Creativity in the design process: co-evolution of problem–solution

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Empirical data on design processes were obtained from a set of protocol studies of nine experienced industrial designers, whose designs were evaluated on overall quality and on a variety of aspects including creativity. From the protocol data we identify aspects of creativity in design related to the formulation of the design problem and to the concept of originality. We also apply our observations to a model of creative design as the co-evolution of problem/solution spaces, and confirm the general validity of the model. We propose refinements to the co-evolution model, and suggest relevant new concepts of 'default' and 'surprise' problem/solution spaces. ©

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Creativity in the design process is often characterised by the occurrence of a significant event—the so-called 'creative leap'. Sometimes such an event occurs as a sudden insight which the designer immediately recognises as significant, but often it is only in retrospect that the designer (or an observer of the design process) is able to identify a point during the design process at which the key concept began to emerge. Retrospective accounts of creative events in design made by the designers themselves may not be wholly reliable. However, some recent descriptive, empirical studies of the creative event[1,2] have begun to shed more light on this mysterious (and often mystified) aspect of design. More of these independent studies of creativity in design are necessary in order to develop a better understanding of how creative design occurs. The growing number of protocol studies of design[3–5] tend to be constructed as studies of normal design activity, without any specific intention of looking for creativity.

1 Akin, Ö and Akin, C 'Frames of reference in architectural design: analysing the hyper-acclamation (A-h-a!)' *Design Studies* Vol 17 No 4 (1996) 341–361
2 Cross, N 'Descriptive models of creative design: application to an example' *Design Studies* Vol 18 No 4 (1997) 427–455
3 Cross, N, Christiaans, H and Dorst, K (eds) *Analysing design activity*, Wiley, Chichester, UK (1996)
4 Suwa, M and Tversky, B 'What do architects and students perceive in their design sketches? A protocol analysis' *Design Studies* Vol 18 No 4 (1997) 385–403
5 Gero, J S and McNeill, T 'An approach to the analysis of design protocols' *Design Studies* Vol 19 No 1 (1998) 21–61

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Studying creative design is seen as problematic because there can be no guarantee that a creative 'event' will occur during a design process, and because of the difficulty of identifying a solution idea as 'creative'. However, in every design project creativity can be found—if not in the apparent form of a distinct creative event, then as the evolution of a unique solution possessing some degree of creativity.

Christiaans[6] studied industrial design students with the particular intention of looking for creativity in design. Our research presented in this paper develops this work with students by extending a similar research methodology into studies of experienced designers. The empirical basis of this research consisted of protocol studies of nine experienced industrial designers working on a small design assignment in a laboratory setting[7]. The industrial design domain is particularly interesting for the study of creative design because it calls for new, integrated solutions to complex, multidisciplinary problems.

1 *The protocol study*

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[6,8]. Christiaans found that when specialist assessors were asked to grade designs on 'creativity', they were quite consistent. Apparently, they are much more in agreement (in an admittedly intuitive way) about recognising the creativity of a design than the inconclusive discussions about the definition of creativity would suggest. For our purposes, the results suggest that it is reasonable to claim that creative design can be assessed dependably in this manner. The participants we recruited for this study were nine industrial designers with five or more years of professional experience (the minimum was 5 years and the maximum was 20). The participants were all working in design consultancies, which is important because the assignment is modelled on design consultancy practice.

1.1 *The design assignment*

The assignment (problem or brief) developed for these studies was designed to be challenging, realistic, appropriate for the subjects, not too large, feasible in the time available and within the sphere of knowledge of the researchers. The assignment was to create a concept 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, construction, engineering, aes-

6 **Christiaans, H** *Creativity in design* PhD Thesis, Delft University of Technology, Delft, The Netherlands (1992)

7 **Dorst, K** *Describing design: a comparison of paradigms* PhD Thesis, Delft University of Technology, Delft, The Netherlands (1997)

8 **Christiaans, H and Dorst, K** 'An empirical study into design thinking', in **N Cross, N Roozenburg and K Dorst** (eds) *Research in design thinking*, Delft University Press, Delft, The Netherlands (1992)

thetics and business aspects. The written design brief (Figure 1) outlined the problem, introduced the stakeholders and defined the designer's position.

