Solution driven versus problem driven design: strategies and outcomes

Journal Item

Design Studies, Vol. 27, No. 5, pp. 527-548, 2006

Solution driven versus problem driven design: strategies and outcomes

Corinne Kruger
School of Industrial Design Engineering
Delft University of Technology
2628 CE Delft, The Netherlands

Nigel Cross
Department of Design and Innovation
The Open University
Milton Keynes MK7 6AA, Great Britain

Data from protocol studies of nine experienced industrial designers, performing the same task, were analysed to develop an expertise model of the product design process. The protocol data and the expertise model were used to identify four different cognitive strategies employed by the designers: problem driven, solution driven, information driven, and knowledge driven design strategies. These strategies were then related to task outcomes such as solution quality and creativity, and to process aspects such as iterative activity. The different strategies appear not to be related to overall solution quality in any straightforward manner. Designers using a solution driven strategy tended to have lower overall solution quality scores but higher creativity scores. Designers using a problem driven design strategy tended to produce the best results in terms of the balance of both overall solution quality and creativity.

Keywords: Cognitive strategies, design process, protocol studies

In concluding a recent review article on expertise in design, Cross (2004) suggested that 'expert designers appear to be "ill-behaved" problem solvers', especially in respect of their focus on solution generation, rather than problem analysis. This aspect of design cognition has been observed many times, and can be traced back to Lawson's (1979) formalised problem solving experiments with science and architecture students, from which he categorised their problem solving strategies as either 'problem focused' or 'solution focused', and claimed the latter as being more characteristic of design-based problem solving.

The recent focus of studies in design cognition has been through the use of protocol studies (Cross, Christiaans and Dorst, 1996). Many studies have relied on experiments and observations with student designers, rather than experienced, practising designers possessing more mature cognitive strategies. However, Dorst (1997) provided a study of design processes derived from protocol studies of experienced industrial designers, and Dorst and Cross (2001) related these to a problem-solution co-evolution model of creative design. Dorst and Cross reported examples of co-evolution in which the designer formulates a partial structuring of the problem-space and then transfers that partial structure into the solution-space, and so develops both problem and solution in parallel. They suggested that there were also converse cases in which solution structuring preceded problem structuring, that is, in which the designer first identifies a partial structure in the solution space, such as a preferred shape or form, and then uses that to structure the problem space. These two variant strategies of co-evolution might be labelled as 'problem driven' and 'solution driven' design strategies. Following Lawson (1979) and others, solution driven strategies might be expected to be the dominant form in design.

For some time, there has also been interest in relationships between cognitive style, design strategy and design performance (Cross, 1985; Kvan and Yunyan, 2005). In the study reported here, a fuller analysis has been made of the cognitive strategies employed by the nine designers who were the participants in the protocol studies of Dorst. We found that not only were both problem driven and solution driven strategies employed, but also some sub-variants. For example, a variant of problem driven design is information driven design; a variant of solution driven design is knowledge driven design. Different designers appear to use different cognitive strategies. In this paper, we provide empirical evidence of these different strategies, and also relate the strategies to design performance, including the quality of the outcomes (the solution concepts) produced by the designers.

1 The protocol study

The empirical basis of this research consisted of protocol studies of nine experienced industrial designers (with a minimum of five years post-graduation practice experience) working on a small design assignment in a laboratory setting (Dorst, 1997). This empirical study developed from earlier work based on the study of student designers, which included procedures to measure the perceived creativity and the overall quality of the resulting designs (Christiaans, 1992).

1.1 Experimental procedure

The assignment (the design problem or brief) developed for these studies by Dorst was to create a concept design for a 'litter disposal system' in a new Netherlands train. This problem is typical as far as industrial design practice is concerned, in that it calls for the integration of a variety of aspects, such as ergonomics, manufacturing, engineering, aesthetics and business aspects. The written design brief (Figure 1) outlined the problem, introduced the stakeholders and defined the designer's position.

The experiments were conducted as 'think-aloud' protocol studies (Ericsson and Simon, 1993; van Someren et al., 1994). The designers (each working alone) were requested to think aloud as they were solving the design problem, and the design session was preceded by a short training exercise, to help them become accustomed to thinking aloud. The design brief was then given to the designer. The time allotted was 2.5 hours. The sessions were recorded by two high-level video cameras in the corners of the room; one pointing down at the designer to capture sketching and drawing behaviour, and one to take a general picture.

Insert Figure 1 The design brief

1.2 Design quality measurement

In these studies, the interest was not only in the design process but also in the design outcomes – that is, in qualitative aspects of the resulting design concepts produced by the designers. Assessments of the design concepts were made by independent, skilled assessors. (See Dorst, 1997, for a full description of the assessment procedure.) Each of the nine design concepts produced was assessed independently by five design teachers from the TU Delft Faculty of Industrial Design Engineering, all of whom are also practising designers. In a randomised assessment procedure, different scoring categories were used: creativity, aesthetics, technical aspects, ergonomics and business aspects. Each judge graded the concepts individually in each category. Finally, the judges were asked to give a total or overall judgement of the concepts. Thus the 'total' judgement is not a mean of the other scores, but a separate, 'overall impression' score.

1.3 Results

An overview of the scores awarded for each design on the different aspects is given in Table 1. The concepts of Designers 3 and 4 clearly stand out as the best on most aspects. Design concept 8 was considered the worst overall, although scoring high on creativity. There appear to be some 'anomalies' in the results, such as where the 'total judgement' score is lower than any of the individual aspect scores (Designers 2, 5 and 8), suggesting that the overall judgement score is independent of the individual aspect scores.

