

The Expertise of Exceptional Designers

Nigel Cross

Three studies of creative design in engineering and product design are reported. The studies are of outstanding or exceptional designers and comprise one protocol study and two retrospective case studies. In each case, an example of the designer's creative approach to a particular design problem is analysed. Comparisons between the three examples are drawn, and there appear to be some striking similarities, despite the very different project domains. A general descriptive model of the creative strategies adopted by exceptional designers is developed from these commonalities.

Most studies of designer behaviour have been based on novices (e.g. students) or, at best, designers of relatively modest talents. The reason for this is obvious – it is easier to obtain such people as subjects for study. However, if studies of designer behaviour are limited to studies of rather inexpert designers, then it is also obvious that our understanding of design expertise will also be limited. In order to understand expertise in design, we must study expert designers. In some instances, it will be necessary to study outstanding, or exceptionally good designers. This is analogous to studying chess masters, rather than chess novices, in order to gain insight of the cognitive strategies and the nature of expertise in chess playing.

As in chess playing, in design practice it also seems clear that individual designers have differing design abilities – some designers just seem to be better than others, and some are outstandingly good. However, there have been only a few studies of outstanding designers, such as Roy's (1993) studies of successful product designers, Lawson's (1994) studies of successful architects, and Candy and Edmonds' (1996) study of a successful racing bicycle designer. This paper reports three studies – a protocol study and two retrospective case studies – of exceptional designers. The studies are of the engineering designer Victor Scheinman, the product designer Kenneth Grange, and the racing car designer Gordon Murray. The focus is on identifying the designers' creative strategies in responding to the problems they tackle. There appear to be several striking similarities in their design strategies, which suggest that a common understanding, and indeed a general model might be constructed of high level, creative expertise in design.

1. Three studies of exceptional designers

1.1 Protocol study: Victor Scheinman

Victor Scheinman is an American engineering designer with many years of experience in designing both mechanical and electro-mechanical machines, and robotic systems and devices. He was one of the earliest designers of modern robotic devices, and he has won several design awards from the American Society of Mechanical Engineers. He is an accomplished, expert designer, outstanding in his field. He volunteered to participate in a protocol study experiment, in which he was video recorded whilst he 'thought aloud' over a 2-hour session. The observations of Victor's design strategy are therefore based on the artificial situation of a controlled experiment. Although Victor has a wealth of design experience, the design task set in the experiment was a novel task for him. The task was to design 'a carrying/fastening device that would enable you to fasten and carry a backpack on a mountain bicycle'. Full details of the experiment are reported in the proceedings of the 'Delft Design Protocols Workshop' (Cross et al., 1996), where Victor Scheinman is identified anonymously as 'Dan'. Victor has subsequently agreed that he can be properly identified.

In the following analysis of Victor's strategy, quotations are taken from the transcript of his 'think aloud' comments, preceded by the timestamp for the quotation. After some preliminaries, the substantive experimental session began at timestamp 00.15 minutes.

Quite early in the session Victor began to identify particular features of the problem that would influence his approach to developing a design concept. For example, very early in the session, in reading the design brief, he made a comment that suggested he saw something special about the design problem:

(00.19) it is to attach to a bicycle, a mountain bike, and to me that makes it different.

Victor was also able to draw on personal experience that helped him to formulate some of the implicit requirements for a good design solution:

(00.26) having used a backpack on a bike in the past and having ridden over many mountains, unfortunately not on a mountain bike but I can imagine that the situation is similar, I learned very early on that you want to keep it as low as possible.

He also drew upon personal experience to confirm that the preferred location for the backpack would be on the rear wheel rather than the front wheel:

(00.51) my first thought is hey the place to put it is back here; there's another advantage by the way of having it in the back I can see immediately, and that is it's off the side in the front, and you're on a mountain bike trail and you hit something you're out of control in the front wheel.

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(00.52) downhill work on mountain bikes, I know you want to keep your weight back rather than forwards.

