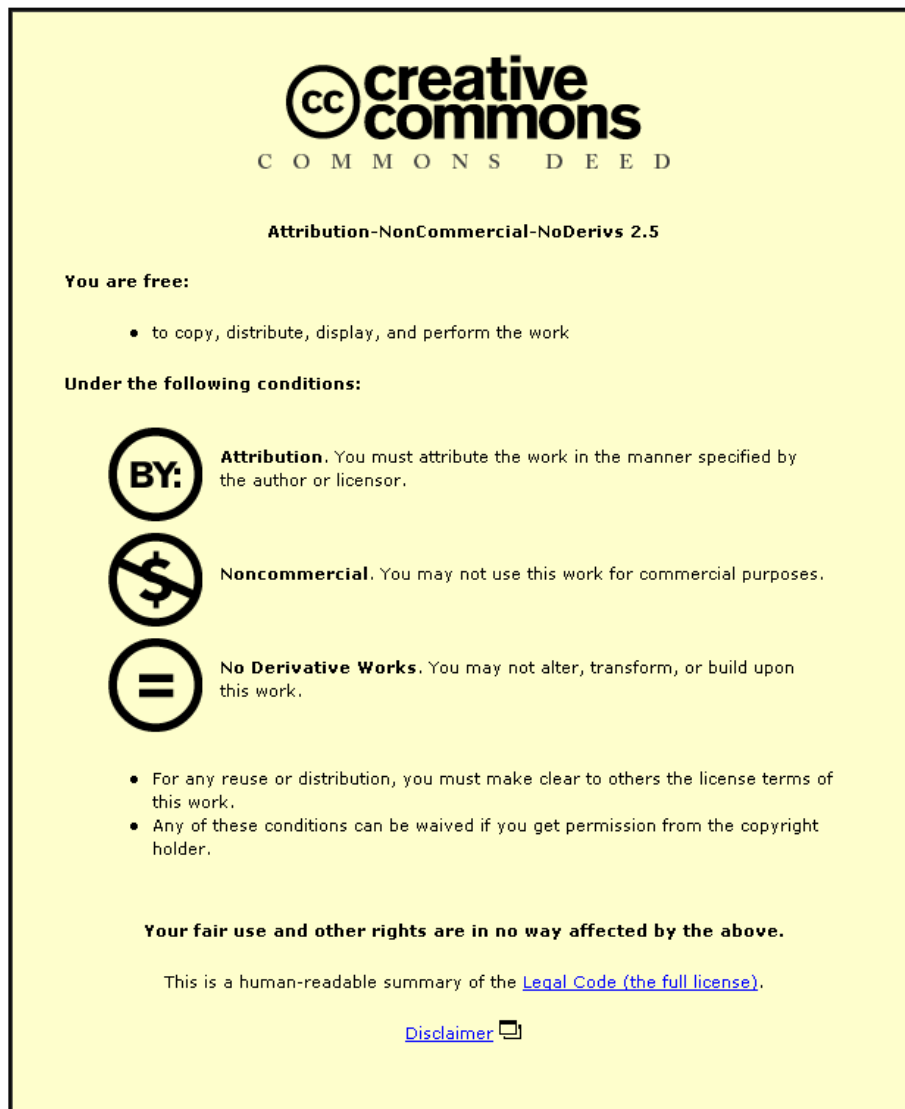


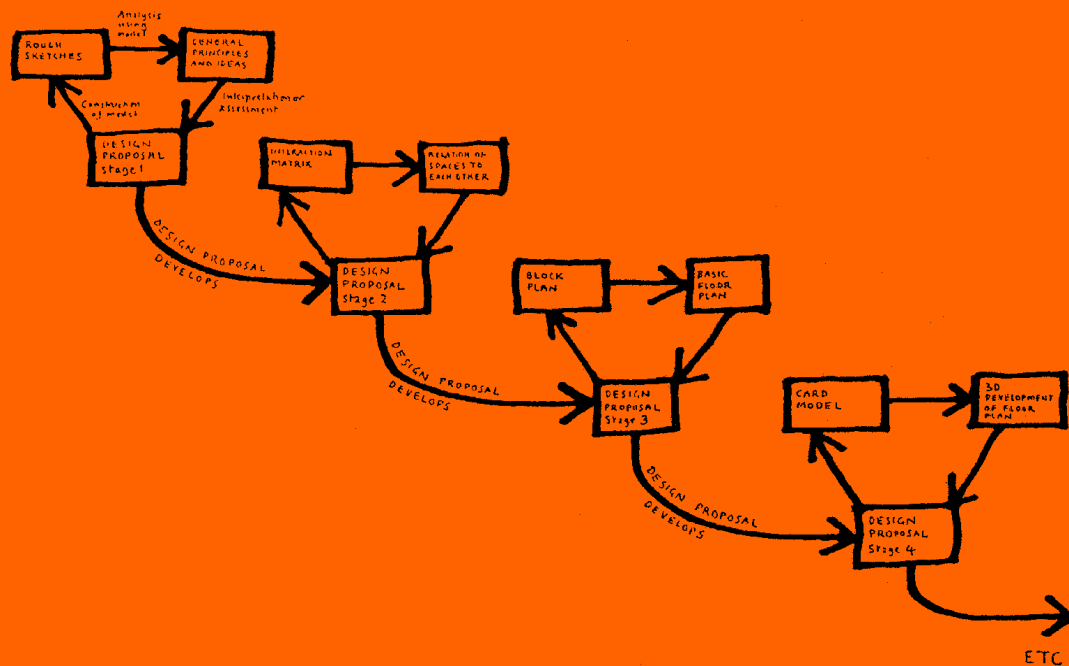
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MODELLING: THE LANGUAGE OF DESIGNING

Design: Occasional Paper No 1
Phil Roberts Bruce Archer Ken Baynes



Department of Design and Technology
Loughborough University of Technology

Design: Occasional Papers

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But 'design' is also commonly used as a verb. Again at the high level of generality, designing may be characterised as an intentional activity: to do with bringing about change. More specifically - and as with Design when used as a tag for a field - what 'designing' is intended to mean relates also to the specific area in which it is used, and by whom. The field has many specialist communities, many languages of discourse and, within and around those, different persuasions and differing voices.

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Loughborough University of Technology
Department of Design and Technology

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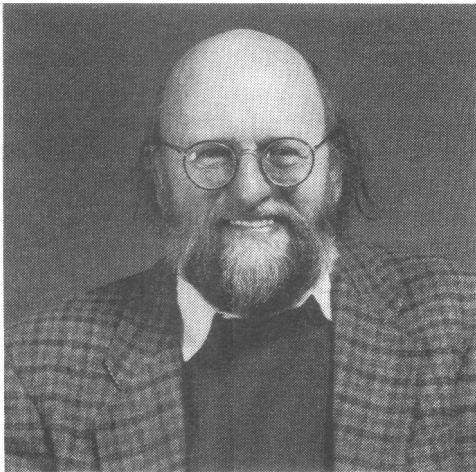
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INTRODUCTION

The subject matter of this Occasional Paper is 'Modelling: the Language of Designing'. Several observations are worth noting in that title. First, modelling is related to the activity. Secondly, it reflects the view that modelling is the essential 'language' of that distinctive activity. Thirdly, while modelling is the contributors' prime object of attention, they use - in the main, and necessarily - natural language as the medium of their discourse. So the phrase has implicit within it some distinctions: between (i) modelling-as-language and (ii) natural language; and between (iii) modelling-as-language, and (iv) the meta language (of discourse, about modelling) that employs (v) natural language. Finally, the title itself may serve, perhaps, as a signal of the difficulties inherent in articulating and discussing phenomena which are not linguistic.