Figure 2 shows a scattergram for the 'creativity' scores of the design concepts against the 'total judgement' scores. It shows that, on the whole, the more creative designs were considered better in the total judgement, with Design 8 being an exception to this general trend. So it may be that creativity is normally regarded as a significant aspect of an overall 'good' design. However, 'creative' design is not necessarily 'good' design. For example, Design 8 scores high on creativity, but low on overall quality. It therefore provides an interesting observation on the role of creativity within the total set of design goals. A designer's aim normally is to achieve a high-quality design, with newness, novelty or creativity being treated as only one aspect of an overall, integrated design concept.

TABLE 1 The mean scores of all judges (on a 1 to 10 scale)

Concept	ergonomics	technical aspects	aesthetics	business aspects	creativity	total judgement
D 1	4.2	6.4	6.4	6.6	3.8	3.8
D 2	6.2	6.2	6.2	6.4	4.8	4.6
D 3	8.6	6.6	5.2	5.4	7.6	6.6
D 4	7.2	7.0	8.4	7.8	6.4	7.0
D 5	6.6	6.4	5.0	6.4	5.2	4.8
D 6	4.6	6.4	6.6	5.6	5.0	5.6
D 7	6.0	7.2	2.6	4.8	3.2	3.8
D 8	3.8	5.0	4.8	5.0	6.8	3.4
D 9	4.8	6.6	6.0	6.8	3.4	5.4

Insert Figure 2 Scattergram for the means of 'total judgement' and 'creativity'

2 An expertise model of the product design process

In order to study the cognitive strategies employed by the designers, a conceptual model of the product design process was developed (Kruger, 1999). This model was based on empirical data derived from the protocol studies, analysed with the aid of the CommonKADS conceptual modelling language (Wielinga et al., 1993; Schreiber et al., 1994). CommonKADS offers a methodology for constructing knowledge based systems, which can also be used as a cognitive modelling tool. An *expertise model* was developed; a model of the problem solving behaviour of an agent in terms of knowledge that is being applied in carrying out a certain task. An expertise model consists of *application knowledge* and *problem solving knowledge*. Application knowledge consists of task knowledge, inference knowledge and domain knowledge. These are the primary epistemological categories in CommonKADS. Problem solving knowledge consists of problem solving methods and strategic knowledge.

The expertise model shown in Figure 3 was developed. It comprises the following tasks or activities:

1 *Gather* data
2 *Assess* value and validity of data

3 *Identify* constraints and requirements
4 *Model* behaviour and environment
5 *Define* problems and possibilities
6 *Generate* partial solutions
7 *Evaluate* solutions
8 *Assemble* a coherent solution

The model is not dis-similar to other models of the engineering product design process (see Cross, 2000). A significant additional feature in this model is the *model* task, which was identified from the designers' protocols. In the *model* task, a designer forms a mental image (sometimes using sketches to aid this) of the object to be designed, within its environment of use. For example, a designer might report imagining sitting on a train and having to reach across other passengers to use the litter bin. Thus some implicit constraints and/or requirements might be derived in this way.

Insert Figure 3 The derived expertise model of product design

3 Evidence of different cognitive strategies

We can use the empirical data from the protocol studies to categorise each designer according to the design strategies they appeared to operate. The designers' protocol statements were encoded according to the eight categories of tasks or activities identified in the expertise model. In Table 2 the percentages of frequencies of coded protocol statements per activity of the nine participants are shown. The amount of statements made within each category is an indicator of the amount of time and attention a designer gave to each activity. The frequencies data indicate some basic differences in the design strategies used by the designers. For example, Designers 1, 4 and 5 have relatively higher percentages of statements in the categories of data gathering and identifying constraints than they do in other categories (except generate). We identify their strategy as 'problem driven'. A variant of this appears with Designer 9, who has a very high frequency in data gathering and a much lower frequency in solution generating; we identify this strategy as 'information driven'. Designers 3, 7 and 8 have high frequencies in generating and assembling solutions, and can be categorised as using a 'solution driven' strategy, whereas Designers 2 and 6 have a high frequency of modelling activity (i.e. utilising prior knowledge) and can be categorised as using a 'knowledge driven' strategy.

TABLE 2 Percentages of statements per task in verbal protocols of the nine participants.

Designer ---------- Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**mean**
Gather	19	6	13	17	15	18	18	4	39	16.5
Assess	2	1	2	2	1	2	1	0	2	1.4
Identify	21	17	19	25	27	17	18	16	28	20.9
Model	0	15	3	1	2	17	0	2	1	4.6
Define	3	4	0	5	7	4	2	4	3	3.6
Generate	28	31	28	27	29	13	37	39	16	26.9
Evaluate	13	2	8	5	3	10	3	12	1	6.3
Assemble	8	4	12	11	3	3	1	10	1	5.9
Strategy type	P	K	S	P	P	K	S	S	I	

P = Problem driven strategy I = Information driven strategy
S = Solution driven strategy K = Knowledge driven strategy

On the basis of the data analysis, and on the evidence of the designers' behaviour from the verbal protocols, we identified the following four design strategies.

Problem driven design: the designer focuses closely on the problem at hand and only uses information and knowledge that is strictly needed to solve the problem. The emphasis lies on defining the problem, and finding a solution as soon as possible.

Solution driven design: the designer focuses on generating solutions, and only gathers information that is needed to further develop a solution. The emphasis lies on generating solutions, and little time is spent on defining the problem, which may be reframed to suit an emerging solution.

Information driven design: the designer focuses on gathering information from external sources, and develops a solution on the basis of this information.

Knowledge driven design: the designer focuses on using prior, structured, personal knowledge, and develops a solution on the basis of this knowledge. Only minimal necessary information from external sources is gathered.