Victor's personal experience of biking with a backpack led him to identify an issue that only someone who has had such experience might be aware of:

(00.55) when I biked around Hawaii as a kid that's how I mounted my backpack . . . and I have to admit if there's any weight up here this thing does a bit of wobbling, and I remember that as an issue.

So the view that Victor formed of the problem was that of the total task that encompasses the dynamic system of the rider plus bicycle plus backpack, and the issues of control of the bicycle that arise in the situation of riding over rough terrain with a heavy backpack attached to the bicycle. This is a different situation to that of everyday, smooth-surface, level-grade riding, and it accentuates the needs to position the backpack low and to the rear. The view that Victor had of the design task was significantly different from a view that might be formed from considering the bicycle and backpack in a static situation, or without considering the effects on the rider's ability to control the bicycle with a mounted backpack. Victor's understanding of the dynamic situation therefore enabled him to formulate a broad view of the design task.

From this overview of the total dynamic system of rider + bicycle + backpack, Victor identified stability as a key issue. Quite early in the session, commenting on a prototype design that had been developed earlier by other designers, he surmised about the user-evaluation report on this prototype that:

(00.22) it probably says the backpack's too high or something like that, and that bicycle stability's an issue.

Victor therefore framed the problem as 'how to maintain stability', given that a heavy backpack had to be carried over the rear wheel of the bicycle, and given his experience of the 'wobbling' that can occur in the riding situation. This problem-framing and his prior experience led him to conclude that he must design a rigid carrying device:

(00.59) the biggest thing that I remember in backpack mounting is that it's got to be rigid, very rigid.

He then developed this viewpoint into the requirement that the structural members of any carrying device must be stiff:

(01.06) making the carrier stiff enough for holding the backpack, that seems to be a big issue.

So, at about halfway through the session, Victor had derived a framing of the problem which directed him to design a stiff, rigid carrier, mounted as low as possible over the rear wheel. Soon after, a secondary viewpoint emerged, which arose from considering the client's needs as well as those of the user (which had dominated Victor's thinking so far). The client for

the design task was a manufacturer who wanted to sell the carrying device in conjunction with their already-existing backpack. The device therefore needed to have unique selling points that differentiated it from other, similar products. During the development of his design concept, Victor kept in mind that he needed the product to have a 'proprietary feature', as emerged in some of his comments, discussed below.

Having established a need for rigidity, Victor was able to utilise his knowledge of structural engineering principles as he developed a concept design for the carrying device – in particular, knowledge that a triangulated structure is inherently rigid. This led him to avoid designing a rectangular, parallelogram form of structure, which was the form that rather naturally seemed to arise from considering the basic shape of the carrier and the location of its supporting structure on the bicycle. Whilst sketching a basic position and layout for the device, Victor commented:

(01.07) one of the problems with a bicycle carrier where the frame is mounted out here and it goes to that, is that you end up with a parallelogram - bad thing, bad thing!

He expanded on this comment, identifying his concern with stability as a key requirement:

(01.08) if I were to make a frame that looked like this, that would be a very poor design because basically what I've got is, I've got a parallelogram which has very little lateral stability.

He then introduced the principle of triangulation, whilst drawing a triangular form onto the layout:

(01.09) it would be nice if I could, for instance, run these rods up here to some point and therefore create a triangle, this would give me great stiffness - good idea!

The principle of triangulation subsequently guided Victor's generation of the basic form and the detailed design features of his carrier. As he drew his design in more detail, he commented:

(01.16) we're going to have this as a triangular structure here to provide the lateral stability.

As he continued to develop his design, he constantly referred to structural principles, seeking to avoid 'bad' configurations and to generate 'good' ones, making comments such as:

(01.42) my detail here is going to have to be something like this because my forces along this tube are this way . . good, this is good; and then this detail is going to be, er, let's see . . alright that's bad . . that's bad . . that's bad, so I'm going to need something like that.

In the meanwhile, as noted above, Victor also used the client's requirement of a unique selling proposition to help guide and to reinforce his decision to seek a design based on triangular structures:

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(01.10) that is going to be our proprietary feature, a triangular, rigid structure with no bends in it; these rods are then going to be in tension and compression, no bending.