Not surprisingly, therefore, the contributors approach, probe, and consider 'modelling' from different angles in order to contribute towards a more holistic understanding.

The first paper contextualises modelling, and draws attention to distinctions between the purposes of professional design and technological activity and the 'same' activity used as a medium of general education. A characterisation of design activity is offered; and cognitive modelling is identified as a manifestation of a distinctive capacity of mind that is central to design and technological activity. That paper, incidentally, was written in 1977: that is an indicator, in part, of the notion that 'conversational communities' develop through engaging in a 'running conversation' over time. The second paper illustrates that even better: it originated (in the mid 1970s) within the 'ideas culture' of the Design Education Unit of the Royal College of Art. There, it was a part of the discussion generated with mid-career students pursuing higher degree programmes. It offers a sharper probing into the nature of cognitive modelling.

'As Complex as ABC' returns to the general. But it indicates also the need for students of design to engage with scholars in other areas, notably linguistics. The next paper, 'The Ethics of Representation', presents a quite different perspective again: on the political and ethical dimension of design and technological activity. The issues are to do with access to or participation in decision making, and with the relations between decision making and societal and cultural contexts. This is an area in which much lively work can be anticipated. For example, some re-valuation of mainstream specialist conceptions might be anticipated as the 'end-users' - that term itself being profoundly conventional - of design and technology gain a voice; or, from another starting point, academic feminism may contribute towards a better understanding of design (as well as to the development of its principles and practices).

Philosophers of knowledge, linguistic philosophers, and cognitive psychologists are already contributing towards the understanding of modelling. 'The Role of Modelling in the Industrial Revolution' offers suggestive historical insights in its consideration of the importance of drawing - a particular instance of modelling - in the context of the Industrial Revolution.

The final contribution, 'Of Models, Modelling and Design', is a brief introduction to the discussion of some questions and issues that have arisen through reflecting upon the generally low status attributed to models and cognitive modelling.

What holds this short collection together is a focus on modelling; the scope for further publications is enormous. The sub-title might well be, 'Towards a Research and Development Agenda'.

Phil Roberts

Design and Technological Awareness in Education

BRUCE ARCHER AND PHIL ROBERTS

(In the course of work in the Royal College of Art's Design Education Unit, there has been [in the 70s] considerable discussion on the relation of 'technological awareness' to design activity. This paper represents part of that discussion.)

Design, like science or scholarship, is the product of a distinctive kind of activity and is governed by a distinctive capacity of mind.

Designing and the development of technological awareness, as educative activity, consists in relating and drawing attention to purpose, the self, and the means and significance of man's intervention in his habitat. Design activity, when distinguished from design-educational activity, is directed towards the manipulation of things and systems so as to achieve the most acceptable and practicable fit between a particular set of desires and needs, on the one hand, and a particular means for fulfilling them, on the other.

But the development of things and systems is not necessarily sufficient as the purpose of design activity in general education. The things and systems devised or commented upon by a child are indicators of the development of the cognitive modelling capacity which is the core of learning-through-designing. That is to say, the educational ends of design activity are, primarily, the development of the cognitive modelling capacity of the pupils. This capacity is manifested and developed in intentional activity, of which design is a sub-class. Design activity is concerned more with the attainment of a result than with the acquisition of knowledge. Design educational activity is concerned not only with achieving an effective result, it is also concerned with the development of the pupils' knowledge and understanding. This knowledge and understanding is to do with self, self in relation to made things and systems, and the appreciation of the effect of his or her own, and other people's activity in and on the world.

Design activity is always a grappling with the unknown. Whilst design activity in a particular instance will demand knowledge and understanding of particular kinds, some of this demand may be met after the need for it has been appreciated rather than before the task is started. Indeed, some phenomena may be legitimately treated with in an empirical way, without their ever becoming truly understood. The legitimacy and efficacy of a design result resides in the demonstrability and appreciation of its appropriateness to purposes rather than in the clarity of understanding of the principles governing the production of the result.

Design activity is characterised by being specific, that is, by being concerned with the attainment of a particular effect rather than with the drawing of generalisable conclusions; by being holistic, that is, by being concerned with the integration of variables rather than with the isolation of them; and by being commutative, that is, by being concerned as much with the fitting of ends to means as it is with fitting means to ends.

It is a problem-centred activity, but it is distinguishable from some other sorts of problem-solving activity by the fact that it is chiefly concerned with 'ill-defined problems'. In this context, the term 'problem' refers to the presently-existing state of affairs; it does NOT refer to the statement of requirements which a (possible) thing or system is expected to meet. Nor does the term 'solution' refer to the design arrived at, that is, to the resulting tangible thing or system. The design act is one of discovering and elaborating and adapting requirements and provisions to match one another. The problem is obscurity about what the requirements might be,

ignorance as to what sorts of provisions might be suitable and uncertainty as to how well the one might fit the other. The solution is the achievement of a requirement/provision match that is both sufficiently described and demonstrably a good enough fit.

Design problems are described as 'ill-defined' because there is no way of arriving at a provision description merely by the reduction, transformation or optimisation of the data in the requirement specification. By the same token, it is rarely possible to determine whether or not the finished design is 'the correct', 'the only' or 'a necessary' answer to the requirements. It must usually be possible, of course, to establish whether or not the design is 'a proper' or 'an acceptable' answer to the requirements. It may or may not always be possible to judge whether or not one 'proper' answer to the requirements is better or worse than some other 'proper' answer. Where such doubts do NOT exist, the problem is not 'ill-defined' and might therefore have been resolvable by scientific or mathematical methods rather than designerly methods. Most real-world problems encountered by most people are 'ill-defined'.

The conduct of design activity is made possible by the existence in man of a distinctive capacity of mind, analogous with the language capacity and the mathematical capacity. This is the capacity for cognitive modelling. A person acting in the role of designer or appraiser of designs forms images 'in the mind's eye' of things and systems as they are, or as they might be, and evaluates them and transforms them so as to gain insights into their structure and into the likely quality of fit between alternative conceivable configurations and the interaction of perceivable requirements. Its strength is that light can be shed on intractable problems by transforming them into terms of all sorts of schemata drawn from the agent's experience no matter how logically improbable. Cognitive modelling is not limited to spatial configurations. Aspects such as colour, texture, sound, flavour and anything else relevant to the system can be imaged and manipulated. Cognitive modelling is independent of language or symbol systems, but when appropriate, the concepts modelled can be translated into or supplemented by language or notational terms. The image is usually externalised through models and simulations, such as drawings, diagrams, mock-ups, prototypes and, of course, where appropriate, language and notation, or it can be embodied in the construction or enactment of the emerging responses. These externalisations capture and make communicable the concepts modelled.

All design activity involves continual appraisal and reappraisal of the meritoriousness of existing realities and alternative propositions being handled. There is also a transitive form of the same activity which is wholly or largely concerned with the appreciation of states of affairs and with the choosing and deciding, rather than with the creation of things and systems. All human beings rely heavily on cognitive modelling in both these forms for the pursuit of their everyday activity. Most pursue at least occasional explicitly designerly activity when they are appraising, using or devising things or systems. Technological awareness is the ability to bring knowledge and skill to bear in the pursuit of intentional activity.