1.2 The experimental procedure

A special condition in the experiment was the manner in which information was provided to the designers. All the necessary information was prepared in advance on information sheets, with one specific topic on each sheet. Topics included interviews with the client, technical information about materials and production techniques, or a survey of train passengers. If a designer wanted to know something, they asked the experimenter (who was sitting nearby), who would then hand over the appropriate sheet. This was done to ensure a quick but natural flow of information. The information on the sheets was presented as if it had come from different natural

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

sources: from textbooks or catalogues and from the different stakeholders who were presented in the design brief. As a result, the information sheets contained natural amounts of vagueness and inconsistency. If the information was not available on the sheets, or if the designer's question related to a detail of a sheet, the experimenter answered the question.

The experiments were conducted as 'think-aloud' protocol studies[9,10]. The designers 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 to them was 2.5 h. During this period designers were encouraged to think aloud only if intervals of silence lasted for more than 30 s. After the design session, there was a brief interview to determine the motivation and attitude of the designer towards the test situation and his/her own design. 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.

1.3 Design quality measurement

In this study, we were interested in the overall 'quality' of the resulting design concepts produced by the designers. One aspect of that quality is the perceived creativity of the design concepts. Assessments of the design concepts were made by independent, skilled assessors. The design concepts developed by all of the designers were re-drawn and presented in a similar format (see Figure 2). Each of the concepts was then assessed independently by five design teachers from the TU Delft Faculty of Industrial Design Engineering, all of whom are also practising designers. The procedure was as follows:

- First, the assignment was read and some of the relevant information was shown to them in an abbreviated form. The judges could ask questions for further clarification.
- Then slides of all the concepts were shown in random order for 15 s, accompanied by a one-sentence summary to explain the way each of them works.
- The first scoring category was briefly introduced, and all the design concepts were again shown for 15 s in random order. Each judge graded the concepts individually in this category. The scoring categories were: creativity, aesthetics, technical aspects, ergonomics and business aspects (in random order).
- In the last run-through, the judges were asked to give a total judgement of the concepts. Thus the 'total' judgement is not a mean of the other scores, but a separate, 'overall impression' score.

9 **Ericsson, K A and Simon, H A** *Protocol analysis: verbal reports as data* MIT Press, Cambridge, MA (1993)

10 **van Someren, M W, Barnard, R and Sandberg, J** *The think aloud method: a practical guide to modelling cognitive processes* Academic Press, London, UK (1994)

