investigates expertise development in design – product (industrial) design in particular. The research concentrates on the modelling of design expertise. The research stands on the premise that knowledge — domain-specific knowledge in particular — plays a significant role in distinguishing a novice from an expert. The knowledge identification is based on the analysis of designers' visuals generated during the early stage (conceptual stage) of the design process. Differences and similarities between novice and expert designers during the early (conceptual) stage of the design process and how they utilise strategic knowledge are outlined. The paper also addresses the transitional process through which a novice becomes an expert and concludes with the finding's implications to design and design education.

This research is a further development of work related to the study of general strategic knowledge models and their interaction with domain-specific knowledge during the early (conceptual) stage of the design process (Popovic 2002). The intention of this work was to illustrate the connections between general knowledge and strategies, and how they interact with the domain-specific design knowledge within two design domains (information and product design). The integrated knowledge connection models presented in this work demonstrated their adaptability and supported the notion of design being an "adaptive expertise" by attempting to find answers to cross-disciplinary utilisation of strategic knowledge and clarification of the utilisation of domain-specific knowledge within the early stage of the design process. However, the main thrust of this paper is on the design expertise and its development within the product design domain.

Expert behaviour relates to the study of knowledge levels. It is founded on the study of how experts process information, and how domain-specific knowledge is represented during the problem solving. There is considerable evidence about differences between novices and experts in knowledge representation, its processing and the way that knowledge is used. Expert performances have been studied in many different domains and different scientific approaches have been used to investigate outstanding performances (Ericsson and Smith 1991, Ericsson and Lehmann 1996, Feltovich, Ford and Hoffman 1997). In general terms, expertise can be defined as "the possession of a large body of knowledge and procedural skills" (Chi, Glaser and Rees 1982). There are diversities observed in experts' performances which are elaborated by Ericsson and Smith (1991) and Holyoak (1991). These authors reviewed the approaches in expertise research with an emphasis on different approaches undertaken in expertise domains. Holyoak (1991) reported on the work of Hatano and Inagaki (1986) and Hatano (1988) and their distinction of two kinds of expertise: (a) routine expertise and (b) adaptive expertise. Routine experts were able to solve familiar problems quickly and accurately, showing an outstanding performance. They did not show the same capabilities when confronted with novel problems. However, adaptive experts were able to adjust to situations and apply new procedures by utilising their expert knowledge.

Expertise in design is understood as the possession of a body of knowledge and the creative and analytical ability to extract, analyse and apply that knowledge. In this work the design is categorised as an "adaptive expertise" (Popovic 2000, 2002) within the framework of the "non-routine activity" of designing (Love 2002) as designers adjust to the design task by utilising their knowledge which they adapt to the current tasks (Suwa, Gero and Purcell 1999).

Within this work strategic knowledge refers to knowledge of processes and strategies that are used during acquisition or utilisation of knowledge (Alexander and Judy 1988). Strategies can be associated within the domain and across the domains. Two categories have been identified – "goal-limited" and "general" strategies. This classification was developed by Pressley et al and reported by Alexander and Judy (1988). Goal-limited strategies (GLS) include processes that are relevant to accomplish tasks while general strategies (GS) are applied on a broader level and might interact with goal-limited strategies (Alexander and Judy 1998, Popovic, 2002).

## 1. Studies of Novice and Expert Designers

There are studies of design activity (Cross, Christiaans and Dorst 1996) or how experts utilise strategic knowledge (Cross 2001). However, there is very limited evidence on designers' progression from a novice to an expert (Eteläpelto 2000).

The concentration of this study is to utilise novices' and experts' design visuals generated as a part of problem solving, during the early (conceptual) stage of the design process. Its objective is to illustrate the connections between general knowledge and strategies and how they interact with domain-specific knowledge. It aims to outline the differences between novices and experts in the product design domain. Popovic (2002) reported on general strategic knowledge models and how they interact with the domain-specific knowledge in design. This work was presented at the Common Ground Conference in the United Kingdom in 2002. This analysis was concentrated on the early (conceptual) stage of the design process and the visuals were analysed only. The designers had dated all visuals and archived them.