The differences between designers, suggesting their different strategies, are indicated graphically in Figures 4 and 5, where scattergrams of the percentage frequencies of activity statements for the nine designers are shown. The abscissa in each scattergram represents the activities in the following order: 1 Gather data, 2 Assess, 3 Identify, 4 Model, 5 Define, 6 Generate, 7 Evaluate and 8 Assemble. The different patterns of higher frequency scores in different design strategies have been highlighted in the scattergrams. For almost all designers, the most frequent activities are those of *gather* data, *identify* constraints and requirements and *generate* partial solutions. As can be seen in the scattergrams, solution driven designers put a greater emphasis on solution generation, exhibiting a much higher frequency of *generate* activities relative to *gather* and *identify* activities (more sharply-upward sloping ellipses encompassing these three frequencies). Problem driven designers exhibit a flatter pattern, and in the extreme case of the information driven designer 9, the encompassing ellipse slopes in the reverse direction, with *gather* and *identify* activities having much higher frequencies than *generate* activities. For knowledge driven designers, the key factor is the relatively high frequency of the *model* activity.

Differences between solution driven and problem driven strategies can also be verified numerically. A solution driven versus problem driven index (S/P index) can be generated for each designer by computing the ratio of *generate* activities to the mean of *gather* and *identify* activities. The S/P indices are 1.75, 2.0 and 3.9 for designers 3,7 and 8 respectively (solution driven designers), and 1.4, 1.3 and 1.4 for designers 1, 4 and 5 respectively (problem driven designers).

Insert Figure 4 Scattergrams of activities of problem driven and solution driven designers.

Insert Figure 5 Scattergrams of activities of information driven and knowledge driven designers.

3.1 The derived cognitive strategies

The rationale for the categorisation of strategies is based on the main activity generators of the design process, which are: the problem, gathered information, generated solution ideas, and prior knowledge. The choice of the generator will depend on the particular situation in the design process and the general preference (perhaps the cognitive style) of the particular designer. Here it is suggested that differences between design processes and their outcomes are the consequence of the application of strategic knowledge. Strategic knowledge is knowledge of design strategies and how to apply them. In the following descriptions, derived from the protocol studies, the influences of different strategies on the design process, and their likely effects on the outcome of the design process are assessed.

- **Problem driven design**

In problem driven design, the designer characteristically pays attention to carefully reading the design assignment. The designer’s focus is on understanding and defining the given problem. Information that has a direct bearing on requirements and constraints is selected and given emphasis. The search for information is not exhaustive, but focused on defining the problem. Soon after reading the design assignment and gathering the minimal necessary information the next step of defining the design problem is taken. During the process of defining the problem new information is gathered, but only if it is needed to further formulate the problem. Information is treated as a source to be used only when absolutely necessary. Little time is spent enlarging the information space by looking for topics that are not directly related to the design problem.

The problem driven strategy results in either a highly defined problem, that leaves little room for solution alternatives, or a problem that is defined on an abstract level, that does leave more room for alternative solutions. The solutions and the final design either reflect the highly specified problem, or the more abstract defined problem. In either case the generating of solutions is strongly focused. An expected result would be that fewer alternative solutions are generated. This does not necessarily mean that the quality of the solution is lower. The evaluation of solutions in this strategy is requirement orientated.

The knowledge used in the strategy is knowledge about structuring and abstracting or refining problems. This knowledge may be based on knowledge of former related cases. Knowledge of former cases may be used for establishing general problem structures or as a general frame of reference.

- **Solution driven design**

In solution driven design, the assignment is quickly scanned for basic requirements. The design problem remains ill-defined. The designer skips the Assess task. On the basis of this ill-defined design problem, solutions are generated. Only if information is needed for certain solutions will information be gathered. So only very specific information on certain topics is gathered. Little time is spent in enlarging the information space by looking for topics that do not seem to have an immediate bearing on the solution or design problem.

The process consists of a short problem analysis stage, and long generate and evaluation stages, with short steps back to the analysis stage. In solution driven design the amount of time spent in the analysis stage is similar to information driven design, but instead of gathering information, knowledge is retrieved from memory. More time is spent in generating solutions, and a larger number of solutions are generated than in problem driven and information driven design. These solutions are possibly qualitatively more varied because of the larger search space that is the result of leaving the design problem ill-defined. The evaluation of solutions has the function of further defining or reframing the design problem; the evaluation is solution orientated.

In solution driven design the design solution is based on a large amount of knowledge. The use of knowledge is intensive, for example knowledge of similar design problems and their solutions, and knowledge from individual experience. New developments might be overlooked, but the solution is less dependent on the information available at that particular moment.

- **Information driven design**

In information driven design the designer spends a lot of time reading the design assignment and gathering information. The strategy while reading the assignment is to look for pointers to other information sources. During this reading, questions are asked when ambiguities arise in the design assignment or an information source. The definition of the design problem is based on the design assignment and the information that is gathered. As in problem driven design, in information driven design the designer tries to define the design problem as strictly as possible. However, in information driven design, the data gathering is aimed at fuller information.

The design solution reflects the requirements found in the design assignment and the information gathered, as opposed to a more individual view on the necessary solution, as may be found in solution driven or knowledge driven design. The generating of design solutions is focused, the strict problem definition strongly directs the generating of solutions. This also influences the number of proposed solutions, which is expected to be low. Solutions are evaluated thoroughly with criteria established on the basis of the information gathered, as opposed to evaluating solutions on the basis of general design criteria as in knowledge driven design. The evaluation is requirement orientated.

Domain knowledge is used less than in knowledge driven design, the emphasis lies on gathering information, and use of this information as the basis for further design activities. The knowledge that is used is mostly process knowledge on how to gather and structure information. The process shows a long information gathering stage, with less time spent in defining the problem and on generating solutions.

- **Knowledge driven design**

In knowledge driven design the assignment is read carefully, and is compared to knowledge about similar problems. Those aspects that seem new are explored through gathering information. The designer takes the knowledge they already have as the basis for proceeding. Only when this knowledge appears to have shortcomings is new information gathered. The existing knowledge is not compared with the state of the art at that moment. This strategy shows less time expended during the information gathering stage.