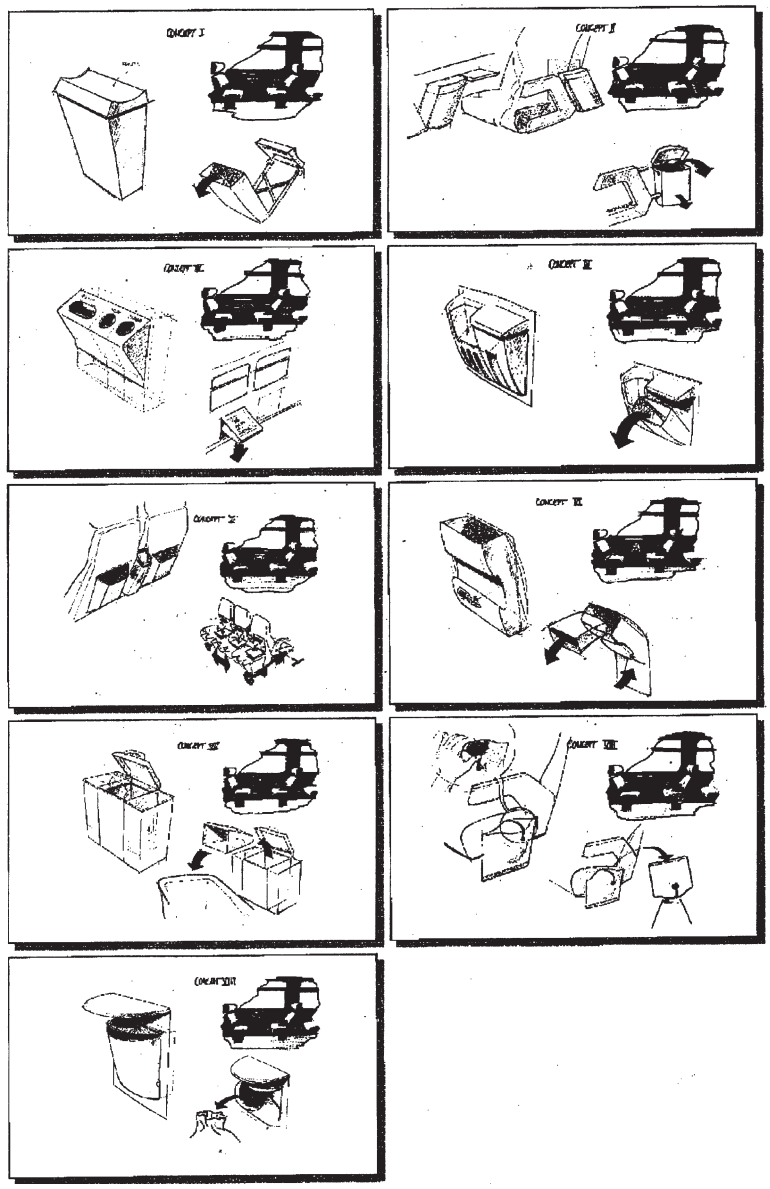

Figure 2 Sketches of all nine designs

This rather laborious multi-step procedure enabled us to analyse the rationale behind the judging behaviour and to test the consistency between raters. The interrater reliability was determined by computing the alpha-coefficient for the agreement between the judges[6,11]. The alpha-coefficient for the end measure in this study, the total judgement, was a very reasonable 0.71.

11 **Nunnally, J C** *Psychometric theory* McGraw-Hill, New York (1967)

Table 1 The mean scores of all judges (on a 1–10 scale)

Concept	*Ergonomics*	*Technical aspects*	*Aesthetics*	*Business aspects*	*Creativity*	*Total judgement*
D1	4.2	6.4	6.4	6.6	3.8	3.8
D2	6.2	6.2	6.2	6.4	4.8	4.6
D3	8.6	6.6	5.2	5.4	7.6	6.6
D4	7.2	7.0	8.4	7.8	6.4	7.0
D5	6.6	6.4	5.0	6.4	5.2	4.8
D6	4.6	6.4	6.6	5.6	5.0	5.6
D7	6.0	7.2	2.6	4.8	3.2	3.8
D8	3.8	5.0	4.8	5.0	6.8	3.4
D9	4.8	6.6	6.0	6.8	3.4	5.4

1.4 Results

An overview of the scores given for each design on the different aspects can be found in Table 1. The concepts of designers 3 and 4 clearly stand out as the best on most aspects. Design concepts 7 and 1 are consistently bad on all aspects. Design concept 8 was considered the worst on all criteria, except creativity; it is decidedly new, and 'different', but has many shortcomings.

As it turned out, the 'ergonomics' judgement correlated most heavily with the 'total judgement', and 'creativity' correlated least (but see Figure 3 and discussion, below), but none of the aspects were of overriding importance (Table 2). This was confirmed by the factor analysis: the 'ergonomics' aspect correlated 0.95 with the main factor of the factor analysis, good for 43.4% of the variance of the data. The relatively even distribution shown in Table 2 is precisely what was aimed at in the formulation of this

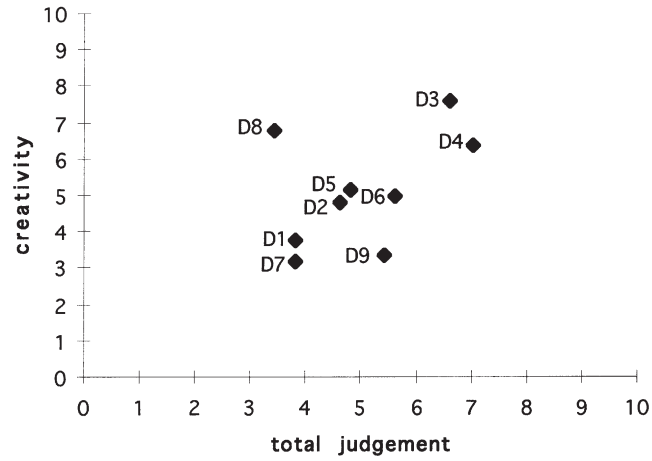

Figure 3 Scattergram for the means of 'total judgement' and 'creativity'

Table 2 Correlations between the ratings of the design concepts on different categories and the total judgement of the design judges

	Ergonomics	*Technical aspects*	*Aesthetics*	*Business aspects*	*Creativity*
Correlation with total judgement	0.68	0.46	0.44	0.57	0.32

design assignment: it was supposed to be a typical, all-round industrial design engineering assignment. The perceived need to balance aspects was built into the design assignment to invite integrative behaviour, rather than a bias towards any one aspect. Thus creativity (or any other aspect) was not emphasised to the designers as an all-important consideration.

