“Research in Design Thinking”, in N. Cross, K. Dorst and N. Roozenburg (eds.), *Research in Design Thinking*, Delft University Press, Delft, 1992, pp. 3-10.

Research in Design Thinking

Nigel Cross

Faculty of Industrial Design Engineering,
Delft University of Technology, NL
and Faculty of Technology,
The Open University, UK

Introduction

Designing is something that people do. Animals do not do it, and machines (so far) do not do it. The ability to design is a part of human intelligence, and that ability is natural and widespread amongst the human population. It appears that some people have this ability more highly-developed than other people - either through some genetic endowment or through social and educational development. In fact, some people are very good at designing. Therefore it seems natural that a major part of design research should be concerned with trying to understand just how it is that people do design. This kind of research is what we are calling 'research in design thinking'. The purpose of my paper is to review some of this research, to provide a background and context for the papers that are to follow.

Research Methods

For at least thirty years there has been a slow but steady growth in research in design thinking - the pioneering paper is perhaps the study of engineering designers by Marples (1961). Research methods that have been used have included the following:

- Interviews with designers

These have usually been with designers who are acknowledged as having well-developed design ability, and have usually been unstructured interviews which sought to obtain these designers' reflections on the processes and procedures they use - either in general, or with reference to particular works of design.

- Observations and case studies

These have usually been focused on one particular design project at a time, with observers recording the progress and development of the project either contemporaneously or post-hoc. Both participant and non-participant observation methods have been included, and both real and artificially-constructed design projects have been studied.

- Protocol studies

This more formal method has usually been applied to artificial projects, because of the stringent requirements of recording the protocols - the 'thinking-aloud' and associated actions of subjects asked to perform a set design task. Both inexperienced (usually student) designers and experienced designers have been studied in this way.

- Controlled tests

By these I mean the kinds of tests conducted under controlled, laboratory conditions, in which subjects are required to perform a specialised task, and data on their performance is recorded and analysed. The models for these kinds of tests are the controlled laboratory studies of psychology research. There are relatively few controlled tests in design research.

- Simulation trials

A relatively new development in research methodology has been the attempt to simulate human thinking through artificial intelligence techniques. There are as yet few examples of this method being used in design research. Although AI techniques may be meant to supplant human thinking, research in AI can also be a means of trying to understand human thinking.

• Reflection and theorising

As well as the empirical research methods listed above, there has been a modest history in design research of theoretical analysis and reflection upon the nature of design thinking.

We therefore have a varied and probably adequate set of methods for research in design thinking. The set ranges from the more abstract to the more concrete types of investigation, and from the more close to the more distant study of actual design practice. The studies themselves have ranged over naïve or non-designers, through inexperienced or student designers, to experienced and expert designers, and even on to forms of non-human, artificial intelligence.

Research Results

Although the amount of research in design thinking is not huge, and the results of that research are varied and often unconfirmed by repeat studies, I believe that some consistent patterns in those results can be discerned. Here, I would like to present my interpretation of those patterns in three main areas: how designers formulate problems, how they generate solutions, and the cognitive strategies they employ.

Problem Formulation

At the start of a design project it is often not at all clear what 'the problem' is; it may have been only loosely defined by the client, many constraints and criteria may be un-defined, and everyone involved in the project may know that goals may be re-defined during the project. It is widely accepted that design problems are a category of ill-defined problems. Despite the prescriptions of many design theorists, designers do not normally tackle these problems by first attempting to define them rigourously or analytically. Rather, the following features of problem formulation by designers have been observed.

• Designers explore problem-and-solution together, using 'languages' of drawing and modelling

This was observed in an early protocol study of architects by Eastman (1970), who found that:

> One approach to the problem was consistently expressed in all protocols. Instead of generating abstract relationships and attributes, then deriving the appropriate object to be considered, the subjects always generated a design element and then determined its qualities.
> [...]
> The most important general finding from these studies thus far has been the significance of representational languages to problem-solving ability.

Schön's (1983) more recent observational studies of design tutors have also reinforced the central role of drawing as a modelling language of design, and of the way solution-and-problem are explored together through this medium. According to Schön, this exploration is almost conversational between the external representation and the designer's internal cognitive model of the problem-and-solution:

> [The designer] shapes the situation, in accordance with his initial appreciation of it; the situation "talks back", and he responds to the back-talk.