Popovic (2002) reported on work of Oxman (2002) who "demonstrated that a high-level domain knowledge of visual form might be seen as cognitive content". In design domain, words, images and shapes in combination or independently are used to communicate the concepts and represent the understanding of the physical world of artifacts. These are the most common media that designers use to interpret and reformulate the design concepts. The visual language (Horn 1998, Bucciarelli 2002) might be the media "to represent classes and structure of domain knowledge" (Oxman 2002) shown in them. This supports the hypothesis that the images and other visuals used by the designers might convey the strategies and knowledge representation within and across design domains" (Popovic 2002). The study presented here is based on the same approach in order to identify the following for both - novices and experts:

general strategies (GS) goal-limited strategies (GLS) domain-specific knowledge (DSK) experiential knowledge (EK) knowledge interaction

The designers' work was selected from the educational context. The complexity of the design projects increased within the level of their expertise. The designers whose work was selected for the purpose of this study are classified as follows:

novice designers - first year undergraduate students; intermediate designers - second and third year undergraduate students; expert designers – post graduate students with practical work experience in product design of three to ten years.

Expertise Level	Design Constraints (Criteria)	GLS (Goal Limited Strategies)	GS (General Strategies)
Novice	One or maximum two design constraints (small "chunks")		Strategies applied to integrate GLS into a satisfactory design outcome.
Intermediate	Several design constraints (criteria) grouped into medium and larger "chunks" (three to ten design constraints).	Processes relevant to accomplish tasks that relate to "chunks" of design constraints (criteria).	
Expert	Design constraints (criteria) grouped together into large complex "chunks".		

Table 1 - Coding scheme

Assumption (ASS)	Knowledge applied that did not contribute to accomplish satisfactory design outcome.	
Domain-specific Knowledge (DSK)	Knowledge applied that contributed to accomplish satisfactory design outcome.	

In order to make this study compatible with the one already reported, the analysis of data was identical (Popovic 2002). The visuals were divided into segments that were numbered and dated. The coding process was done by one person and was repeated three times with an interval break of one week between the coding. The coding scheme was based on the identification of design constraints (criteria) and how designers grouped them in order to achieve satisfactory outcomes (Table 1). Three concept development books were analysed for each designer's category. The characteristic segments were used as representative examples.

#### **1.1** Novice Designers

The work of novice designers (first year students) was based on the analysis of their concept development books at the idea generation stage (beginning of design project). All projects started with analysis and the understanding of the given project brief. The students were asked to design a table marker and active jewellery (wearables). Characteristics of these projects' conceptual stage were that they incorporated 707 segments of goal-limited strategies (GLS) which were domainindependent representations of design criteria or constraints and they used weak methods (Figures 1). It seems that novices' problem representation was based on commonsense knowledge which was domain independent (Anzai 1991). They represented tasks in the form of concrete representations (Adelson 1984). They performed tasks step-by-step, applying knowledge in a more laborious manner by restructuring the problem numerous times before solving it (Figure 1). The number of context and domain-independent goal-limited strategies (GLS) demonstrates this.

Educational research has pointed out that students "may fail to invoke strategies" because they are not aware that they will make any difference (Gardner and Alexander 1989). Novices do not know which procedure will bring them to the task's completion. Therefore, they apply trial-and-error processes. This was demonstrated with the number of assumptions made – 226 assumptions by novice designers.

Figure 1 shows segments from the active jewellery project and demonstrates that goals-limited strategies (GLS) were independent and related to one constraint only. In this case, the novice designer's ' representation tended to be fragmented and superficial. This might due to the structure of his knowledge and supports the notion that novices have weak or unstable representation and therefore weak solution outcome. These segments (Figure 1) illustrate visual thinking regarding various kinds of earpiece design. For example: solar panel on an earpiece or how an earpiece might be held or its form. The constraints that were annotated were interpreted as assumptions (ASS) as they did not contribute to accomplish a satisfactory design outcome. The integration of different design tasks occurred at the end of each project where weak general strategies (GS) were applied in order to achieve an integration of goal-limited strategies (GLS).