Figure 3 shows a scattergram for the 'creativity' scores of the design concepts against the 'total judgement' scores. It shows that design 8 is an exception to the general trend: on the whole, the more creative designs were considered better in the total judgement. (The low correlation of 0.32 in Table 2 rises considerably to 0.8 when design 8 is omitted.) 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. 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.

2 *Observations of creativity in design*

From the protocols, we are able to make several observations on the nature of creativity in design.

2.1 *Creativity and definition of the design problem*

Christiaans[6] reported from his study that "the more time a subject spent in defining and understanding the problem, and consequently using their own frame of reference in forming conceptual structures, the better able he/she was to achieve a creative result". Defining and framing the design problem is therefore a key aspect of creativity. When we inspect our protocols, we can see that the designers used different strategies to organise their approach to the assignment. Some began by deciding whether the process should be one of design or redesign, others focused on which stakeholder should have priority in this project: the client manufacturing company, the railways, the passengers or the cleaners. Some of the designers also explicitly arranged their design assignment to be new and challenging,

i.e. to help provoke a creative response. They used a variety of techniques to ensure this newness, such as searching for technical, behavioural or cultural factors that were not addressed in the design of the current product, the standard litter bin in Netherlands trains. An example of such an episode can be found in the protocol record of designer 3 (whose design concept was rated very highly overall, including the highest 'creativity' rating):

In the 26th minute, the designer has the idea of doing away with the litter bins all together, and just make a hole in the floor of the train. He then asks whether or not such an idea would be outside the scope of the assignment, saying he likes to manipulate assignments, because they are often too narrow. Then he realises that there is already a litter system in a train, namely the toilets. He asks for some information about that, and is genuinely shocked to hear that they are just a hole in the train floor, which opens onto the rails. He finds this an ugly, primitive, and very backward solution, and adopts a new goal, namely to change this also. He starts designing a special litter container, which sucks in all the litter and compresses it. After some sketching he asks to confer with the Dutch Railways about his interpretation of the design assignment.

We observed that the designers did not treat the design assignment as an objective entity (a given 'design problem'). All the designers interpreted the assignment quite differently, in awareness of their own design environment, resources and capabilities. This design assignment manipulation is an almost constant process, but there were episodes in which this modification of the design assignment (especially tailoring it to the 2.5 h available) was particularly clear. An example can be found in the protocol record of designer 4:

In the 20th minute, the designer checks whether he is dealing exclusively with the litter bin or with other factors as well. He notes that "…they talk about a litter *system*… which means we'll also have to deal with the carrying of the litter out of the train…" So for him the assignment had grown, from 'bin' to 'system', and this became a bit of a problem. The designer asked for more information and translated this 'carrying out of the train' into: "I'll note down that this is about the litter bin and emptying method…" Later on, the design assignment was reduced again by ignoring the design of a new emptying method, and adopting the current solution for this part of the system. Some time later the assignment was explicitly reduced again by letting go of a possibly complicated idea of combining the litter bin into the chair: "I'll drop the chair idea because of time pressure…"

The designer thus decides what to do (and when) on the basis of a personally perceived and constructed design task, which includes the design problem, the design situation and the resources (time) available, as well as the designer's own design goals. The creativity of the design is thus influenced by all these factors.

2.2 *Creativity and originality*

There is a particular example in this design exercise that makes one reflect upon the very nature of what is meant by 'creative design' and the notions of 'originality' and 'ideas'. In the information sheets that the designers could ask for, the problem of the newspapers that people leave in trains pops up, in several separate places, e.g.:

- newspapers make up 40% of the contents of the bins—the single largest ingredient of train litter;
- sometimes they are left behind on the luggage racks;
- the cleaners complain about having to collect the newspapers;
- the railway company wants to attain an environmentally-friendly image, and they are thinking about ways of recycling the waste collected in trains.

All designers found most of these four issues in their exploration of the assignment, amongst many other issues to which they had to attend. These loose bits of information can be combined into the idea that newspapers should be collected separately. All nine designers got this idea, and all of them reported upon it as an original idea, a key concept in their solution. (What is more, all 21 students in the previous studies by Christiaans, with the same design assignment, also had this same idea.) The designers were very enthusiastic about this idea, and they were convinced that they were going to beat any competitors with this idea. It is a real 'aha' event[1].