The slipperiness of the relationship between problem and solution in designing is conveyed in the comments of an expert designer - the furniture designer Geoffrey Harcourt, interviewed by Davies (1985), and discussing how a particular design emerged:

> As a matter of fact, the solution that I came up with wasn't a solution to the problem at all. I never saw it as that.....But when the chair was actually put together [it] in a way quite well solved the problem, but from a completely different angle, a completely different point of view.

In designing, 'the solution' does not arise directly from 'the problem'; the designer's attention oscillates, or commutes, between the two, and an understanding of both gradually develops, as Archer (1979) has suggested:

> The first thing to recognize is that "the problem" in a design problem, like any other ill-defined problem, is not the statement of requirements. Nor is "the solution" the means ultimately arrived at to meet those requirements. "The problem" is obscurity about the requirements, the practicability of envisageable provisions and/or misfit between the requirements and the provisions. "The solution" is a requirement/provision match that contains an acceptably small amount of residual misfit and obscurity. Thus the relationship between design problem and design requirements and design provision lies along one axis and the relationship between design problem and design solution lies along another axis. The design activity is commutative, the designer's attention oscillating between the emerging requirement ideas and the developing provision ideas, as he illuminates obscurity on both sides and reduces misfit between them.

- <u>Designers use alternative solution conjectures as the means of developing their understanding of the problem</u>

Since 'the problem' cannot be fully understood in isolation from consideration of 'the solution', it is natural that solution conjectures should be used as a means of helping to explore and understand the problem formulation. This was recognized by Marples (1961) from his observations of engineering designers, although it was also clear that the designers were not necessarily adept at generating several alternative solutions in order to expand their search space. Marples commented that:

> The nature of the problem can only be found by examining it through proposed solutions, and it seems likely that its examination through one, and only one, proposal gives a very biased view. It seems probable that at least two radically different solutions need to be attempted in order to get, through comparisons of sub-problems, a clear picture of the "real nature" of the problem.

So we know that designers formulate problems essentially in terms of potential solutions, and that they use potential solutions as a means of exploring the problem as given. Frequently they 'solve' an alternative to the problem as given. They need to generate alternative solutions as a means of helping their problem exploration, but they are not always very good at generating an appropriate range of alternatives.

Solution Generation

If the solution does not arise directly from the problem, then how, and from where, does it arise? Expert designers tend to emphasise the role of 'intuition' in the generation of solutions, and 'creativity' is regarded as an essential element in design thinking. But a design solution is not an arbitrary construct - it usually bears some relationship to the problem as given, which is, after all, the starting point for considering solution possibilities. However, once again the prescriptions of the design theorists - such as exploring the whole solution space - are not usually followed in practice. The following features of solution generation have been found from observation of design practice.

• Designers impose additional constraints that narrow the solution space and help to generate concepts

In early observational studies of urban designers and planners, Levin (1966) realised that they 'added information' to the problem as given, simply in order to make a resolution of the problem possible. Levin saw this as like adding a 'missing ingredient':

> The designer knows (consciously or unconsciously) that some ingredient must be added to the information that he already has in order to arrive at an unique solution. This knowledge is in itself not enough in design problems, of course. He has to look for the extra ingredient, and he uses his powers of conjecture and original thought to do so.

Often, the 'missing ingredient' is a constraint on the geometrical form that the new design should take.

A similar conclusion was reached by Darke (1979) from her interviews with successful architects. In discussing particular designs, she saw that they had all used solution conjectures early in the design process, as a means of narrowing the solution space:

> The greatest variety reduction or narrowing down of the range of solutions occurs early on in the design process, with a conjecture or conceptualization of a possible solution. Further understanding of the problem is gained by testing this conjectured solution.

Darke also concluded that the architects had all found, generated or imposed particular strong constraints, or narrow sets of objectives, upon the problem, in order to help generate the early solution concept. These constraints and objectives are the 'missing ingredient' of Levin; Darke called them the 'primary generators' of the solution concepts.

• Designers change goals and adjust constraints during the process of designing

Problem goals and constraints are not sacrosanct, and designers exercise the freedom to change goals and constraints during solution generation, as understanding of the problem develops and definition of the solution proceeds. This was a feature of designer behaviour noted by Akin (1979) from his protocol studies:

> One of the unique aspects of design behaviour is the constant generation of new task goals and redefinition of task constraints.