In schools, whilst the application of designerly and technological awareness cuts across the whole curriculum, there are some curriculum areas that embrace explicitly design-related activity, in whole or in part. These include art, craft, dance, drama, environmental studies, home economics and technology. Such areas can be described as comprising the design dimension of the curriculum. Each and any of the subjects in the design areas, when well taught, can develop the capacity for cognitive modelling and skill in the handling of ill-defined problems, and can transmit the values underlying the essential design concepts of specificity, holism and commutativity in dealing with the practical world. Each has its particular sorts of knowledge and skill but all contribute to the general development of technological awareness.

A Definition of Cognitive Modelling in relation to Design Activity

BRUCE ARCHER

(These notes were intended to clarify and carry forward some of the ideas at the centre of the debate in the Design Education Unit of the Royal College of Art on the nature of design activity.)

The term 'cognition' is intended to embrace all those processes of perception, attention, interpretation, pattern recognition, analysis, memory, understanding and inventiveness that go to make up human consciousness and intelligence. Philosophers of mind and cognitive psychologists tend now to talk of cognition as the mental function of construing sense experience as conceptions, and of relating conceptions with one another. The use of the word 'construe' is significant. It is intended to acknowledge the circumstance that the individual conscious being cannot 'know' anything of the reality beyond its own skin except by the collection and interpretation of the signals received by its sense organs. These signals are overlaid by all sorts of irrelevance, interference and noise, and distorted on reception by all sorts of errors, illusory juxtapositions and omissions. Moreover, in the neurological sense, the signals are ultimately received as electrochemical impulses scattered over different parts of the grey matter of the brain. There is no screen anywhere in the mind on to which a collected picture is projected. The conception in the mind which is built from these scattered impulses is that of a coherent set of signals betraying the presence of a supposedly equally coherent causal phenomenon beyond the sense organs. Subsequent patterns of signals may reinforce or deny the conception, or permit the useful association of conceptions into greater conceptions. When they are sufficiently integrated these constructions in the mind become a general cognitive model of external reality. Since the cognitive model is all the individual consciousness has, as evidence of external reality, then for all practical purposes the cognitive model is seen as if it were that reality. Memory and imagination are those further capacities of mind which are capable of conjuring up models of reality in the absence of causative sense data.

There is evidence that the human mind is predisposed to construe sense experience in particular ways, so that conceptions of space, form, object-coherence, colour, temperature, sound and so on, are common to all human beings. These could be called categories of perception. There is also evidence that the human mind is predisposed to seek similarities within and between its accumulating conceptions, and to assign these to categories. It is from the labelling of conceptions and categories, and from the labelling of the relations between conceptions and categories that rational thought springs. It is from the recognition of pattern in and amongst conceptions, and in and amongst categories, and from the recognition of pattern amongst the kinds of relations which conceptions and relations have with one another, that designerly thought springs. There is a third predisposition of the human mind which lifts it above and beyond that of other sentient beings. This is the predisposition to assign symbols to represent conceptions, categories and relations. The use of symbols permits abstraction in inner thought, and the externalisation of thought for recording or communication purposes.

In the course of evolution the left half of the human brain has learned to specialise in the arts of categorisation from which is developed rational sequential thought, and in the use of digital symbol systems to construct language, mathematics and forms of notation. At the same time the right half of the human brain has learned to specialise in pattern recognition, and the use of presentational symbol systems to construct images, diagrams and other spatial forms of representation. Interplay between the two halves of the brain permits the pursuit of thought both to the highest levels of abstraction and to the furthest reaches of practical planning and design.

The terminology used in current dimensions can be clarified as follows:

The expression 'cognitive modelling' is intended to refer to the basic process by which the human mind construes sense experience to build a coherent conception of external reality and constructs further conceptions of memory and imagination. The expression 'imaging' is intended to refer to that part of cognitive modelling which construes sense data and constructs representations spatially and presentationally, rather than discursively and sequentially.

As Complex as ABC

BRUCE ARCHER

(This is one of a series of seminar papers which introduced a course in design research that was offered in the Department of Design Research at the Royal College of Art in the 1970s. The series formed a module called A Philosophy for Design.)

In the second seminar in this series, I introduced the twin notions that there is a distinctive area of human experience, skill and understanding that we can call design, spelt with a big D, equivalent to Science and the Humanities but distinguishable from them; and that the language of the Design area is modelling. I tried to support the first notion with argument on that occasion. I want to develop the second notion now. We can approach this subject from two directions: from the basis of design practice, as this is understood by architects, engineers, fashion designers, graphic designers, silversmiths and all the other kinds of design practitioner; and from the basis of the broader philosophy which sees Design as a general cultural phenomenon. Let us take the operational or professional view first.

It has sometimes been said that drawing is the language of design. There has certainly been an intimate relationship between drawing and design from time immemorial. Archeology yields exemplars of drawings of structures and implements from the most ancient civilisations. All the design professions today rely heavily upon drawings of various types for both the development of ideas and the communication of findings. If one extends the definition of drawing to include graphs, diagrams, vectorial analyses and all the other forms of graphical representation and communication, then drawing is not only a very important means for handling ideas in design, it is also a skill used in many disciplines and widely dabbled in, at least, by the general population.

Drawings are not the only means which designers use to represent ideas, things and systems, however. Physical models, formulations in mathematical or chemical or other notation, and verbal specifications or descriptions, are also widely employed. Several modern fields of enquiry, including systems research and computer science, have come in recent times to describe any act of employing one system, such as graphical representation or a physical model or a formulation in notation, to stand for another system, such as a structure or a mechanism or a designed object, as an act of modelling. A model is anything which represents anything else for informational, experimental, evaluative or communication purposes. Because professional designers are mainly trying to devise, evaluate and communicate facts about objects and systems which do not yet exist, and which would be expensive, time-consuming and sometimes dangerous to experiment with in reality, they spend much of their time constructing, manipulating and contemplating models of various kinds, especially graphical models. This fact alone does not justify a claim, however, that graphical models, or design models generally, constitute a language.

Linguistics

It is true that linguistics theorists define a language as a symbol system, and a symbol as something which stands for something else. Designer modelling techniques are certainly symbol systems. According to linguistics principles, however, in order to rank as a language, the collection of modelling means used in design would need to have: a lexicon, that is, a body of units of recognised meaning (eg words); a morphology, that is, a recognised way of constructing meaningful units from its morphemes or basic elements (eg letters); a syntax, that is, a recognised way of assembling units of meaning into coherent statements (eg sentences).

Does the system of design graphics or the larger system of design modelling possess these characteristics? Insofar as designers do indeed succeed in making coherent statements, one can guess that they do. The trouble is that no-one has formally tested these propositions.

Linguistics scholars recognise the existence of languages whose structure has not been formally analysed. The very term "lexicon" is used instead of the term "dictionary" in order to emphasise the fact. The act of compiling a formal dictionary from the informal lexicon is called lexicography. The study of the Natural morphology and syntax of a language and the identification of the rules that seem to govern them is called grammar. The design language has lacked its lexicographers and grammarians, but that does not necessarily make it any less a language. How have design teachers and practitioners seen it? On the whole, I think, the design professions have seen freehand drawing, technical drawing, graph drawing, diagram making, mathematical modelling, physical modelling and specification writing as a rack of quite separate tools to be taken down and used in quite different ways for quite different purposes. The same tool used in the same or different ways has had quite different purposes when used by different branches of the design professions. The possibility that there might be a common structure in their use and meaning did not really become of significance until the development of computer aids for use in design demanded rules for the conversion of graphical, numeric and alphabetical input and output from one form into another. Such rules have been found, and such conversions are now a commonplace.