It is interesting that they all seemed to think that this was an original concept. Indeed it was original in the sense that it is a different concept from the existing litter bin; it was also original to each individual designer. (This is an instance of Boden's[12] distinction between 'personal' creativity and 'historical' creativity; where the latter type represents genuinely unique insights that occur to the first-ever individual in history known to have the insight.) However, the re-occurrence of the idea independently in the minds of different designers suggests that somehow it may be an 'easy' step in originality; that certain kinds of information in the problem data may spur similar 'creative' concepts.

All the designers took this idea as one of the key features in their subsequent design process, even though it led to a number of different designs. For instance, the system level on which they incorporate this idea in the end differs widely among designers: one can take the level of the whole train, a railway carriage or just a compartment as the scope of the design, or simply add a newspaper rack to a litter bin. In Fig. 2, in concepts III, IV, VI and VII we see a product solution at a very local level (adding a newspaper bin to the litter bin), while concept VIIII includes a newspaper

12 **Boden, M** *The creative mind* Weidenfeld and Nicolson, London, UK (1990)

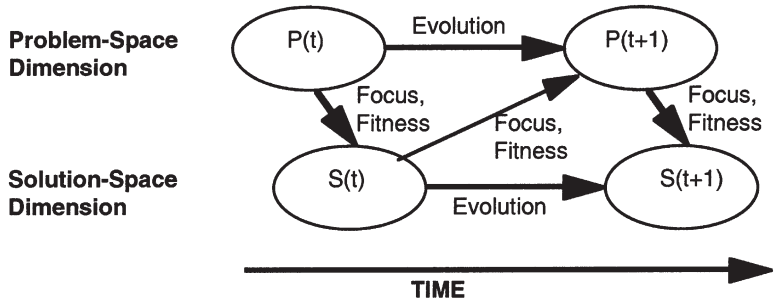

Figure 4 The co-evolution model of Maher et al

rack that is to be placed at the end wall of each passenger compartment (not drawn).

3 *Modelling creative design as co-evolution*

It seems that creative design is not a matter of first fixing the problem and then searching for a satisfactory solution concept. Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution, with constant iteration of analysis, synthesis and evaluation processes between the two notional design 'spaces'—problem space and solution space. The model of creative design proposed by Maher et al.[13] is based on such a 'co-evolution' of the problem space and the solution space in the design process: the problem space and the solution space co-evolve together, with interchange of information between the two spaces (Figure 4).

We can express the case of the 'creative event' of the 'keep newspapers separate' idea, as we found it in our protocol studies, in the terms of this model of the co-evolution of problem space (PS) and solution space (SS). A rough description of what happened in this case is that a chunk, a seed, of coherent information was formed in the assignment information, and helped to crystallise a core solution idea. This core solution idea changed the designer's view of the problem. We then observed designers redefining the problem, and checking whether this fits in with earlier solution-ideas. Then they modified the fledgling-solution they had. This pattern of development can be modelled quite clearly along the lines of the Maher model.

Figure 5 represents what we observed in our experiments. The designers start by exploring the PS, and find, discover, or recognise a partial structure ($P(t + 1)$). That partial structure is then used to provide them with a partial structuring of the SS ($S(t + 1)$). They consider the implications of the partial structure within the SS, use it to generate some initial ideas for the form of a design concept, and so extend and develop the partial structuring ($S(t + 2)$). Some of this development of the partial structuring

13 Maher, M L, Poon, J and Boulanger, S 'Formalising design exploration as co-evolution: a combined gene approach', in **J S Gero and F Sudweeks** (eds) *Advances in formal design methods for CAD*, Chapman and Hall, London, UK (1996)