#### **1.2 Intermediate Designers**

The intermediate designers were second and third year product (industrial) design students and their concept development books were analysed from the beginning of the design project. The products were a ski holder, cooking utensils, a juicer and a blender. Characteristics of these projects' conceptual stages were that they incorporated fewer segments of goal-limited strategies (GLS). Second year students' conceptual stage contained 371 goal-limited strategies (GLS) while the third year students' conceptual stage had 409 goal-limited strategies (GLS). The decreased number of goal-limited strategies (GLS) demonstrated that the designers acquired some domain-specific knowledge (DSK). This suggests that they started to activate domainspecific knowledge and procedures relevant to a particular task (Figures 2, 3 and 4). This indicated the development of relative stability in their representations (Anzai and Yokoyama 1984). The emergence of the use of general strategic knowledge (GS) is evident. It is clearly exhibited in the concept development books of the third year students (Figures 3 and 4). There is also evidence of the improvement of knowledge organisation and

the grouping of goal-limited strategies (GLS) into more complex "chunks" (Figure 3 and 4).



Figure 2 - Intermediate designers concept development book characteristic example

Figure 2 illustrates an example from the concept development book done by second year undergraduate design students. Goal-limited strategies (GLS) are visible and include larger "chunks". However, a large number of assumptions are still evident. For example: blade support, its shape or finger stop in the case of cooking utensils design are coded as assumptions (ASS) as they are not contributing to the satisfactory task completion. The other segment is from the ski poles project. It is evident that goal-limited strategies (GLS) were larger. It illustrates visual thinking and assumptions (ASS) made about "a good shape to hold" the ski. This segment also illustrates the presence of experiential knowledge (EK) as the designer had an experience in utilising different ski poles.

Figure 3 illustrates two segments from the third year undergraduate concept development books. The design students were asked to design consumer products (blender and juicer). Characteristics for this group of project's conceptual stage were that it incorporated 409 segments of goal-limited strategies (GSK). The first segment (Figure 4) is from the juicer project and shows that the designer was looking for basic manufacturing constraints. It represents a goal-limited strategy (GLS) as it relates to the accomplishment of the task. The annotated constraints were interpreted as domain-specific knowledge (DSK) that was utilised to accomplish the task. For example: 'parting line, snaps between both parts, same mould, produce two sides with snap fits and polypropylene'. At this stage the

designer demonstrated utilisation of domain-specific knowledge (DSK) within the goal-limited strategy (GLS) in order to accomplish the task.



Figure 3 - Intermediate designers concept development book characteristic example



Figure 4 - Intermediate designers concept development book characteristic example

Segment two (Figure 4) is from the blender design project. It is coded as a goal-limited strategy (GLS). It illustrates visual thinking regarding the sequences of how to use the blender. This is coded as domain-specific knowledge (DSK) that is used to accomplish the task. Both examples (Figures 3 and 4) demonstrated that general strategies (GS) were present most of the time and applied to direct the procedures in order to integrate the design tasks

The examples in Figures 3 and 4 illustrated an emergence of expertise which is demonstrated through interaction between goal-limited strategies (GLS) and domain-specific knowledge (DSK). It seems that the intermediate designers accessed this knowledge in more efficient ways than novices did.

# **1.2 Expert designers**

Expert designers were postgraduate students and practicing designers who had the opportunity to propose their own project, generate the proposal and justify the need for the proposed design. The projects analysed were an urban taxi, a workstation for disabled children and a device for concrete reinforcement.

Figures 5 and 6 illustrate segments from the urban taxi design. The segments in figure 5 show that the designer was looking for different possibilities of how to organise the space in the vehicle. This is coded as goal-limited strategy (GLS) as it is related to the particular task accomplishment. The annotated constraints are coded as domain-specific knowledge (DSK) to be utilised to accomplish the task. For example: storage compartment for driver or designated passenger storage. Characteristics of this stage are that it incorporated 377 goal-limited strategies (GLS) across all projects. It seems that the experience level of the designers had contributed to the decrease of goal-limited strategies (GLS) that constituted of variable and large "chunks" (Figures 5 and 6).

Figure 6 illustrates the interface segment of the urban taxi design. The segment shows that the designer was exploring the organisation of the interface. The whole segment was coded as goal-limited strategy (GLS) relevant for the accomplishment of the task. The visual on the interface are coded as domain-specific knowledge (DSK) to be utilised to accomplish the task. For example: "fare meter, CD or air/heat".

Figures 5 and 6 suggest that experts arrive at a solution without extensive search. This is evident from goal-limited strategies (GLS) whose content increased and reflects the findings that experts also have knowledge acquired through experience in their own domain, as well as more episodic knowledge (Visser 1996) that can help them in performing domain-specific tasks better than novices. Staszewski (1988) suggested that the development of expert skills depends on their understanding of how to use domain-specific knowledge effectively and efficiently, and that "skilled memory represents a general component of expert knowledge across a wide range of cognitive skills". This is evident from interaction of goal-

limited strategies (GLS) and domain specific knowledge (DSK) (Figures 5, 6 and 9).