This still leaves the possibility, however, that the rules constitute means for translating between quite different languages rather than between dialects of the same language, or even between quite different conceptual systems rather than between languages. Research into design activity at the professional level, at the Department of Design Research of the Royal College of Art and elsewhere, has raised such questions but has not answered them, or, indeed, found it necessary to answer them in a formal or testable way. Fortunately, however, so far as the present argument is concerned, there were parallel streams of enquiry which carried the issues forward.

Externalisation

One of these streams of enquiry was into the use of simulation techniques in design research. Workers in the fields of cybernetics and systems research use the term "simulation" to mean the technique of building logical models which copy or imitate the functional behaviour of the system modelled. This is distinguishable from system synthesis, which is the building of new systems for a given purpose, not in imitation of an existing system. System synthesis is system design, and thus is one of the classes of design activity in which design research is interested. System simulation is system modelling, and is thus one of the facets of design technique in which design research is interested. Cyberneticians and systems analysts have become very expert at the building of logical models and at experimenting with them. The conventions adopted by them for recording and describing system structure and system logic seem to me to come very close indeed to constituting a morphology and syntax for modelling as a language, although cyberneticians have not, so far as I know, attempted the daunting task of assembling a dictionary of the units of meaning in models generally. Moreover, when we came to apply the techniques of system simulation to the analysis of the activity of design teams, we found it appropriate to describe a designer's drawings and other models as external representations of ideas he had formulated and was manipulating in his mind. The significance of this hypothesis will emerge.

Another of the streams of enquiry going on in the Department of Design Research was, and is, the study, in conjunction with our colleagues on the fine arts side, of the art-making activity. Artists and craftsmen operate with a relationship between the output of their own hands and the end-product of their overall activity which is different from that experienced by designers. For a designer the drawing or mock-up or specification describes a product yet to be made. For the

artist and craftsman the drawing or artefact is the object itself. Furthermore, for the designer, the meaning or usefulness or quality embodied in the product is at least one or two stages still further removed, separated from his personal role by production and distribution and product usage and use environment and user's values and needs, and goodness knows what else.

For the artist or craftsman the meaning and value of his product is directly embodied in it. It is not simply a matter of the medium being the message, as MacLuhan put it. For many artists, the art-making act itself is the meaning. This telescoping of the complex connections between design act, medium, message, model, product, function, purpose and meaning which design research workers have had to contend with, has been immensely valuable. Not the least valuable has been the bringing into sharper focus of the relations between external reality; an observer's perception of external reality; his understanding or cognitive model of what that reality is and means, or could be and could mean; and his externalisation of that understanding through action or utterance. In 1928, an early linguistics scholar, I A Richards, offered one of the first and best definitions of communication, thus: communication takes place when one mind so acts upon its environment that another mind is influenced in a relevant way. In these terms, all art and design is communication and all externalisations of what the artist or designer has in mind are models.

Deep structure

The workers in both these streams of activity found inspiration in the writings of J Piaget, the Swiss educational psychologist who has given such edge to our understanding of the human mind's use of symbols in the development of understanding. So, too, did the team engaged in the study of the role of design as a subject for the education of children in secondary schools. I have already dealt at some length with the proposition that design can be considered as a broad area of understanding, extending beyond the limits of professional design activity, so I will restrict myself here to the language question. G E Moore and the Oxford school of philosophy had developed the argument during the 1940s that natural language is the basic and unavoidable matrix of all thought. Piaget, on the other hand, had identified in children three stages of learning: a pre-language and direct or sensorimotor stage which he called enactive learning; a language development and symbol recognition stage which he called iconic learning; and a language- and notation-using stage which he called abstract learning.

Many people concerned with design education would argue that there exist ways of knowing and kinds of knowledge concerned with doing and making and the material culture which either have not got beyond the enactive learning stage even for adults, or are handled abstractly by means of a language which is not the language of Science or the Humanities. Certainly it is very difficult to transmit through the medium of natural language or scientific notation knowledge of certain sorts of dextrous skill or sensory discrimination, or to render into natural language adequate equivalents of, say, musical notation or engineers' orthographic drawings of mechanisms, although people like patent agents and writers of codes of practice try. In the 1950s N Chomsky postulated that there exists beneath the surface of any natural language a "deep structure" which connects ideas in a more fundamental way than do the rules of grammar. Recent work in linguistics based upon Chomsky's theories admits of ungrammatical statements such as "Arsenal rule, OK?" and "Right on, man!", and of translation between such differently structured natural languages as English and Chinese or between natural language and (say) musical notation. If Piaget is right about communication and learning without natural language, and the design educationists are right about the existence of unvocalisable ideas in the material culture, then Chomskian linguistics offers a theoretical basis for considering the admissibility of the means for handling this way of communicating and this set of ideas as a symbol system, that is, a language, specific to the Design area.

Status

Molière put into the mouth of M Jourdain the phrase, "I've been talking prose for the last forty years and have never known it!" Perhaps designers have been handling ideas in the prose which I have called modelling for 6,000 years without knowing it. If linguistics itself, the theory of language, were fully developed it might be easy to test by established means the status and unity of the various systems of modelling which designers use. Unfortunately linguistics has not, according to its own authorities, reached that degree of stability. It is admitted that language remains a partially understood phenomenon. Even if it were easy to test the status of modelling and it were found to be good, this would no more turn design language into a more creative and versatile tool than M Jourdain's self-realisation turned him into a scholar. Why, then, should we bother with the status of modelling? For my own part, I have five reasons for so doing.

Firstly, I have long felt that the quality and status of the teaching of most of the techniques of modelling in design, that is, technical drawing, freehand drawing, mathematical representation, diagrammatic representation, specification writing, physical model building and so on, is less high than it deserves, and certainly less well co-ordinated than it could be.

Secondly, the relationship between the modelling conventions adopted by the different branches of the design profession, that is, between architects, engineering designers, fashion designers, graphic designers, industrial designers and so on, is less consistent and mutually appreciated than it should be.

Thirdly, the incorporation into design modelling theory and practice of useful concepts derived from studies of artificial intelligence, cognitive psychology, mathematical modelling and system simulation is less far advanced than it ought to be.

Fourthly, the understanding and advancement of design practice, and the introduction of further modelling techniques such as computer aids, has been held back by the absence of a consistent theoretical basis for design modelling.

And fifthly, the acceptance of design as an area of education comparable with Science and the Humanities demands recognition of a coherent knowledge base and a language for discourse for that area.

That the wish is father to the thought, the thought sister to belief, and the belief pretender to truth does not give the wish the status of doctrine. If modelling is the language of design, what sort of meaning would need to be found in its lexicon of ideas? One could list classes of ideas about configuration, form, proportion, construction, mechanism, structure, physical properties, perceivable attributes, colour, texture and so on, some of which would be very difficult to capture, manipulate and communicate in natural language or scientific notation. The distillation of the lexicon into a dictionary of design modelling is a nice life's work for somebody. What sorts of morphemes constitute the basic elements of the language of modelling? Not, I would have thought, the conventions of drawing. Just as natural language can be embodied in spoken sounds, handwriting, printing, shorthand, Morse code, semaphore, electro-magnetic pulses, and a variety of other types of signal carried by appropriate media, so the design language can be embodied in orthographic drawing, freehand drawing, diagrams, vectors, special notation, actions, gestures and sounds according to medium. The morphemes or basic elements of design language have already been identified or codified, at least to some extent, for the purposes of computer-aided design, and both the morphology and the syntax developed to a considerable extent in codes of design practice. They are, I would have thought, capable of co-ordination within a "deep structure" framework, if not within a "grammar".