The design problem is defined with clear links to existing knowledge about the problem. Knowledge about similar solutions is used for generating design solutions rather than developing entirely new solutions. In knowledge driven design the emphasis lies on retrieving knowledge from memory rather than gathering information. Knowledge driven design therefore depends heavily on prior knowledge, and this knowledge is used during the solution generating stage. In knowledge driven design this knowledge is also used during the definition of the problem. So in knowledge driven design there is a relatively long analysis stage, followed by a shorter synthesis stage.

4 Strategies versus outcomes

The design strategies described in the previous section are summaries or categorisations, based on the data and a global overview of the protocol studies of the nine designers. The strategies might be assessed by treating them as hypotheses of designer behaviour. The strategy descriptions give rise to some expectations of behaviour and outcomes, as in Table 3. For example, we expect problem driven design to result in the generation of only a few solution ideas and low creativity of solution, whereas we expect the reverse outcomes in solution driven design. To attempt to verify these expectations, we will summarise results obtained from the data of the protocol and then compare the expectations against the results.

TABLE 3 Expectations about design strategies

Outcomes	*Problem driven design*	*Solution driven design*
Solution ideas	Few	Many
Requirements identified	Many	Few
Activities	Emphasis on problem defining	Emphasis on solution generating
Solution score: Creativity	Low	High
Overall	High	Low
Outcomes	*Information driven design*	*Knowledge driven design*
Solution ideas	Few	Few
Requirements identified	Many	Few
Activities	Emphasis on data gathering	Emphasis on modelling
Solution score: Creativity	Low	High
Overall	High	Low

4.1 Solution quality

As mentioned earlier, all the final solutions developed by the designers were rigorously assessed, not only for overall quality of the design solution but also on a set of sub-aspects – creativity, aesthetics, technical, commercial and ergonomic aspects. We can now relate the designers' strategies to the scores for their solutions on these aspects and on overall quality. Table 4 shows the rank order of the designers according to their overall quality score, with their strategies, as identified above. Table 5 shows the mean overall quality scores achieved by the designers grouped into their types of strategy.

Table 5 suggests that there may in general be a slightly higher quality score achieved by designers using problem driven and information driven strategies, although Table 4 shows that the overall quality score varies considerably against the strategy followed, and therefore cannot be claimed to relate strongly to any of the strategies. Also note that only one designer used the information driven strategy.

TABLE 4 Overall solution quality against design strategy

Designer	Score	Strategy
4	7.0	Problem driven
3	6.6	Solution driven
6	5.6	Knowledge driven
9	5.4	Information driven
5	4.8	Problem driven
2	4.6	Knowledge driven
1	3.8	Problem driven
7	3.8	Solution driven
8	3.4	Solution driven
	Mean: 5.0	

TABLE 5 Mean overall solution quality score by design strategy

Mean	Strategy
5.4	Information driven
5.2	Problem driven
5.1	Knowledge driven
4.6	Solution driven
Mean: 5.0	

4.2 Creativity

Table 6 shows the rank order of the designers according to the creativity score for their solutions, against strategy type. Again, there is considerable variation of strategy type against the individual designers' scores. However, Table 7 shows the mean creativity score for each design strategy, and shows that solution driven design resulted in an average creativity score well above the mean, even though Designer 7 (solution driven) had the lowest individual creativity score. On the basis of these data it may be suggested that the creativity score is related to the design strategy.

TABLE 6 Creativity score against design strategy

Designer	Score	Strategy
3	7.6	Solution driven
8	6.8	Solution driven
4	6.4	Problem driven
5	5.2	Problem driven
6	5.0	Knowledge driven
2	4.8	Knowledge driven
1	3.8	Problem driven
9	3.4	Information driven
7	3.2	Solution driven
	Mean: 5.1	

TABLE 7 Mean creativity score by design strategy

Mean	Strategy
5.9	Solution driven
5.1	Problem driven
4.9	Knowledge driven
3.4	Information driven
Mean: 5.1	

4.3 Other aspects

Table 8 shows the individual designers' scores on the other four solution aspects that were assessed as well as creativity. Grouping the designers by strategy, and considering the mean scores by strategy over the various aspects, suggests that a problem driven strategy almost always results in a higher score. The exceptions are on the creativity and ergonomic aspects, where a solution driven strategy scores higher. However, there are strong individual variations between designers. For example, whilst Designer 4 has high scores across all aspects, most designers have low scores on at least one or two aspects.

TABLE 8 Designers' scores on all solution aspects

Designer	Strategy	aesthetic	technical	commercial	ergonomic	creative
1	Problem driven	6.4	6.4	6.6	4.2	3.8
4	Problem driven	8.4	7.0	7.8	7.2	6.4
5	Problem driven	5.0	6.4	6.4	6.6	5.2
	Mean	6.6	6.6	6.9	6.0	5.1
3	Solution driven	5.2	6.6	5.4	8.6	7.6
7	Solution driven	2.6	7.2	4.8	6.0	3.2
8	Solution driven	4.8	5.0	5.0	3.8	6.8
	Mean	4.2	6.3	5.1	6.1	5.9
2	Knowledge driven	6.2	6.2	6.4	6.2	4.8
6	Knowledge driven	6.6	6.4	5.6	4.6	5.0
	Mean	6.4	6.3	6.0	5.4	4.9
9	Information driven	6.0	6.6	6.8	4.8	3.4

4.4 Number of solution ideas

In Table 9 the number of solution ideas per designer is given. This number is derived by counting all different partial and full solutions identified in the generate and assemble activities per participant. The number of solution ideas varies widely among the participants. Correlation coefficients show that there is no relation between the number of solution ideas and the creativity of the end result, i.e. with the creativity score. However there is a reasonably strong negative relation between number of solution ideas and the overall quality score ($C = -0.47$, $R = 0.23$). That is, the more partial or full solutions identified, the lower the overall quality score.