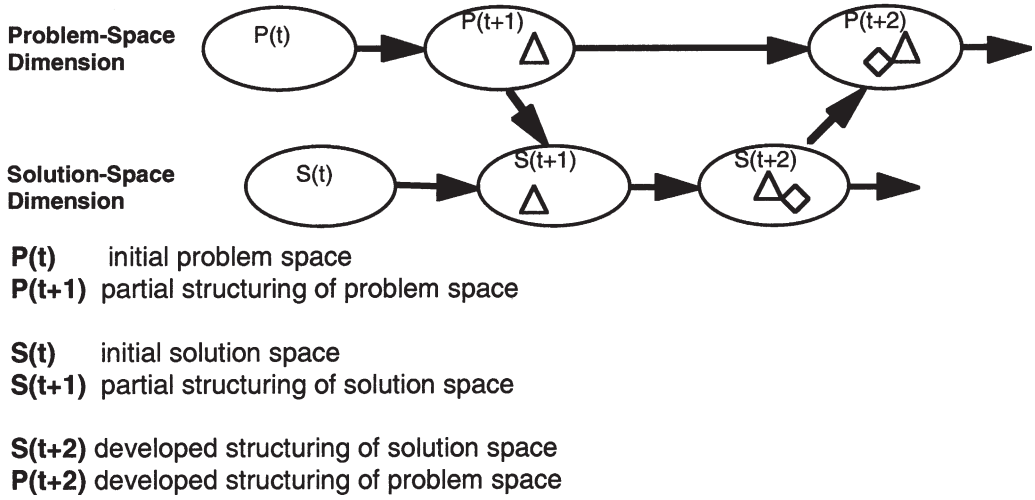

Figure 5 Co-evolution of problem–solution as observed in this study

may be derived from references to earlier design projects. They transfer the developed partial solution structure back into the PS ($P(t + 2)$), and again consider implications and extend the structuring of the PS. Their goal is to create a matching problem–solution pair.

4 *Bridges, frames, defaults and surprises*

Cross[2] suggested that the creative event in design is not so much a 'creative leap' from problem to solution as the building of a 'bridge' between the problem space and the solution space by the identification of a key concept. Our observations confirm that creative design involves a period of exploration in which problem and solution spaces are evolving and are unstable until (temporarily) fixed by an emergent bridge which identifies a problem–solution pairing. A creative event occurs as the moment of insight at which a problem–solution pair is framed: what Schön[14] called 'problem framing'. Studies of expert and outstanding designers[15] suggest that this framing ability is crucial to high-level performance in creative design.

How do designers frame the partial problem space? In the protocols we observed, with respect to the 'keep newspapers separate' idea, there is the recognition of a cluster of related information in the PS. This recognition enables the designers to make a partial structuring of the PS. The designers appear to have a strategy for this. They search through the information by asking a quasi-standard set of questions, such as: 'capability of the company', 'available investment', etc. Apparently, they have a set of expectations about the answers to these questions. These expectations more or less constitute a *default* project with which they compare the current chal-

14 Schön, D A *The reflective practitioner: how professionals think in action* Basic Books, New York (1983)

15 Cross, N and Clayburn Cross, A 'Expert designers', in **E Frankenburger, P Badke-Schaub and H Birkhofer** (eds) *Designers—the key to successful product development*, Springer Verlag, London, UK (1998)

lenge. (This is in marked contrast to the students that were studied earlier, who did not display this checking behaviour, but clearly had to try to absorb all the information, and then structure it.) In doing this, they check the information related to the assignment to build up a general image, and to look for *surprises*. This process of checking then leads to (1) an overview of the project (and of the priorities of the stakeholders) and (2) a collection of 'interesting points'—for instance, designers can be seen to make a small stack of information sheets that interest them, or make a list of these items.

In the case of the 'keep newspapers separate' idea, the creative event can be observed to happen as follows:

(1) Loose, surprising information is linked into a coherent chunk, which offers a simplification of the design problem.
(2) The recognition of the simplification happens suddenly, and is experienced as an idea (a creative insight). This finding of a coherence between the interesting information items apparently gives the designers the feeling of having grasped the core of the problem ('the problem behind the assignment'). This is a highly emotional step, and none of the designers could ignore the impact.
(3) This 'keep the newspapers separate' idea is then (mistakenly but understandably) seen as being original. Thus the simple (obvious) selection and combination of information leads to the same core idea for all the designed products.
(4) Then (and just by accident in this case) the transformation of this problem-chunk into a solution turns out to be very simple, too. The designer only has to turn the problem around to arrive at a solution: "If it is too much trouble putting the newspapers into the bin, keeping them there and getting them out again—then why put them in?" And as it happens, a product to hold some newspapers is easily imagined. None of our designers could resist this reasoning path.

5 *Conclusion*

We hope to have shown that the 'problem-solving' aspect of design can be described usefully in terms of Maher's model of the co-evolution of problem and solution spaces, and that the 'creative' aspect of design can be described by introducing the notions of 'default' and 'surprise' problem/solution spaces. Schön[14] used the notion of 'surprise' in his theory of creative design, where it has the pivotal role of being the impetus that leads to framing and reframing. Surprise is what keeps a designer from routine behaviour. The 'surprising' parts of a problem or solution drive the originality streak in a design project.

The process of evolution in the natural world is nowadays seen as driven by a reaction to a surprise (change in environment), rather than a gradual changing of a phenotype and genotype in an ever closer approximation to an optimum in the fitness function. We suggest that creativity in the design process can validly be compared to such 'bursts of development'.

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