(01.41) I want to make sure that this rod here comes to a point, not stop right there . . . that's to a point; that's going to be my feature.

In these comments, Victor demonstrated that he regarded the pronounced triangular form at the rear of the carrier as something to be retained as a feature that would help give the product an attractive and distinctive appearance. His design for the carrying device is therefore based on an integrated concept in which user requirements are addressed through the problem frame of stability, leading to the use of triangularity as the guiding first principle, which he then also uses to address the client's goal of having a proprietary, unique selling feature to the product.

Having the benefit of a 'think aloud' transcript, we can see that Victor's creative strategy involves addressing issues at several levels of generality – forming a broad, system's view of the required product in its situation; from that, developing a particular perspective or problem frame for guiding the solution concept; using that perspective to identify relevant first principles of engineering design to embody the concept; and also maintaining in mind the satisfaction of the client's goal of a successful consumer product. Let's now see if this analysis of a formal experiment helps to identify whether similar strategies can be observed in the real-world work of other outstanding designers.

1.2 Case study: Kenneth Grange

Kenneth Grange is a highly successful British designer of a great variety of products that range in scale from ball-point pens and disposable razors to train seats and railway engines. His career has spanned over more than forty years, and many of his designs became (and remain) familiar items in the household or on the street – or on the railtrack. These designs include the first UK parking meters for Venner, food mixers for Kenwood, razors for Wilkinson Sword, cameras for Kodak, typewriters for Imperial, clothes irons for Morphy Richards, cigarette lighters for Ronson, washing machines for Bendix, pens for Parker, and the front end – driving cab and nose cone – of the British Rail high-speed train. He is one of the Royal Society of Arts' elite corps of 'Royal Designers for Industry', and his designs have won many awards. In 2001 he was awarded the Prince Philip Designer Prize – a kind of 'Oscar' for lifetime achievement. His career began with his first independent commissions in the nineteen-fifties, and in 1972 he was a founding-partner in what was to become the world-renowned interdisciplinary design consultancy, Pentagram. This study is based on personal conversations and a more formal taped interview with Kenneth (a fuller presentation of the study has been given elsewhere – Cross, 2001).

A significant feature of much of Kenneth Grange's design work is that it is not based on just the styling or re-styling of a product. His designs often arise from a fundamental reassessment of the purpose, function and use of the product. A typical example is his design of a sewing machine for the Japanese company, Maruzen. They were looking for new designs for their European market where their high-quality, well-engineered machines were sold under the name of Frister & Rossman. Kenneth's resulting design incorporated the standard Maruzen machinery, but repackaged it in novel ways that made it easier to use and gave the overall machine a new and distinctive form and style, as required by the clients.

The origins of the new design features lay in Kenneth's functional, practical approach, and on his personal experience. His starting point was to make some personal use of a sewing machine. He quickly found what he regarded as a 'contradiction' in the design, in that the sewing machine mechanism was located centrally on its base, whereas the user needs more surface space on their side of the needle than behind it. The user needs to assemble and lay out the material to be sewn, and control it as it passes under the needle, and therefore needs a flat working surface in front of the needle; once the work is behind the needle there is not the same need for space. Kenneth therefore saw one important aspect of the problem as being to increase the available work-surface space in front of the sewing needle. His solution concept simply moved the sewing machine mechanism rearwards on its base, creating an asymmetrical layout with more base-table space in front of the needle than behind it. To him, this appeared a virtually self-evident improvement to make, but the reason it had not been done before was because sewing machines had developed from regular engineering practices. The mechanism was from the very beginning simply put centrally on the base and nobody had thought about challenging this arrangement.