Scholarship

All this is hypothesis, however. When all the listing and coding and co-ordinating is done, it could well turn out that the rack of separate modelling tools is no more than that. The set of systems of representation used by designers could prove to be a set of separate and rather limited languages rather than the dialects of one underlying language. We shall see. The set of systems of representation in design remain, nevertheless, a very important means for handling a very important range of ideas. A general theory of modelling is highly desirable for the benefit of design practice, whether or not modelling can aspire to the status of a single language system. Its development must surely rank as one of the principal preoccupations of design scholarship.

Footnote

1 The Department of Design Research at the Royal College of Art was in existence from 1968 to 1986. It pursued research into all aspects of design, often by engaging in contract design work for government agencies or private clients. Professor Archer was head of department throughout its existence.

The Ethics of Representation

KEN BAYNES

The role of modelling in design has not had the analysis it deserves. As it is the 'language' used by designers in developing their designs, we might conclude that it is very important to understand it more thoroughly. And yet, there is not (so far as I know) any substantial historical study of the development of modelling skills and forms in different cultures. Equally, the effect of modelling conventions on how designers design has been little explored. For example, we do not know if some modelling systems inhibit creativity while others encourage it.

In this short article, I want to highlight another aspect of the field: the 'social role of modelling'. Here ethical and political issues are thrown up by the attempts of various groups to shape the future. Access to modelling skills and the ability to understand and interpret modelling conventions play their part in deciding whose view of the future will in fact be brought into existence.

The term 'model' is used by scientists, mathematicians, technologists and designers to mean something that stands for something else. In general, models are powerful because they isolate an aspect of reality and allow us to represent, interpret, manipulate or control it. Models have predictive power because, to use computing language, they can be 'run' to simulate what will happen if proposed changes are carried out. They are indispensable for design activity because they allow designers to develop their designs and understand their likely effect before they are put into practice.

Cognitive psychologists recognise a close link between models and perception. The theory is that the mind itself works by constructing multi-layered models of the world. The linguistic process of labelling and manipulating reality through the symbolic sound system of language can be viewed as a modelling system but it is 'imaging' or 'seeing in the mind's eye' that has special relevance for design capability. Imaging has its roots in the act of perception but what can be imaged is also shaped by the predisposition of the human mind to see, hear, touch and taste the world in a particular way. We can only use models that have life and meaning breathed into them by perception, imaging and understanding. This means that the models available to us are determined on the one hand by deep structures in the mind and on the other by the content of our culture.

All models are an abstraction from the chaos of information presented by the complexity of the real world. This is their value. It enables us to isolate variables, describe them accurately and analyse their significance. Different kinds of model have been developed to do different kinds of job - in essence, to describe and manipulate different aspects of reality.

At the most general level, models can be categorised into three types:

ICONIC. These are models that work by looking like a selected aspect of existing or proposed reality

SYMBOLIC. These are models that work by using an abstract code to stand for a selected aspect of existing or proposed reality

ANALOGUE. These are models that work by means of diagrams that stand for but do not look like a selected aspect of existing or proposed reality.

An architect's drawing or an industrial designer's appearance model are typical examples of iconic models. Mathematical formulae are typical symbolic models. Critical path analysis diagrams and algorithms are typical analogue models.

It is immediately obvious that some models are more accessible than others. In general, iconic models of future proposals are likely to be readable by more people than symbolic or analogue models.

In typography, for example, it is possible to write the basic specification for a book entirely in symbolic notation. A typesetter or printer can work in the specialist language of margins, headings, type names and sizes. This abstract code is quite sufficient to allow designer and printer to see the finished book in the 'mind's eye', to cost it and to discuss it in quite fine detail. What it won't do is communicate outside the charmed circle of the specialist. For that, a 'dummy' is needed, a mock-up of the book that has the same weight and appearance as the finished product. This iconic model will demonstrate the proposals to people as diverse as booksellers, buyers, the author, the marketing department and potential co-publishers.

In many fields, the appropriate modelling forms are well-established. Publishers are completely familiar with such phenomena as:

- sample setting
- page roughs or thumb-nails
- illustration roughs
- dummys
- marked-up copy
- galley proofs
- finished art work

The industry has, over the years, developed an efficient way of designing, producing and marketing books. The forms of modelling used are not problematic because they are totally familiar.

Problems begin when some of the people involved in a design proposal are not totally familiar with the modelling forms. An example might be: the predicted traffic flow along a new by-pass where it runs near to some existing houses. If the future situation is presented symbolically using mathematical notation for traffic density, noise and exhaust emissions it is very likely that the true significance will not be fully appreciated by those most directly affected.

Iconic models would be more reliable and comprehensible. A drawing of the road at various times of day showing a simulation of the actual traffic would stimulate the viewer's imagination. 'If it looks like that, I know it will sound and smell like this.' Alternatively, a video or computer simulation of a similar situation could be shown. Perhaps best of all, a visit could be made to an actual roadside.

Of course, this begs all kinds of questions:

How much will it cost to make controversial proposals understandable?

Do people making the proposals actually want them widely understood?

Is there a tendency to adopt the most apparently 'scientific' modelling form at the expense of the most understandable?

Do we know which modelling forms actually are likely to be understood by the target audience?

When questions such as these emerge, it becomes clear that it is the designer's ethical responsibility not only to use modelling skills to solve a client's problems but also to open up the area of understanding around the project.

In their book on the social applications of mathematics (1) Davis and Hersh reproduce this very simple analogue of the use of mathematical models:

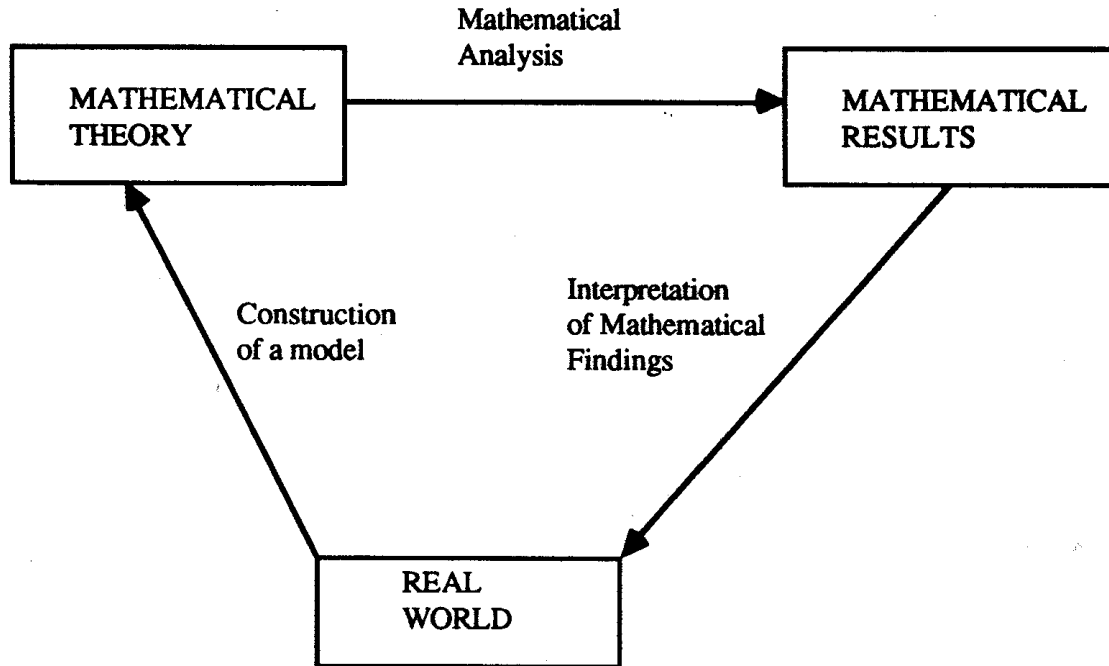


Fig 1

It appears to fit the designer's use of models of all kinds. A repeated sequence of these loops, using different kinds of model, is a good way of capturing the iterative nature of design activity in graphic form. The diagram overleaf (fig 2) shows such a sequence as used by the architects involved in the design development of the Greenwich District Hospital in 1972. (2) At each stage they used a particular form of modelling adapted to the task in hand. The models were employed as an aid to thinking, a focus for discussion and decision-making and a means of evaluating the likely success of the proposals.

It is interesting to notice, once again, that models were not only being used to develop the design: they were also the basis of the social process of designing. The models were the focus for meetings and discussions at which design decisions were taken. In a very real sense, it was the production of a series of evermore precise models that structured the management of the design project.

This moves the question of the 'ethics of representation' into the design team itself. Very few products or environments are designed by individuals, most result from the interaction of complex teams of specialists. It is seldom the case that such teams take a unified view of a particular piece of design development. The value systems of architects, for example, may be very different from the value systems of heating engineers and different again from the end-users of a building. What the members of the team have to achieve is a resolution of their personal areas of expertise which, at the same time, achieves a resolution of the design.

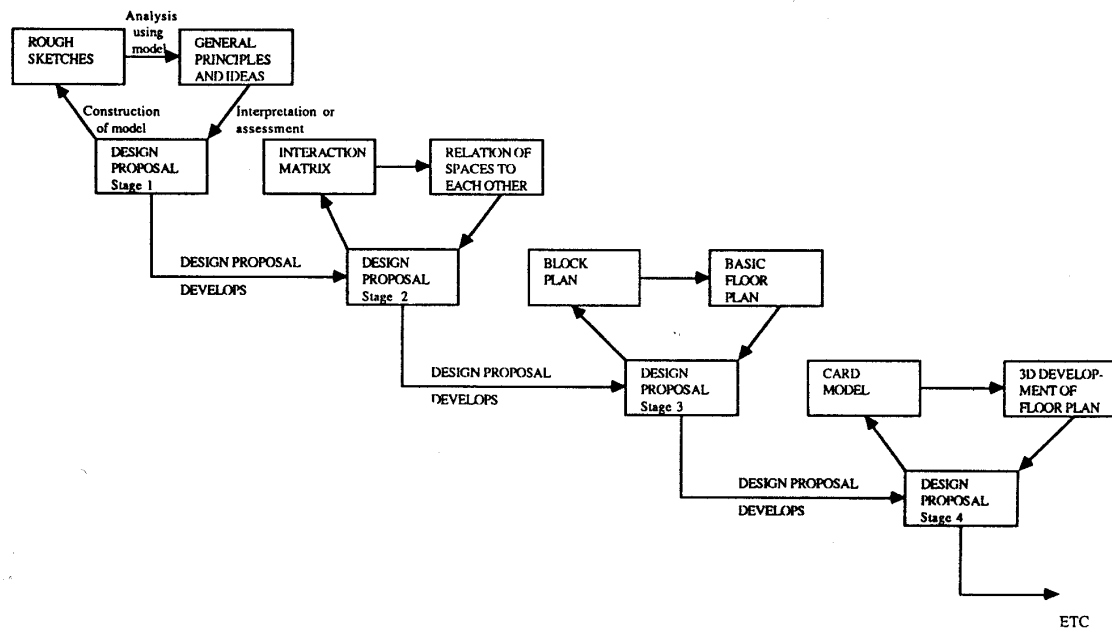


Fig 2

MODELS AND DESIGN DEVELOPMENT

ACTUAL EXAMPLE OF THE TYPES OF MODELS USED IN THE DESIGN OF THE GREENWICH DISTRICT HOSPITAL AND THEIR ROLE IN DEVELOPING THE DESIGN PROPOSALS.

THIS SEQUENCE SHOWS AN EARLY PART OF THE DESIGN DEVELOPMENT.

Team members would be less than human if they did not wish their own view to prevail. At least to begin with, they will be using their skill in presenting and manipulating models to make a case rather than to explore the situation. It is part of becoming a team to move away from this and to begin to use models in a more dialectical, exploratory and open way.

Very little work has been done on the development of modelling approaches that would assist this process of team building. However, it is not difficult to set an agenda for future research:

- * Research into the way specialist team members react to various modelling conventions. For example, which conventions suggest open-ended situations and invite further contributions, which - on the other hand - suggest a 'finished product' and make what seems to be a closed specialist statement.
- * Development of modelling forms that can be manipulated by specialist team members working together. This could well be a computer program but equally might be an adaptable, full-size three-dimensional environment or product simulation.
- * Research into management styles and attitudes which recognise the crucial importance of modelling in team-building and communication between specialist team members.

During the 1960s, the hope was that the newly emerging design methods movement (3) would help to make the design process transparent. This, in turn, would enable multi-disciplinary teams to work together and to involve non-specialists in the development of design proposals. At that time, the emphasis was on techniques for achieving transparency and involvement. Techniques remain important but it now looks as though attitudes and values are the key factor.

Many individual designers - and certainly professional groups - have tended to look uncritically at their particular modelling techniques. They have seldom asked if they communicate effectively. They certainly have not tried to assess their ability to 'tell the truth' about design proposals. Too often glamorous or mystifying modelling systems are used to end debate rather than to widen it. The argument made here is that the 'ethics of representation' call for the opposite approach. Designers need to re-examine familiar modelling practices in an attempt to develop new approaches which reveal more about what is proposed to a greater number of people.

References

- 1 Philip J Davis and Reuben Hersh, *Descartes Dream: the world according to mathematics*, Harmondsworth: Penguin Books, 1988. (First published, 1986)
- 2 See *Hospital Traffic and Supply Problems and Hospital Research and Briefing Problems*, both edited by Ken Baynes and published by King Edward's Hospital Fund for London.
- 3 J C Jones, *Design Methods: seeds of human futures*. London: John Wiley and Sons, 1970.