Table 10 shows the mean number of solution ideas of the participants grouped by design strategy. As would be expected, the number of solution ideas in relation to the design strategies shows that the solution driven strategy generates above average number of solution ideas. However, this is also true of the problem driven strategy.

TABLE 9 Number of solution ideas against design strategy

Designer	Solutions	Strategy
8	49	Solution driven
1	44	Problem driven
4	37	Problem driven
7	37	Solution driven
3	28	Solution driven
2	26	Knowledge driven
6	25	Knowledge driven
5	16	Problem driven
9	14	Information driven
	Mean: 30.7	

TABLE 10 Mean number of solution ideas by design strategy

Solutions	Strategy
38	Solution driven
32.3	Problem driven
25.5	Knowledge driven
14	Information driven
Mean: 30.7	

4.5 Design process

The empirical data from the protocol studies can also be examined for evidence related to general process features. Table 11 is an aggregate transition matrix, showing the mean percentages of transitions made between the separate activities, for all nine designers. A transition occurs when a protocol statement of one category type is immediately followed by a statement of another type. Thus, for example, a transition from Activity 1, gathering data, was made to Activity 2, assessment of information, 7.1% of the time, or to Activity 3, identifying requirements or constraints, 12.4% of the time, averaged over all nine designers. The ninth activity covers strategic remarks made by the designers, such as, 'This is taking too much time, I need to start generating solutions.'

The transition matrix data indicate that, in general, a strong iterative loop of activities occurs within the overall process, around Activities 1, 2 and 3, gathering and assessing data and identifying constraints or requirements. There is a weaker iterative loop between Activities 6, 7 and 8, generating, evaluating and assembling solutions. However, there are considerable differences between designers in the number and pattern of transitions, and the frequency of iterations that they make.

TABLE 11 Matrix of mean percentage transitions between activities

To Activity \ From Activity	1	2	3	4	5	6	7	8	S
1	-	3.5	13.4	1.0	0.5	3.0	0.6	0	5.4
2	7.1	-	0.3	0	0	0.1	0.1	0	0.1
3	12.4	2.6	-	1.0	0.6	0.7	0.5	0	3.8
4	0.4	0	1.0	-	0.6	0.5	0.3	0	0.8
5	0.1	0	1.0	0.5	-	0.2	0.3	0	0.9
6	1.5	0.4	1.9	0.6	0.6	-	2.8	0	3.5
7	0.2	0	0.1	0.2	0.1	3.9	-	2.2	0.4
8	0	0	0	0	0	0	3.4	-	0.2
S	4.5	1.2	3.8	1.0	0.2	3.3	0.6	0.1	-

Key to activities: 1 Gather data, 2 Assess or verify data, 3 Identify constraints or requirements, 4 Model behaviour, 5 Define problems, 6 Generate solution ideas, 7 Evaluate solutions, 8 Assemble solution, S Strategic remarks.

An iteration is defined as a backwards transition, or a step back in the sequence of activities as determined in the expertise model (Fig. 3). Table 12 shows the number of iterations made by each designer, and Table 13 shows the mean number of iterations grouped by design strategy. Solution driven and problem driven strategies appear to be the more purposeful and sequential strategies, with relatively low numbers of iterations.

TABLE 12 Number of iterations against design strategy

Designer	Iterations	Strategy
6	103	Knowledge driven
9	100	Information driven
4	77	Problem driven
7	72	Solution driven
3	58	Solution driven
5	54	Problem driven
1	51	Problem driven
2	45	Knowledge driven
8	27	Solution driven
	Mean: 65	

TABLE 13 Mean number of iterations by design strategy

Iterations	Strategy
100	Information driven
74	Knowledge driven
60	Problem driven
52	Solution driven
Mean: 65	

5 Outcomes versus expectations

In Table 3, we indicated some expectations for the outcomes and results from the empirical data of the protocol studies, according to the types of design strategy. Table 14 summarises the observed results against our prior expectations, in terms of the overall solution quality scores, creativity scores, and number of requirements identified and of solutions generated. The results that contradict the expectations are underlined in the Table.

TABLE 14 Summary of observed and expected results by design strategy

Strategy	over-all score	expected	creat-ivity score	expected	require-ments	expected	solut-ions	expected
Problem driven	5.2	high	5.1	low	36	many	32	few
Solution driven	4.6	low	5.9	high	41	few	38	many
Inform'n driven	5.4	high	3.4	low	46	many	14	few
Know'ge driven	5.1	low	4.9	high	37	few	26	few
Mean	5.0		5.1		40		28	

For *problem driven design* it was expected that there would be few solutions, many requirements identified, a low creativity score, and a high total score. Problem driven design in fact resulted in many solutions, identified few requirements, received a high score on creativity, and a good total score. Problem driven design therefore did not produce the results we expected. All round, problem driven design turns out to achieve relatively good results.

For *solution driven design* it was expected that there would be many solutions, few requirements identified, a high creativity score, and a low total score. Again, most of these expectations were borne out in the results, although solution driven design did not result in (relatively) only a few requirements being identified. This may be the result of identifying new related requirements during the generating of solutions. Solution driven design does seem to produce solutions of high creativity but low overall quality.

For *information driven design* it was expected that there would be few solutions, many requirements identified, a low creativity score, and a high total score. All of these expectations were borne out in the results, although only one designer was identified as using the information driven strategy.

For *knowledge driven design* it was expected that there would be few solutions, few requirements identified, a high creativity score, and a low total score. Knowledge driven design in fact did result in relatively few solutions, and there were relatively few requirements identified. But knowledge driven design achieved moderate scores on both creativity and overall score, contrary to expectations. In general, knowledge driven design seems to be the design strategy that produces average results.