Another radical change in this particular sewing machine design was also a result of a simple, fundamental assessment of how the machine is used. Kenneth gave the base of the machine pronounced, rounded lower edges, which look like a mere styling feature, but in fact also arose from function. A recurring need in using a sewing machine is to clean the bobbin mechanism (under the needle, in the base of the machine) of the lint and loose fibres that inevitably gather and affect the functioning of the machine. In previous designs, this was achieved by the user tilting the machine backwards, away from them, into a precarious, unstable position that only allowed restricted access to the shuttle mechanism. To Kenneth Grange, this was simply inadequate. He wanted the user to be able to get easy, unrestricted access to the mechanism. So he designed it to tilt upright to the side, and that action in itself suggested a rolled edge to the base plate. The rolled edge made it easier for the user to tilt the machine, it rested stable and secure, and the complete underside was accessible for cleaning and oiling the lower mechanisms. A radiused top front edge was also provided to the base plate, to allow the fabric to slide over it more

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easily, and various other features were added, such as small drawers for holding accessories.

The sewing machine design illustrates how Kenneth Grange's approach is to consider the whole pattern of use of the product he is designing, exemplified here by considering the requirements of periodically cleaning the machine, and by considering how the user prepares and introduces the fabric into the stitching mechanism, thus requiring more make-up space in front of the needle than behind it. The innovative 'style' and features of the new machine were generated from considering and responding to the functional patterns of its use.

1.3 Case study: Gordon Murray

This case study is of an expert with a long-established record as a highly successful and highly innovative designer in a highly competitive environment; that of Formula One racing car design. The South African engineer Gordon Murray was chief designer for the Brabham team from 1973 to 1987, and the McLaren team from 1987 - 1991. Brabham cars designed by him and driven by Nelson Piquet won World Championships in 1981 and 1983, and his McLaren cars, driven by Alain Prost and Ayrton Senna, won World Championships in 1989 and 1990. In over 20 years in Formula One design, he established an outstanding reputation not only as a successful designer (over 50 race wins) but also as a consistently radical innovator.

Gordon Murray is clearly an exceptional designer who has achieved considerable success. In his case the measures of his success as a designer are clear – his achievements have been in a competition field where absolute performance standards are the criteria. We have been able to gain some insight into Gordon Murray's design strategies and approaches through conversations and interviews (these have been reported in more depth elsewhere – Cross and Clayburn Cross, 1996). Here I will discuss just one example of Gordon's radical approach to racing car design.

At the start of the 1981 racing season, the Formula One governing body, FISA, had introduced new regulations intended to reduce 'ground effect' on the cars. This effect had been pioneered on Lotus cars some three seasons earlier; very low, smooth underbodies, flexible side-skirts and careful aerodynamic design provided a ground-effect downforce which increased the car's grip on the track surface. This meant much higher cornering speeds were possible, and by the 1980 season there were worries about safety and the lateral *g*-force effects that were being imposed on the drivers. In 1981 FISA set a minimum ground clearance under all cars of 6 cm, by which they intended to eliminate or substantially reduce 'ground effect'. But for Gordon Murray this change in the regulations was simply a stimulus to innovation. He said, 'The 1981 car, which was a World Championship-winning car, came absolutely from the regulation change. You sit there and you read the regulations and

think, how we are going to do it? How the hell can we get ground effect back?’

Gordon realised that the authorities had to accept that at some points during a race, any car’s ground clearance is going to be less than the 6 cm minimum, simply because of the effects of braking, or roll on corners, etc. His radical solution concept – which he said came as a sudden illumination after a long period of worrying at the problem – took advantage of this. Knowing that any driver-operated, mechanical device to alter the ground clearance was illegal, he focused on the physical forces that act on a car in motion. The braking and cornering forces he felt unable to work with because of their asymmetrical effects on the car, but the downforce pressure from airflow over a fast moving car will, if the car is well designed aerodynamically, push the car down equally over its whole length and width. The design challenge, therefore, as Gordon interpreted it, was to let the natural downforce push the car down at speed, and then somehow to keep it down when it slowed for corners, but allow the car to return to 6 cm ground clearance at standstill. Gordon had therefore framed the problem as one of sustaining a temporary lowering of the car, from natural forces, only whilst it was at racing speeds.