An earlier case study of the design of a school, by Krauss and Myer (1970), had also noted this behaviour. They reported how one particular element - the school music room - was shifted around in its location in the plan, as the designers changed goals and constraints during the process of designing:

> For example, it moved south to take advantage of a dip in the site which permits it to have a greater volume, to get more sun, to have a distinctive view, and to be near the

> entry and circulation focus. Note that the designers have dropped one constraint: they no longer consider it necessary for the music room to be near the major play area. They have added other constraints: the music room should have a prominent location and greater volume. In other words, the designers are dropping old concerns and raising new ones, and they even change their minds again as they create forms and react to them.

This aspect of designer behaviour is also evident in engineering design. It may be viewed negatively as evidence of designers adjusting goals and constraints in order to make their solution concepts 'work' (see below), or more positively as a learning experience for the designer, which is inevitable in resolving ill-defined problems. The latter view is taken by Waldron and Waldron (1988), in their comments on an engineering design case study:

> The premises that were used in initial concept generation often proved, on subsequent investigation, to be wholly or partly fallacious. Nevertheless, they provided a necessary starting point. The process can be viewed as inherently self-correcting, since later work tends to clarify and correct earlier work.

- Designers resist radical reformulations of solution concepts

Although designers change goals and constraints as they design, they hang on to their major solution concept for as long as possible, even when detailed development of the scheme throws up difficult problems. Part of the changing of goals and constraints is associated with resolving such difficulties without having to start again with a major new concept.

From his case studies of architectural design, Rowe (1987) observed that:

> A dominant influence is exerted by initial design ideas on subsequent problem-solving directions....Even when severe problems are encountered, a considerable effort is made to make the initial idea work, rather than to stand back and adopt a fresh point of departure.

So we know that designers generate solutions with the aid of self-imposed constraints that appear to be necessary simply in order to make a resolution of the problem possible at all. This leads to initial concepts that may, in fact, subsequently be found to have been based on invalid premises, and that may be be difficult to resolve in detail. Nevertheless, designers resist changing their initial concepts. Designers exercise considerable freedom in changing the problem goals and constraints as designing proceeds; this may be partly to take advantage of opportunities that emerge in the developing design solution, and partly to avoid having to change the original concept.

Cognitive Strategies

It has been argued, and there is some evidence to suggest that designers use forms or styles of reasoning that are particular to design thinking. What we know about designers' approaches to problem formulation and solution generation already indicate some particularities. Observations about the cognitive strategies of designers include the following.

- Designers habitually treat problems *as though* they are ill-defined problems

One of the concerns in other areas of design research has been to formulate design problems in *well*-defined ways. This is intended to overcome some of the inherent difficulties of attempting to solve ill-defined problems. However, designers' cognitive strategies for problem-solving are obviously based upon their normal need to resolve ill-defined problems. Thomas and Carroll (1979) carried out several observational and protocol studies of a variety of problem-solving tasks, including design tasks. One of their findings was that designers' behaviour was characterised by their treating the set problems *as though* they were ill-defined problems, even when they could also be treated as well-defined problems, for example by changing the goals and constraints. Thomas and Carroll concluded that:

> Design is a type of problem solving in which the problem solver views the problem or acts as though there is some ill-definedness in the goals, initial conditions or allowable transformations.

- Designers use a solution-focused cognitive strategy for problem resolution

We have already seen that designers move rapidly to early solution conjectures, and use these conjectures as a way of exploring and defining problem-and-solution together. This is not a strategy employed by all problem-solvers, many of whom attempt to define or understand the problem fully before making solution attempts. This difference in cognitive strategies was observed by Lawson (1979), in his controlled tests of problem-solving behaviour in which he compared scientists with architects:

> The scientists were [attempting to] discover the structure of the problem; the architects were proceeding by generating a sequence of high-scoring solutions until one proved acceptable....[The scientists] operated what might be called a problem-focussing strategy....architects by contrast adopted a solution-focussing strategy.

- Designers use a particular form of reasoning

Several theoretical arguments have been advanced in support of the view that design reasoning is different from the conventionally-acknowledged forms of inductive and deductive reasoning. For example, March (1976) distinguished design's mode of reasoning from those of logic and science:

> Logic has interests in abstract forms. Science investigates extant forms. Design initiates novel forms. A scientific hypothesis is not the same thing as a design hypothesis. A logical proposition is not to be mistaken for a design proposal. A speculative design cannot be determined logically, because the mode of reasoning involved is essentially abductive.