Problem driven design particularly shows results contrary to our expectations. The designers employing the problem driven design strategy were expected to identify many requirements, and fewer solutions. An explanation could be that designers employing the problem driven design strategy manage to distribute their efforts successfully over both the stages of analysis and synthesis. Designers employing the problem driven strategy put more effort in the analysis stage than the designers using the solution driven strategy, and they put more effort in the synthesis stage than the designers who employed the knowledge driven or information driven strategies.

Another result contradicting the expectations of problem driven design is the high creativity score. This is probably the result of the longer synthesis stage and the generation of more solutions. The difference between problem driven design and solution driven design is the high total score that the designers with the problem driven design strategy received. This may be due to the designers employing the problem driven design strategy putting more effort into the analysis stage.

6 Conclusions

Individual differences between designers were clear in most of the data relating to both design process and solution outcomes, even though they were performing the same task under the same conditions. Nevertheless, some commonalities of approach did emerge in the types of cognitive strategies the designers employed, enabling them to be classified into the four types of design strategies: problem driven, solution driven, information driven and knowledge driven.

The data suggest that most designers employ either a problem driven or a solution driven design strategy, with each of these strategies being equally prevalent. Contrary to expectations, solution driven design did not feature clearly as the dominant strategy.

However, the ‘generate’ activity was the most frequently occurring single activity, thus tending to confirm the solution focused nature of design thinking.

In the derived expertise model, a strictly sequential process of activities was not evident. The data show a complex structure where activities alternate. There was an overall sequencing of activities in the process, but also iteration. Iterations within the analysis stage mainly account for this observation, with many iterations occurring between data gathering and identification of requirements. There was also a secondary iteration loop in the synthesis-evaluation stages. Both the problem driven and the solution driven strategies used fewer iterations than the variants of information driven and knowledge driven strategies.

The score for overall solution quality was not related to any of the strategies in a straightforward manner, although the designers that employed a solution driven strategy tended to have lower overall scores. The creativity score does appear to be related to the design strategies. Designers employing a solution driven strategy tended to have higher creativity scores. This seems also to relate to the total number of solution ideas generated. Designers employing a problem driven design strategy produced the best results for almost all of the assessed solution aspects, except creativity, as well as achieving high overall solution quality.

Acknowledgments

This research was conducted at the Faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands. We are grateful to Kees Dorst and Henri Christiaans for their work in designing and implementing the original protocol study experiments, to other colleagues who evaluated the qualities of the designs produced, and of course to the designers who acted as the experiment participants. We are also grateful to Professor Bob Wielinga of Amsterdam University, who advised the work on deriving the expertise model.

References

Christiaans, H (1992) *Creativity in Design* (PhD Thesis), Delft University, The Netherlands

Cross, N (2004) Expertise in design: an overview *Design Studies* Vol 25 pp 427 – 441

Cross, N (2000) *Engineering Design Methods: Strategies for Product Design (3rd edn.),* John Wiley & Sons Ltd., Chichester, UK

Cross, N (1985) Styles of learning, designing and computing, *Design Studies*, Vol 6 pp 157–162

Cross, N, Christiaans, H and Dorst, K (eds.) *Analysing Design Activity*, John Wiley & Sons Ltd., Chichester, UK

Dorst, K and Cross, N (2001) Creativity in the design process: co-evolution of problem-solution, *Design Studies*, Vol 22 pp 425–437

Dorst, K (1997) *Describing Design: A Comparison of Paradigms* (PhD Thesis), Delft University, The Netherlands

Ericsson, K A and Simon, H A (1993) *Protocol Analysis: Verbal Reports as Data*, MIT Press, Cambridge, Ma., USA

Kruger, C (1999) *Cognitive Strategies in Industrial Design Engineering* (PhD Thesis), Delft University, The Netherlands

Kvan, T and Yunyan, J (2005) Students' learning styles and their correlation with performance in architectural design studio, *Design Studies*, Vol 26 pp 19–34

Lawson, B (1979) Cognitive Strategies in Architectural Design, *Ergonomics* Vol 22 pp 59–68

Schreiber, G, Wielinga, B, de Hoog, R, Akkermans, H and van de Velde, W (1994) CommonKADS: A comprehensive methodology for KBS development, *IEEE Expert*, Vol 9 pp 28–37

van Someren, M W, Barnard, Y, and Sandberg, J (1994) *The Think Aloud Method: A Practical Guide To Modelling Cognitive Processes*, Academic Press, London, UK

Wielinga, B, van de Velde, W, Schrieber, G and Akkermans, H (1993) *Expertise Model Definition Document KADS II/M2*, University of Amsterdam

Figures

Design Brief

- *The Company*

Lemmens Inc. is a producer of plastic bins and buckets. There are 40 employees in the factory, working with 10 injection-moulding machines, an assembly line and a small toolmaking facility. Most of the products made are injection-moulded: small special series are made by vacuum moulding or rotomoulding (done by Ten Cate Rotomoulding). Lemmens has a small own assortment, aimed at professional users, and supply buckets to for instance Curver PC (comparable to Tupperware) in Oosterhout. The company wants increase its own assortment and reduce its supplying activities.

- *This Assignment*

The NS (Dutch Railways) is working on a number of new trains for the nineties, including a new local, the SM90. This will be a totally new design, with an increased passenger capacity attained by putting five (2+3) chairs in a row.

Because of the growing number of travellers they are also thinking about a new litter-disposal system (now: bin + emptying device) for the passenger compartment.