The ingenious solution that he developed incorporated hydro-pneumatic suspension struts at each wheel, connected to hydraulic fluid reservoirs. As the car went faster, the aerodynamic downforce pushed the body lower on its suspension and the hydraulic fluid in each suspension strut was pushed out into the reservoirs. The trick then was to find a way of letting the fluid return to the suspension struts only very slowly when the car slowed down. At cornering speeds, the suspension would stay low, but on slowing down and stopping at the end of the race, the fluid would return from the reservoirs to the suspension struts, giving the required 6 cm ground clearance. Gordon and his team developed such a system, using devices such as micro-filters borrowed from medical technology. The hydro-pneumatic suspension system is an example of radical innovation arising through framing the problem in a particularly focused way and then working creatively with basic physical forces.

2. Comparison of strategies

Although they stem from very different domains of design – bicycle luggage carrier, sewing machine, racing car – all three studies can be seen to demonstrate similarities in the approaches taken by the designers. Firstly, all three designers either explicitly or implicitly rely upon ‘first principles’ in both the origination of their concepts and in the detailed development of those concepts. Victor Scheinman relied strongly on the basic structural principle of triangulation to achieve the rigidity and stiffness that he considered important in the design of the backpack carrier. Gordon Murray stressed the need to ‘keep looking at fundamental physical principles’ for innovative design, and in his design to regain ground effect he focused on the physical forces that act on a car at speed. Kenneth Grange was less explicit about first principles, but it is clear that

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he adheres strongly to the modernist design principle of 'form follows function'; he approaches design problems 'by trying to sort out just the functionality, just the handling of it, and by-and-large out of that comes a direction.' This approach is evident in the sewing machine design, which is based very much on functional, usability aspects. So use of 'first principles' seems to be a crucial aspect in the knowledge and skills exercised by these three designers.

Secondly, all three designers appear to explore the problem space from a particular perspective in order to frame the problem in a way that stimulates and pre-structures the emergence of design concepts. In some cases, this perspective is a personal one that they seem to bring to most of their designing. For example, Kenneth Grange has a strong, emotional distaste for what he considers to be 'contradictions' in design, where the object is not well-adapted to its user and the patterns of use. He said, 'I think it's a question of what your attitude is towards anything, any working thing. My attitude is to want it to be a pleasure to operate.' And it was from operating the sewing machine that the essential concept of an asymmetrical layout emerged, and the rounded edges, which gave the clients the re-styling that they wanted. Victor Scheinman also used a distinct usability perspective in his problem structuring for the backpack carrier, for which, like Kenneth Grange, he drew upon his personal experience of using such a device. For Victor, it soon emerged that 'bicycle stability's an issue', and so 'it's got to be rigid, very rigid.' This led him to the triangularity of his design concept, which he then used to establish a distinctive appearance for the product, to satisfy the client's need for a unique selling feature. In both the sewing machine and the backpack carrier examples we see how the designer's personal problem framing and use of first principles led to a concept that reconciled the designers' goals (on behalf of the user) with the more commercial goals of the client. In the case of the racing car design, Gordon Murray's problem frame was governed by his focus on 'How the hell can we get ground effect back?' in order to achieve his goal of the fastest car, whilst satisfying the criteria set by the FISA regulations. This problem frame, and reliance upon first principles of 'basic physics', led him to the unique concept of the hydro-pneumatic suspension system. For these three designers, therefore, their problem framing arises from the requirements of the particular design situation, but is strongly influenced by their personal motivations, whether they may be altruistically providing pleasure for the product user, or competitively achieving the fastest car despite the regulations.