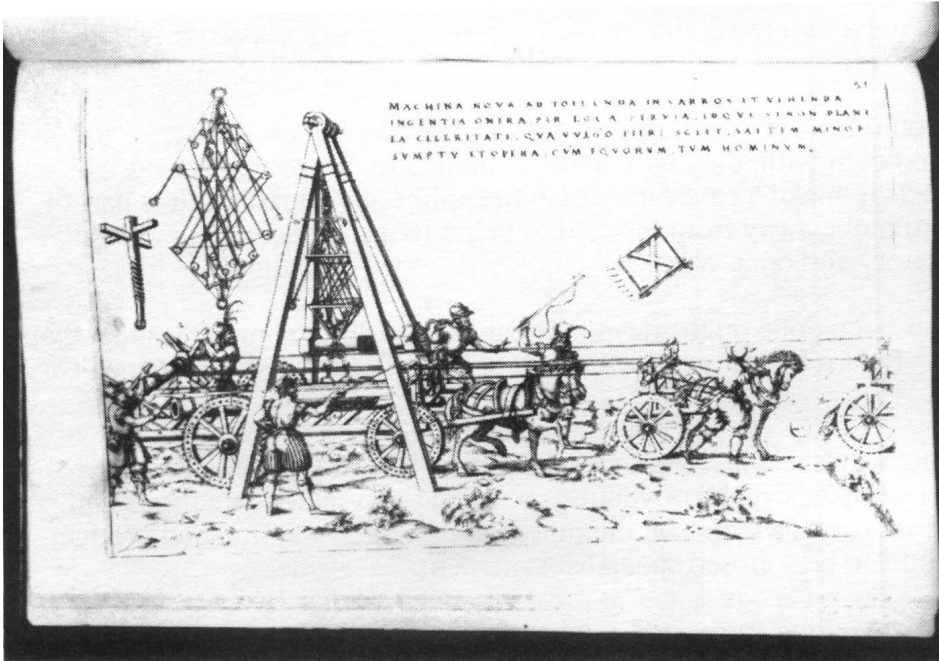


Figure 1. A typical illustration from a Sixteenth century textbook. Characteristically, the book mixes designs, technical advice and instruction on drawing in the same book. (Collection: Ken Baynes)

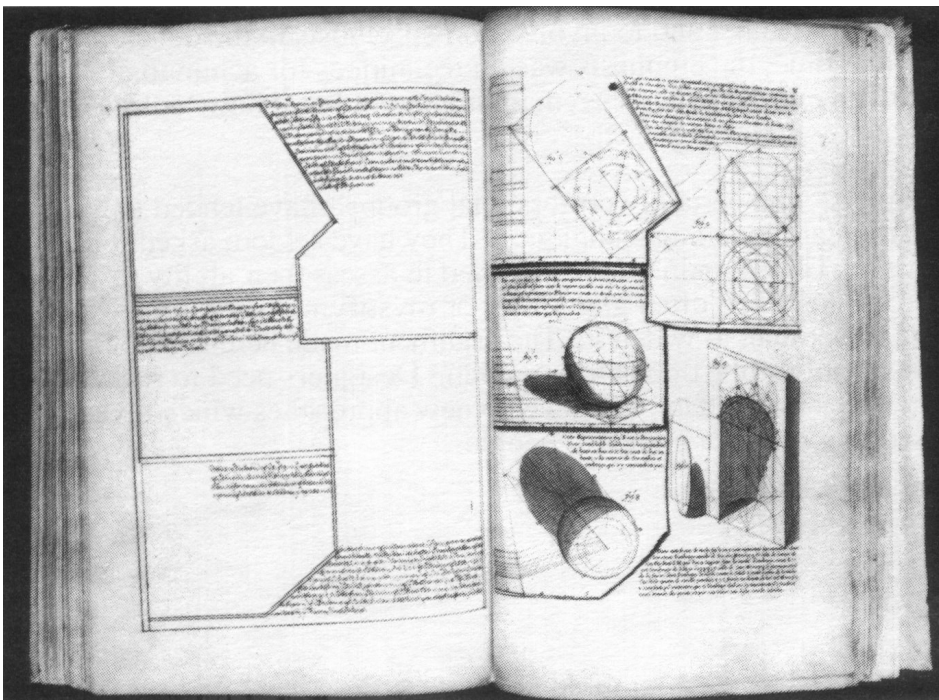


Figure 2. Facing pages from a copy of three volumes on the orders of architecture by Abraham Bosse. The left hand pages consist of English translations of the French original and may have been intended to form the basis of an eventual publication. The French volumes came out between 1659 and 1664. (Collection: Ken Baynes)

The Role of Modelling in the Industrial Revolution

KEN BAYNES

The emergence of engineering drawing as a recognisable graphic form took place at the end of the Eighteenth Century. For the development of design as a separate discipline it was indispensable. Without a method of modelling by drawing, the early engineers could not have distanced themselves intellectually or technically from the limiting conceptual framework of traditional craft procedures. Engineering drawing was a dramatic and powerful modelling tool that made possible a new relationship between management and manufacture and separated the process of design from the process of construction. It was a tool of the new industrial specialisation that the Scots economist Adam Smith christened 'the division of labour'. It was at the heart of the industrial revolution and the new work relationships that it brought into being.

The history of engineering drawing demonstrates that the modelling methods available to designers do directly affect the thoughts they can think. It shows, also, that in the crucial period that bridges the end of the Eighteenth Century and the beginning of the Nineteenth, natural philosophers, manufacturers and engineers were well aware of the importance of engineering drawing. They saw it as an innovation that was both practical and ideological. It is fascinating to recognise that here was a period when designers set out deliberately to equip themselves with a modelling system to reflect and extend the technological and social revolutions of the time.

In his important book on design methods, the English design theorist, J Christopher Jones (1), has shown how and why design by drawing differs from traditional craft methods. The reasons he gives are to do with economics, the organisation of industry and the enlarged 'perceptual span' made necessary by the emergence of a world where ceaseless technological innovation led to a sequence of continual change:

The method of designing by making scale drawings ... [now] the normal method of evolving the shapes of machine-made things [differs essentially from the earlier method of craft evolution in that] trial and error is separated from production by using a scale drawing in place of the product as the medium for experiment and change. This separation of thinking from making has several important effects:

- 1 Specifying dimensions in advance of manufacture makes it possible to split up the production work into several pieces which can be made by different people. This is the 'division of labour' which is both the strength and weakness of industrial society.
- 2 Initially this advantage of drawing-before-making made possible the planning of things that were too big for a single craftsman to make on his own ...
- 3 The division of labour made possible by scale drawings can be used not only to increase the size of the products but also to increase their rate of production. A product which a single craftsman would take several days to make is split up into smaller standardized components that can be made simultaneously in hour or minutes by repetitive hand labour or by machine.

And he says:

The effect of concentrating the geometric aspects of manufacture in a drawing is to give the designer a much greater 'perceptual span' than the craftsman had. The designer can (by use of a drawing) see and manipulate the design as a whole and is not prevented, either by partial knowledge or by the high cost of altering the product itself, from

making fairly drastic changes in design. Using his ruler and compasses he can rapidly plot the trajectories of moving parts and predict the repercussions that changing the shape on one part will have upon the design as a whole.

Jones' interpretation is well supported by the historical evidence. The use of drawing for design and production control appeared first in architecture and shipbuilding. In both these areas, scale and complexity emerged as problems long before engineering based on metalworking became the major area for technological innovation.

However, engineering drawing did not emerge in isolation from other, less specialised, developments in the history of European drawing. Its sources straddle the technical, aesthetic and scientific worlds. Although its application to industry was strictly utilitarian, its origins were at one with the intellectual ferment that began in Italy at the time of the Renaissance. It was Italian architects, shipwrights and military engineers who first used drawings in a recognisably modern way, just as it was Italian artists who first introduced the revolution in the means of representation that is at the basis of objective drawing. It was they who first pursued rational rules for perspective, illusionist representation of solids and depiction of buildings and objects through a series of systematic projections.

It is important to recognise that these early types of drawing did not only - or even mainly - serve design. It is rather that when designers needed a 'language' or 'medium' in which to design, the elements of it were ready to hand, refined and defined by two hundred and fifty years of development. There were three main driving forces: philosophical attitudes; the growth of learning; and professional pride. Often all three were inextricably linked together.