The producer of the current bins has made a new design, but the railway company is not very enthusiastic about it. As a result, they started a small inquiry into the functioning of the current litter disposal system: the kinds of litter were determined, and passengers and litter collectors were asked to comment on it. Then the railways decided to invite Lemmens Inc., among others, to come up with a better concept. There has been a meeting between the manager of Lemmens Inc., Mr. Kouwenhoven, and the leader of the project within the NS, Mr. Van Dalen. Lemmens Inc. sees this project as a chance to give it a higher profile within the market. That is why you, an external designer, are asked to make one or more proposals. Tomorrow you will have a meeting where your proposals will be discussed:

- principal solution
- general embodiment (materials, construction)
- idea behind the form
- 1:1 sketch views
- cost estimation

Figure 1 The design brief

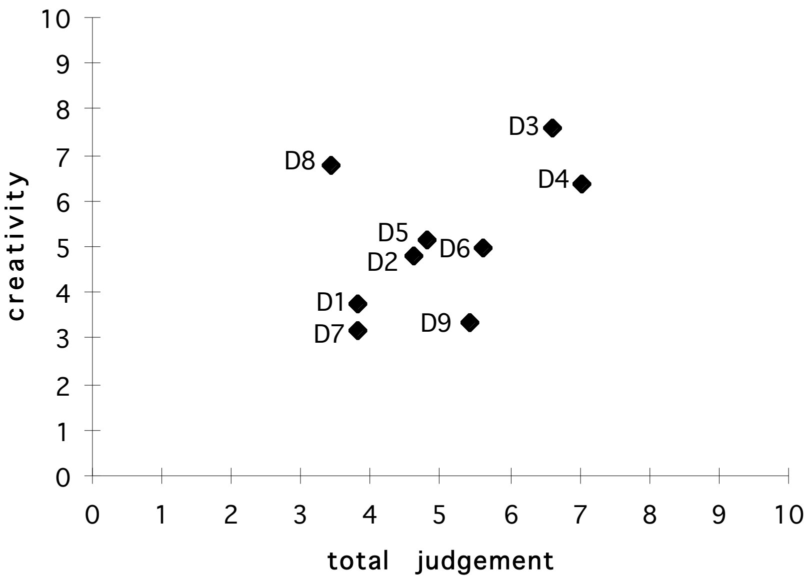

Figure 2 Scattergram for the means of 'total judgement' and 'creativity'