Finally, it seems from these three examples that perhaps creative design arises especially when there is a conflict to be resolved between the (designer's) high-level problem goals and the (client's) criteria for an acceptable solution. Such a conflict is particularly evident in Gordon Murray's design strategy, which was to challenge and somehow circumvent the criteria set by the technical regulations. In Kenneth Grange's case, the potential conflict was with the client's criteria for a

product re-styling job, whereas his goal was to provide the user with an enhanced affordance of use from the product. As he said, 'You are almost invariably brought in by somebody who has got a very elementary commercial motive in changing the perception of the product. It's extremely unusual to be brought in to approach it from this usability, this function theme.' A very similar conflict was resolved by Victor Scheinman, when he reconciled the user's need for a stable, rigid product, with the client's commercial need for a product that had some distinctive marketing feature.

These similarities in strategy are illustrated in Figure 1. In each case, at the upper level there is a conflict, or potential conflict, between what the designer seeks to achieve as the highest goal and what the client sets as fundamental criteria. At the intermediate level, the designer frames the problem in a personal way, and develops a solution concept to both match that frame and satisfy the criteria. At the lower level, all three designers use first principles of basic physics, engineering and design to bridge between the problem frame and a solution concept.

A model that encapsulates and generalises the particulars of all three examples is given in Figure 2. At the lowest level the designer draws upon explicit, articulated knowledge of first principles, which may be domain specific or more general scientific knowledge. At the intermediate level is where strategic process knowledge is especially exercised, and where that knowledge is more variable, situated in the particular problem and its context, tacit and perhaps personalised and idiosyncratic. At the higher level there is a mix of relatively stable, but usually implicit goals held by the designer, the temporary problem goals, and fixed, explicit solution criteria specified by the client or other domain authority.

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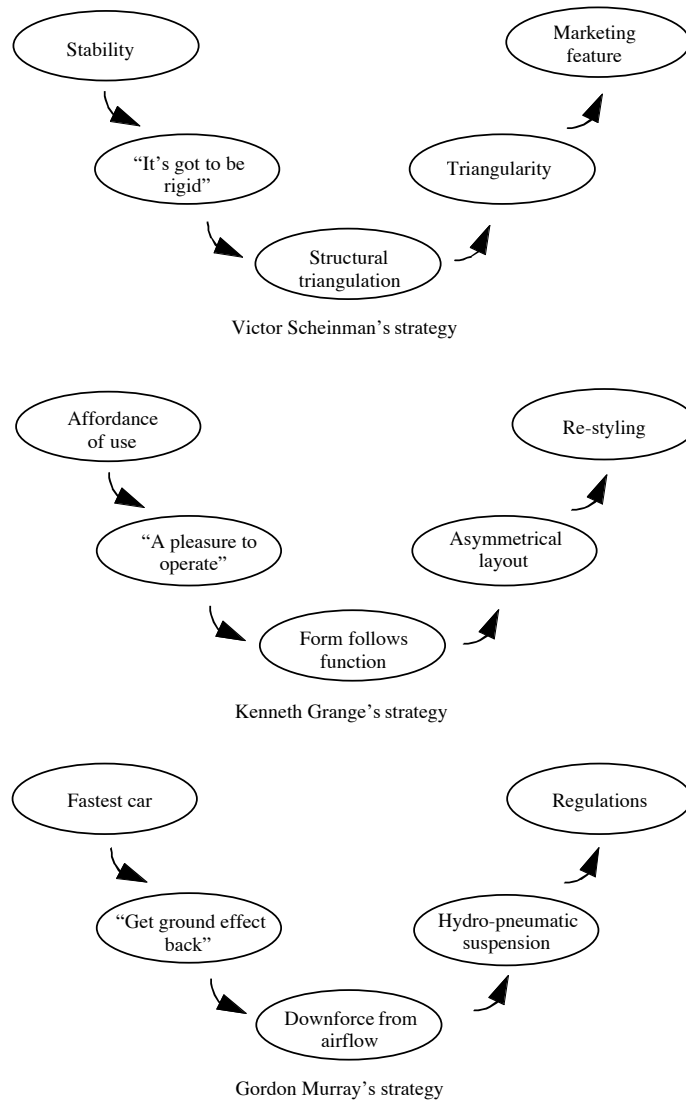