March drew upon the work of the philosopher Peirce in identifying the appropriate mode of reasoning as 'abductive' in character. March himself preferred to use the term 'productive' reasoning for that which produces a design proposal. Several later authors have claimed that Peirce's 'abductive' reasoning is not actually appropriate to design, and have suggested, for example, concepts of 'recursive' reasoning (Zeng and Cheng, 1991) and 'reductive' reasoning (Eekels, 1983). A comprehensive analysis of the forms of reasoning led Eekels and Roozenburg (1991) to the conclusion that the appropriate form of reasoning could in fact only properly be called 'design' reasoning (Roozenburg, 1992).

So we know that designers use a cognitive strategy for designing which *assumes* that the problem is ill-defined, and which is therefore a solution-focused strategy. The form or mode of reasoning in design is particular to design itself.

Conclusion

I have attempted to show that there is a reasonable history of research in design thinking, with some some consistent patterns in the results upon which we can base our understanding of how designers think. At the moment, we seem to have a fairly rich picture of design thinking, but we lack a successful, simplifying paradigm of design thinking. Those simplifying paradigms which have been attempted in the past - such as viewing design simply as problem-solving, or information-processing, or decision-making, or pattern-recognition - have failed to capture the full complexity of design thinking.

The lack of an adequate, simplifying paradigm is perhaps something which inhibits the transfer of knowledge from research into practice and education. Certainly we have to acknowledge that the impact of design research on practice and education has been disappointingly slight.

Apart from seeking a new simplifying paradigm for design thinking, I think that there are two principal questions to be addressed at this meeting. Firstly, what are the implications for design education of what we know about design thinking? To this there is a supplementary question - Are models of professional practice behaviour appropriate models for student learning behaviour? Secondly, what further research is needed? To this there is another supplementary question - Do we just perpetuate how designers think now, or attempt to change it?

References

Akin, Ö. An Exploration of the Design Process, *Design Methods and Theories*, Vol 13, No 3/4, 1979.

Archer, L. B. Whatever Became of Design Methodology? *Design Studies*, Vol 1 No 1, 1979.

Darke, J. The Primary Generator and the Design Process, *Design Studies*, Vol 1, No 1, 1979.

Davies, R. A Psychological Enquiry into the Origination and Implementation of Ideas, *MSc Thesis*, Dept. of Management Sciences, UMIST, Manchester, 1985.

Eastman, C. M. On the Analysis of Intuitive Design Processes, in Moore, G. T. (ed.) *Emerging Methods in Environmental Design and Planning*, MIT Press, Cambridge, Ma., 1970.

Eekels, J. Design Processes Seen as Decision Chains: Their Intuitive and Discursive Aspects, in Hubka, V. and Andreasen, M. M. (eds.) *WDK10: Proceedings of ICED83 (Appendix)*, Heurista, Zurich, 1983.

Eekels, J. and Roozenburg, N. *Productontwerpen, structuur en methoden*, Lemma, Utrecht.

Krauss, R. I. and Myer, J. R. Design: A Case History, in Moore, G. T. (ed.) *Emerging Methods in Environmental Design and Planning*, MIT Press, Cambridge, Ma., 1970.

Lawson, B. R. Cognitive Strategies in Architectural Design, *Ergonomics*, Vol 22, No 1, 1979.

Levin, P. H. Decision Making in Urban Design, *Building Research Station Note EN 51/66*, BRS, Watford, 1966.

March, L. J. The Logic of Design, in March, L J (ed.), *The Architecture of Form*, Cambridge University Press, Cambridge, 1976.

Marples, D. *The Decisions of Engineering Design*, Institute of Engineering Designers, London, 1960.

Rowe, P. *Design Thinking*, MIT Press, Cambridge, Mass. 1987.

Schön, D. A. *The Reflective Practitioner*, Temple-Smith, London, 1983.

Thomas, J. C. and Carroll, J. M. The Psychological Study of Design, *Design Studies*, Vol 1, No 1, 1979.

Waldron, M. B. and Waldron, K. J. A Time Sequence Study of a Complex Mechanical System Design, *Design Studies*, Vol 9, No2, 1988.

Zeng, Y. and Cheng, G. D. On the Logic of Design, *Design Studies*, Vol 12, No 3, 1991.