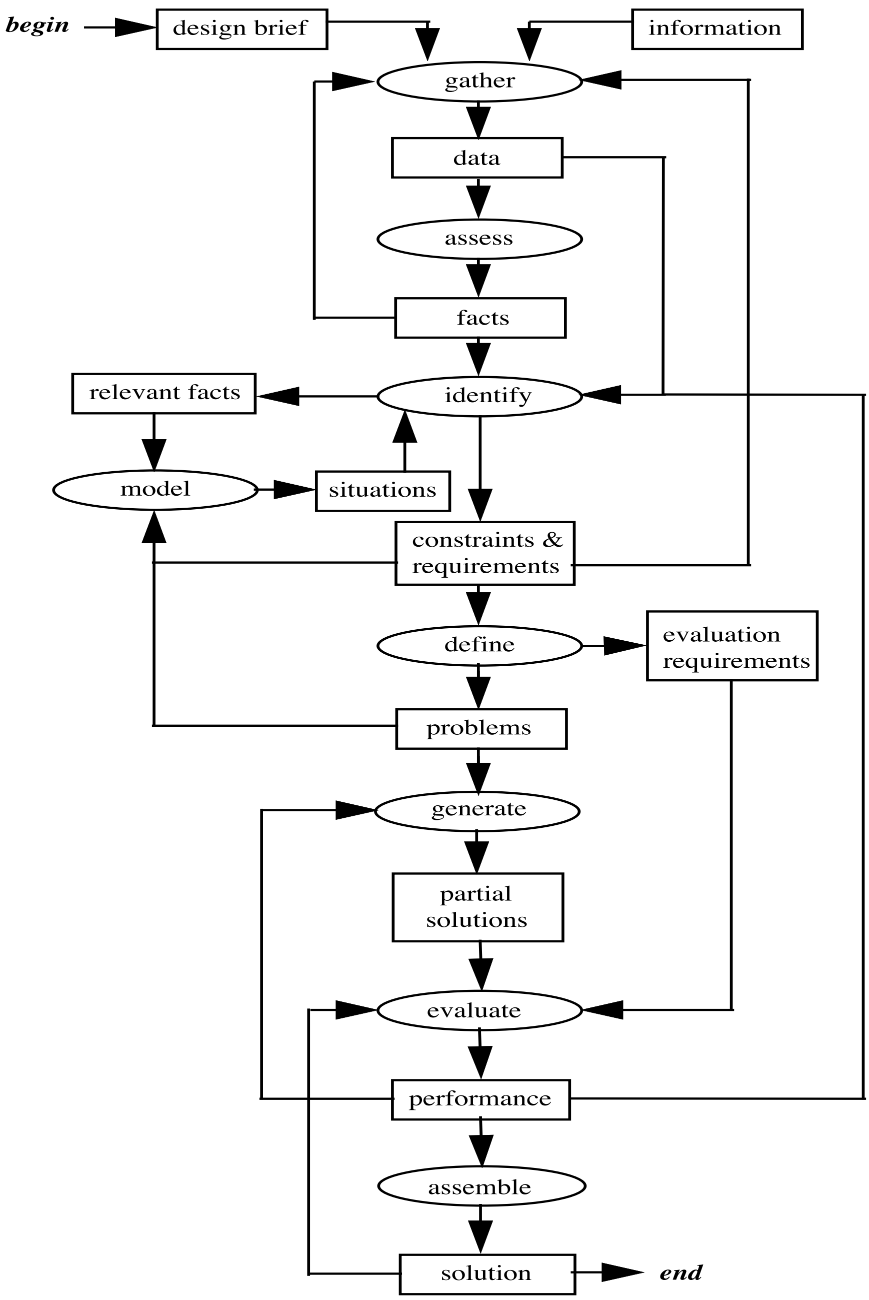

Figure 3 The derived expertise model of product design

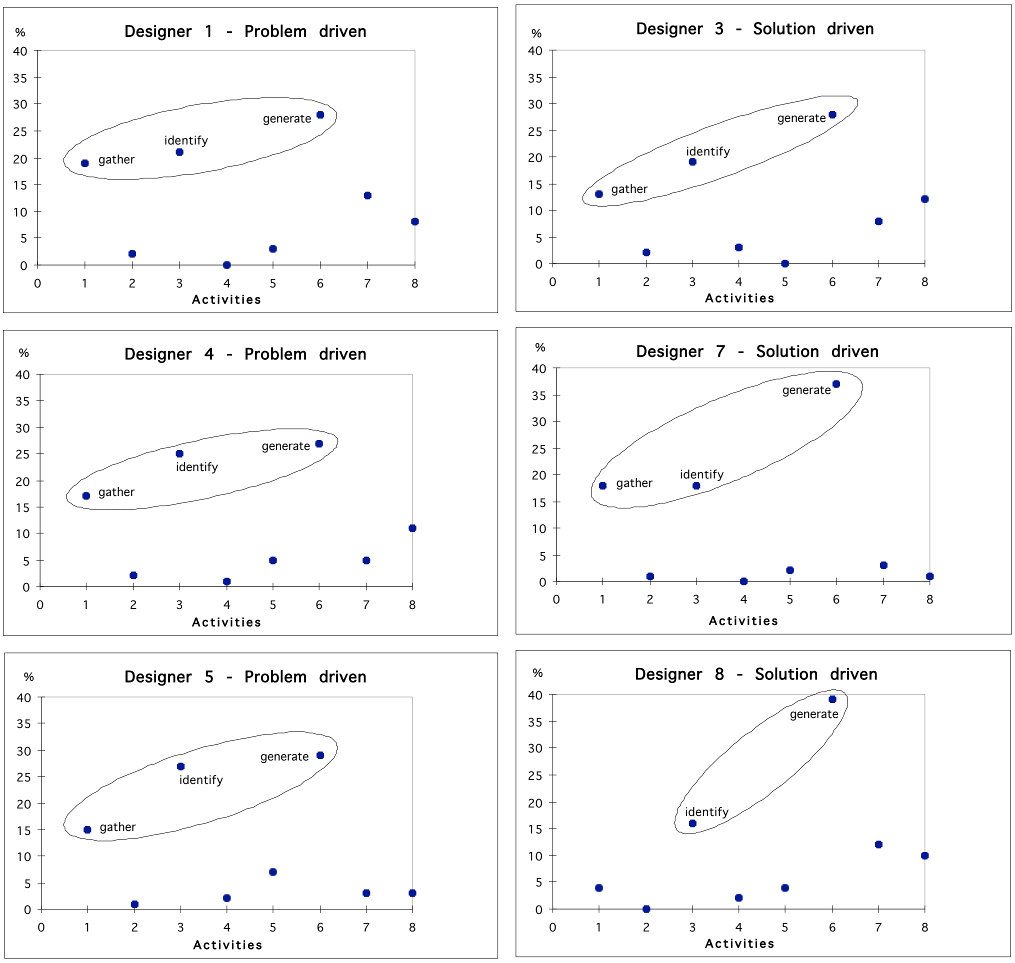

Figure 4 Scattergrams of activities of problem driven and solution driven designers.

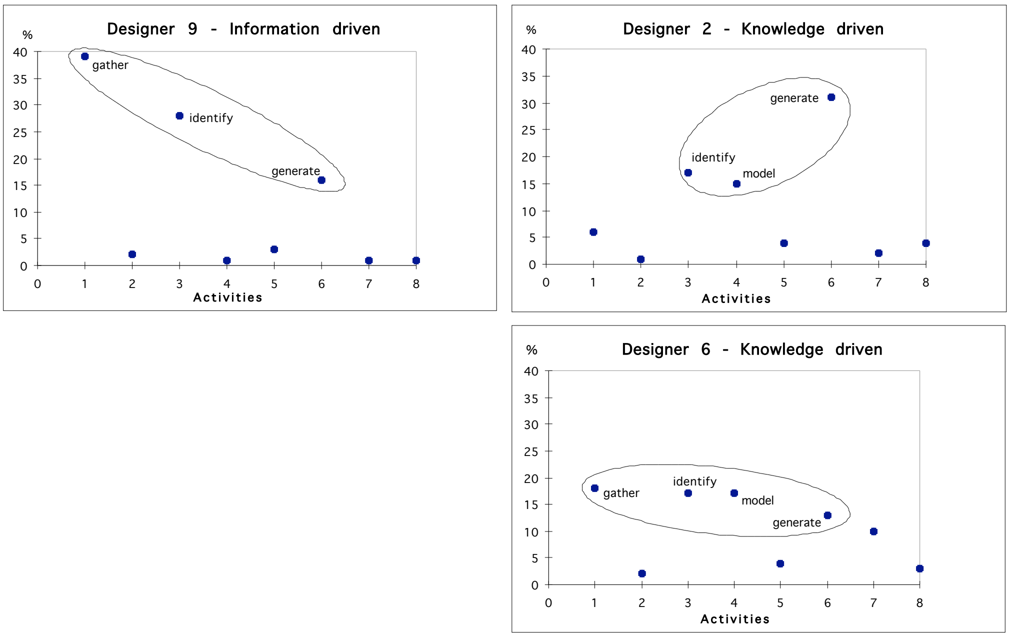

Figure 5 Scattergrams of activities of information driven and knowledge driven designers.