Figure 5 - Expert designers concept development book characteristic example



Figure 6 - Expert designers concept development book characteristic example

The expert designers exhibited the superior ability to perceive large, meaningful patterns in their own domain which reflects an organisation of the knowledge base they have about the problem. The perceptual 'chunk' size is larger for an expert (Newell and Simon 1972, Chase and Simon 1973). This is evident in other domains such as architecture (Akin 1986), geometry (Koedinger and Anderson 1990) and computer programming (Soloway, Adelson and Ehrlich 1988). During their development of a model of skilled performance in geometry, Koedinger and Anderson (1990) found that experts' "step skipping can be captured by knowledge structures that are cued by images in the problem diagram". They claimed that this example illustrates that the diagram was aiding the knowledge search. This might be relevant to the expert designers' utilisation of visuals while they search for knowledge (Popovic 2002). Experts have domain-specific knowledge and are able to perceive large and meaningful patterns in the visuals they developed (Figures 5 and 6). Variable and larger "chunks" of goal- limited strategies (GLS) support this.

Different research demonstrated that experts conduct qualitative analysis while forming a representation (Reimann and Chi 1989) which is rich and more abstract than that of novices. They focus on the key performance steps and skip the ones that are unnecessary (Koedinger and Anderson 1990). In general, experts' representations are more abstract and contain information on what a particular task would achieve in terms of what is to be done, but not in terms of how they are going to do it (Adelson 1984). It seems that through their expertise, experts know how to perform tasks without having access to their detailed representations. This is demonstrated in figures 5 and 6, as the designer's representation was more abstract. He outlined different tasks in terms of what to be done but not how he would do it.

## 2. Knowledge Connection Models

This work stands on the premise that the design visuals provide a rich source of information to analyse the part of the design process that is understood to be the most innovative within the design process. Knowledge connection models were developed on two premises: (a) planning and (b) design. The domain studied was a product (industrial) design and the study included different level of design expertise - novice, intermediate and expert designers. The models developed have structural variations dependent on a designer's level of expertise. They are descriptive models representing the novice - expert designer developmental process. Their representational choices dictate how the selected variables can be best represented as to relate to the design process and to demonstrate novice - expert differences. Therefore, each model is a representation of the progressive development at that particular level of expertise - novice, intermediate and expert. Its graphic representation is shown in four sequences that represent the design process and the progressive steps from start to finish of the design project and attempts to demonstrate that design is an "adaptive expertise". It shows how the acquisition of domain-specific knowledge contributes to the acquisition of expertise. This is demonstrated in the increase of the goallimited strategies content and their grouping. Thus, the graphics signify the representation of goal-limited strategies (GLS), general strategies (GS) and domain-specific knowledge (DSK) connections. The subsequent set of modelling dimensions allows describing the apparent differences between the models, along with their significant structural variations.

#### 2.1 Novice Designer Knowledge Connection Model

Figure 7 illustrates the progressive development of the novice model and its transformation during the design process. After an interpretation of the brief novice designers developed goal-limited strategies (GLS) that have very weak content (Figures 2) eg one design constraint independently associated with the general strategy (GS) and most of the goal-limited strategies knowledge connections were interacting with designers' assumptions (Figure 7a) During the project progressions the novice designer grouped associated goal-limited strategies (GLS) and applied very weak general strategies (GS) (Figure 7 b, c and d). During the design process they brought in domain-specific knowledge (DSK) which assisted them with better interaction with goal-limited strategies (GLS) and general strategic knowledge (GS) (Figure 7c and d). The characteristics for this model of knowledge connection are:

goal-limited strategies with weak content assumptions very weak domain-specific knowledge limited experiential knowledge general strategies very weak