Figure 1. The three designers' strategies

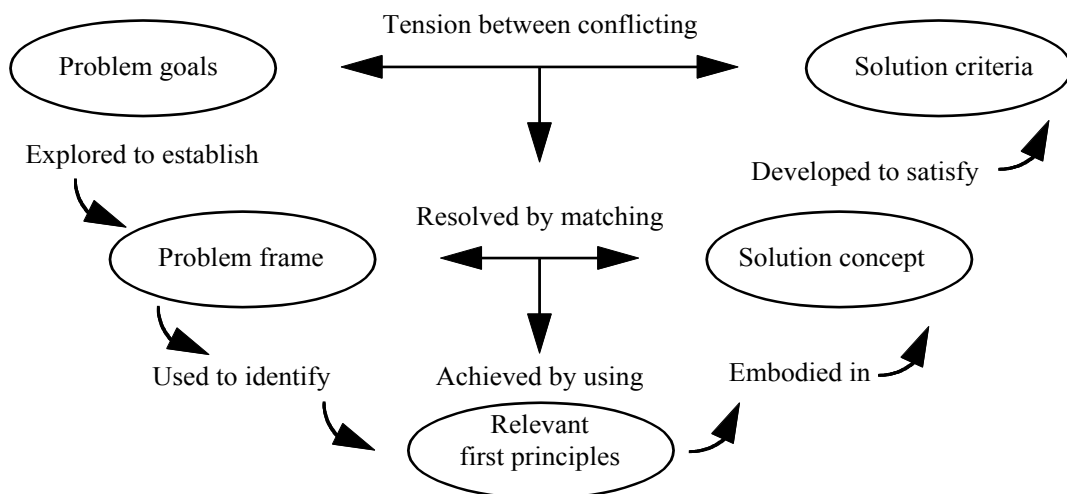


Figure 2. General model of creative strategies followed by all three designers

3. Conclusions

Three key process aspects appear to be common to all three designers: 1) taking a broad 'systems approach' to the problem, rather than accepting narrow problem criteria; 2) 'framing' the problem in a distinctive and sometimes rather personal way; and 3) designing from 'first principles'. These are all aspects that have been (separately) recommended by design theorists or methodologists from time to time. For instance, Jones (1981) recommends a systems approach; Schön (1983) has identified the importance of 'problem framing'; and authors such as French (1985) and Pahl and Beitz (1984) have stressed the values of 'first principles' as design guides in engineering. However, such insights and recommendations have not, in general, been based on much apparent evidence or empirical study. The studies presented here therefore lend some credence to such insights, and perhaps offer more objective evidence about the nature of skilled, expert design behaviour.

The general model presented in Figure 2 also attempts to integrate the separate insights, and perhaps offers a broader understanding of expertise in design. For example, although use of 'first principles' is often stressed in design education and practice, it is not evident *which* particular first principles are relevant to call upon until a problem frame has been established. The model, and the examples, perhaps also help to articulate some more detailed features, in the context of design, of the general observation often made by others (Ericsson and Smith, 1991) of the 'breadth-first' approach of experts in comparison with the 'depth-first' approach of novices.

From the analysis of the three examples, it appears that there are similar aspects to the creative strategies adopted by all three exceptional designers. It is perhaps surprising to see such commonalities between the three, considering the great disparity between the design projects in which they were engaged. However, although there are similarities in creative strategies across domains, this does not necessarily mean that experts can successfully switch practice between domains. Ericsson and Lehmann (1996) found that the superior performance of experts is usually domain-specific, and does not transfer across domains. Extensive training within a domain still seems to be crucial to professional expertise.

It is also worth commenting on the fact that the creative process similarities in these studies emerged from two quite different kinds of study – retrospective interviews and a concurrent protocol analysis. Nevertheless, there remain methodological problems of verifying the accuracy or relevance of the analyses that we and others have so far been able to make of the skills of exceptional designers. The difficulties of studying the performance of such people in formal ways may always limit the validity of the analyses, but more studies of expert and exceptional designers might lead to a more informed consensus about how design skills are exercised by experts, and on the nature of expertise in design.

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