Figure 7 - Progressive development of novice designer knowledge connection model

## 2.2 Intermediate Designer Knowledge Connection Model

Figure 8 illustrates the knowledge connection model based on the designers' concept development books analysis (Figures 2) and their contextual relationships. The model illustrates that the number of goallimited strategies (GLS) decreased. Some assumptions (ASS) were replaced with the domain-specific knowledge (DSK) (Figure 8c and d). There was evidence of experiential knowledge (EK) as well. The characteristics for this model of knowledge connection are:

goal-limited strategies weak but some of them are grouped together fewer assumptions more presence of domain-specific knowledge limited experiential knowledge general strategies weak



Figure 8 - Progressive development of weak intermediate designer knowledge connection model

Figure 9 shows the progression in knowledge development within the projects whose complexity was increased. The model shows the integration of constraints very early during the design process (Figure 9b). The designers started to group design constraints on the basis of information available. Therefore goal-limited strategies (GLS) contained rich data. The emergence of general strategies that were well defined was evident (Figure 9). This is attributed to the presence of domain-specific knowledge (DSK) that replaced assumptions (ASS). However, some of the

assumptions were still present within the projects. The characteristics for this model of knowledge connection are:

goal-limited strategies rich and grouped together very weak assumptions domain-specific knowledge experiential knowledge general strategies better developed



Figure 9 - Progressive development of strong intermediate designer knowledge connection model



Figure 10 Progressive development of expert designer knowledge connection model

## 2.3 Expert Designer Knowledge Connection Model

The expert designers' knowledge connection model is presented in figure 10. This model was developed and reported earlier (Popovic 2002). Goallimited strategies were determined by project constraints. Their expansion depended on the number of constraints taken in consideration. When all constraints were explored they were integrated by utilising relevant strategies to control the integration of the tasks.

The characteristics for this model of knowledge connection are:

goal-limited strategies rich and grouped together domain-specific knowledge experiential knowledge general strategies well developed

#### **3. Expertise Development**

Figure 11 illustrates the descriptive models showing differences between novice and expert designers' knowledge connections. The development process from a novice to an expert is evident. It demonstrates that experts and novices differ in how they organise knowledge, the amount of information they use, how they access the domain-specific knowledge (DSK) and how they apply domain-specific and goal-limited strategies (GLS). The characteristics of experts are studied in relation to the tasks they are doing. The relevant findings are used to support the evidence of this study (Ericsson and Smith 1991 and Popovic 1988).



Figure 11 - Comparisons of models and knowledge connections – expertise development

The knowledge connection model of expert designers demonstrates their superiority within the domain of product (industrial) design. The evidence that experts are superior in their own domains mainly (Voss and Post 1988, Staszewski 1988) supports this. The common outcome of this research was that non-domain experts solve problems in ways similar to those used by novices. Non-domain experts usually described problems at very concrete and specific levels. Contrary to this, domain experts used more abstract categories for description. The explanation for this is that experts have more knowledge in their own domain (which justifies their performance or problem solving superiority). Experts access that knowledge in more efficient ways than novices do (Kolodner 1983) and demonstrate an "intuitive" performance (Blackler, Popovic and Mahar 2001).

Intermediate designers' knowledge model connections (Figures 8 and 9) demonstrated development of product design expertise. There are studies which show that novices "acquired a good deal of strategic competence in using domain-specific methods" (Eteläpelto 2000). This competence development occurred at an intermediate level where the designers acquired knowledge and strategies as they went thought the design process.

The model presented, reflected and supported the findings that domain knowledge is necessary for successful problem solving or task execution. Experts have a good deal of knowledge in their own domain which justifies their performance or problem solving superiority. They access that knowledge in more-efficient ways than novices do and have experience in their own domain. The categorisation studies demonstrate that "experts can encode the problem into deep levels of representation, which enable them to grossly determine the solution method applicable to the problem" (Chi, Glaser and Rees 1982). It is assumed that the experts' knowledge base contributes to this. They explore a problem or task by utilising their domain-specific knowledge (Reimann and Chi 1989).

The evidence shows that experts start with the data variable and work toward the achievement of goals. Backward and forward reasoning were observed in task-based processes where perceptual skills were required, and experts demonstrated more-coherent task representations. This is represented in figures 5, 6 and 10. Novice designers' representations were fragmented into small "chunks" (Figures 1 and 7). Experts have better task representations and therefore better solution outcomes. Nevertheless, it should be noted that experts do not always use forward reasoning and work forward from the problem given. In some domains the given information is inadequate to solve the problem by using forward reasoning. Koedinger and Anderson, (1990) reported on the study of Anderson et al. (1981) in which they studied expert computer programmers who worked from a given goal, such as program specification. It seems that experts used forward reasoning in an information-rich well-defined problem solving domain, while in an illdefined problem solving domain they worked backward from the goal information. This is represented in Figures 4, 5, 6 and 7.

Expert designers had a tendency to start inferences from the information directly available in the design project and to infer in many domains. This is related to the experts' forward reasoning and the application of working-forward strategies that are learned as domain-specific procedures (Simon and Simon 1978, Larkin et al 1980, Anzai 1991). This also suggests that experts possess proceduralisation of domain knowledge which contributes to efficiently doing tasks or solving problems (Anzai 1991). This suggests that experts are able to decide early, the best representation in order to solve the problem or successfully perform the task. The research of Anzai and Yokoyama (1984) suggested that the internal model shift is related to the "attentional cues" and domainspecific knowledge. Experts activate domain-specific knowledge and procedures relevant to a particular task. This suggests relative stability in their representations and supports the interaction among goal-limited strategies (GLS), domain-specific knowledge (DSK) and general strategies (GK).

The models represented indicate the development of design expertise focusing on the importance of domain-specific knowledge (DSK) and how this knowledge interacts with the goal-limited strategies (GLS) and general strategic knowledge (GS). The results indicate that novices focus on problem decomposition, based on the design constraints separated into small "chunks" of goal-limited strategies (GLS) while the expert designers utilised large "chunks" of goal-limited strategies (GLS). The overall design solution was monitored by general strategies (GS) that were weak and unstable among the novice designers but stable among the experts. Table 2 illustrates the summary of the novice – expert designer differences as illustrated in the models.

Novice Designer		Expert Designer
Weak content of goal-limited strategies (GLS). Small "chunks".	$\triangleright$	Rich content of goal-limited strategies (GLS). Very large "chunks".
Very weak domain-specific knowledge (DSK).		Possession of domain-specific knowledge (DSK).
A lot of assumptions (ASS)		Very weak assumptions (ASS)
Limited experiential knowledge (EK)		Possession of experiential knowledge (EK)
General strategies (GS) very weak		General strategies (GS) well developed

Table 2 - Summary of the novice – expert designer differences

The thrust of this work was on describing the progression process of expertise development within the product design domain and to infer the differences between the novice and expert designers. The findings demonstrate the approach to design expertise development regarding the decomposition of the design projects into "chunks" of goal-limited strategies (GLS). It shows the significance of domain-specific knowledge (DSK) in expertise development that is demonstrated by the increase of the content of goal-limited strategies (GLS), which is supported by theoretical construct discussed earlier in this paper.

However, this work differs from that discussed earlier in that its emphasis is focused on the product design domain and analysis of designers' visuals from which it was possible to infer the development of expertise, and outline the differences between novices and experts in that particular domain. The advantage is that this work is based on the analysis of designers' visuals from which the structure of knowledge is captured.

#### 4. Conclusion

The level of expertise plays an important role in problem representation. This is demonstrated by studying different levels of expertise during the early (conceptual) stage of the design process. However, the study of representation of knowledge from visual data is very rarely studied with some exceptions (Goel 1995, Casakin and Goldschmith1999, Oxman 2002, Popovic 2002). It is evident, from this work, that the visual language that designers use can be seen as sources that contribute to distinguish their level of expertise. This is the language of design that represents their thoughts and knowledge, or new thought generation and stimulates new creative and analytical thinking. The knowledge connection models presented support the notion of design being an "adaptive expertise".

However, the main strength of this work is that it describes expertise development through successive stages of the product design concept generation process. Its advantage is that it has opened an avenue for better understanding of the importance of interaction among general strategies (GS), goal-limited strategies (GLS), domain-specific knowledge (DSK) and experiential knowledge (EK). The structure of knowledge captured from the analysis of the designers' visuals can be utilized to support the novice - expert transitional process better, by providing the direction for the integration and connections among the model variables. This might have an implication on design education in order to determine how and when the domain-specific knowledge (DSK) is to be introduced to the students during the design process.

This work was done within an educational context. In order to verify the models and compare the differences in designers' strategic approaches further studies are to be undertaken. This might include the analysis of work of product designers from different cultural and educational backgrounds. In conclusion, these descriptive models can contribute toward better understanding of product design expertise and its development.

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