This can be seen clearly even in Leon Batista Alberti's very early pioneering writing (in Latin and Italian) on art and architecture. First written in 1435, the Latin version contained much philosophical material, systems for perspective and human proportion and the first theory of painting that rooted this art in visual experience and its representation in geometrical terms. Although all subsequent authors were influenced by Alberti, the work was for a hundred years only circulated privately to other artists and theorists. Its ideas were potentially dangerous and revolutionary. These professions were then in the process of discovering their identities and it was the existence of published bodies of knowledge such as Alberti's that helped them to do it.

The tradition which Alberti established was continued in a spate of theoretical publications over the following two hundred years. Typically, these contained both instruction about drawing systems and information on the principles of architecture, military engineering, hydraulics and fortifications. (See Figures 1 and 2). It was only slowly that the two diverged and books began to appear either on drawing alone or on architectural, engineering or shipbuilding principles. It is worth listing a number of these titles to demonstrate something of their character and to show how quickly this interest in drawing spread throughout Europe:

Daniel Barbaro La practica della perspittiva. This was one of the earliest treatises on perspective. It was first published in Venice in 1568. It deals with theatre scenery as well as perspective, Vitruvius and the use of the camera obscura. Barbaro was a scholar, translator of Vitruvius and patron of Palladio who built a villa for him.

Jacques Besson Theatre des intrumens mathematiques et mechaniques. Besson was a French mathematician who worked on this publication in the 1560s. With plates engraved by Jacques Androuet du Cerceau, it deals with drawing instruments, stone-cutting and woodworking machinery, dredging vessels, pontoon bridges, well-drilling and a water-driven mechanical clock.

Jan Vredeman de Vries Perspective. Vries was an old man when this book was published in French at the Hague by Beuckel Nieulandt in 1604. The plates are by H Honduis and deal primarily with the application of perspective to architectural constructions such as staircases and city squares.

The Sixteenth and Seventeenth centuries saw a steady development in understanding the link between mathematics and representation. French mathematicians contemporary with Descartes had already explored the fundamentals of projective geometry in the Seventeenth century. Girard Desargues, Philippe de la Hire and Blaise Pascal all contributed to the development. Desargues, who was a self-educated architect and engineer, saw clearly that his discoveries had potential for a variety of practical applications in engineering, painting and architecture when he wrote (2):

I freely confess that I never had taste for study or research either in physics or geometry except in so far as they could serve as a means of arriving at some sort of knowledge of the proximate causes ... for the good and convenience of life, in maintaining health, in the practice of some art ... having observed that a good part of the arts is based on geometry, among others and cutting of stones in architecture, that of sun-dials, that of perspective in particular.

Here is a glimpse of the utilitarian spirit that was to triumph in the Nineteenth Century. For the moment, however, Desargues' pamphlets had little effect on his contemporaries. It was not until the middle of the Eighteenth Century that government patronage in France began officially to encourage research in perspective, solid geometry and applied drawing. Investigation in these areas was fostered for reasons of state at the military colleges and L'Ecole Polytechnique. The intellectual climate of the enlightenment favoured the pursuit of knowledge for its own sake but, after the Revolution and during the Napoleonic Wars, the importance of commerce and the demands of fighting on a continental scale gave added urgency to official backing. Enlightenment, trade and the emergence of the nation state pushed the development of drawing forward.

All over Europe, but particularly in France, the Eighteenth century saw the rapid development of a wide range of objective drawing techniques. It was a part of the attempt by men of reason in the age of reason to catalogue, quantify and thus understand the natural and man-made world. This work found the height of its expression in Diderot and D'Alembert's Encyclopédie published after enormous difficulties - Diderot and his publisher Le Breton were imprisoned more than once - between 1751 and 1756. Le Breton had originally planned a French translation of Chambers' Cyclopaedia or Universal Dictionary of Arts and Sciences which came out in 1728. He quickly changed to an original ten volume scheme that would celebrate the dignity and progress of man. This finally grew to a 28-volume work, 11 of them being volumes of plates.

The illustrations in the Encyclopédie demonstrate a sophisticated graphic 'language' suitable for depicting and explaining machines and processes. They influence the style of technical publications even today. The Encyclopédie included sections on drawing and there is little doubt that these, together with the work as a whole, provided many of the elements to be found in the first true engineering drawings when they appeared in Britain at the end of the century.

It was the French military engineer, Gaspard Monge, who first codified the conventions of descriptive geometry. It is on his work that the theoretical aspects of modern engineering drawings have been based. Monge was born in 1746 and published his Géométrie descriptive in 1795. It is evident that Monge did not 'invent' descriptive geometry. What he did was to bring together and explain a variety of ad hoc techniques which masons and woodworkers had been using for perhaps two hundred years. Peter Booker, the English historian of engineering

drawing, suggests that these craftsmen recognised clearly what Monge was doing and resented his invading their area. They saw that power of control lay in the new techniques of drawing. Booker describes the situation in this way (3):

At Mezières there were schools of [military] stonecutting and carpentry He [Monge] set about examining the drawing methods used and applied his first principles of descriptive geometry to them in order to replace many rote techniques with generalised methods He came across stubborn opposition from the carpenters, however, who were relying on drawing techniques passed on from father to son for generations and who saw no reason for an academic person to butt in.

This incident was a rehearsal for a change in work relations that went on wherever industrialisation and bureaucratisation took command. What had before been the prerogative of the artisan or the craftsman was now transferred to the manager or the designer. Drawings became one of the ways in which the change could be brought about. They were the portable 'concepts' or models, the easily transmitted instructions, through which designers and managers controlled the production process.

Monge's system of descriptive geometry quickly became an accepted part of the French system of technical education. From there it spread to most of continental Europe but it is doubtful if it had any immediate effect in Britain or the United States where state intervention in training was unusual. In these countries, but not Scotland, it was left to the new capitalist companies to organise their own apprenticeships and to teach trainee engineers the skills they would need in practice.

It is, however, to Britain that we have to look for the emergence of engineering drawing as a design medium directly related to industrial means of production. Its origins there depended to some degree both on Royal patronage and on military and naval interest but pre-eminently on the new class of forward looking manufacturers, mechanics and natural scientists. It is they who had both the commercial energy and the belief in 'progress' necessary to press ahead with the creation of novel products and new processes. With these momentous changes drawing was intimately concerned.

In London, King George III was interested in drawing. When still the Prince of Wales in 1760, he appointed Joshua Kirby as his personal tutor in 'perspective' and, in 1761, Kirby dedicated a splendid book on architectural perspective to him. William Hogarth drew the frontispiece. In addition to the fine illustrations, The Perspective of Architecture included very careful instructions on the use of a new machine for making architectural drawings. Significantly, this device was designed and made by George Adams, the King's instrument maker. These great London craftsmen held a key position in the practical development of Eighteenth century technology and their workshops provided a natural meeting place where cultural and technical ideas could come together.

A further area of state involvement which helped to raise the standards of accuracy in draughtsmanship in Britain was the Military Survey of Scotland. This was begun in 1746 as a part of the Duke of Cumberland's military subjugation of the Highlands. Until the middle of the Eighteenth century, map-making was dominated by a form of pictorial representation that tolerated many errors and inaccuracies. A triangulation of Britain was finally begun by William Roy after many delays in 1787. There were strong professional links between surveyors and engineers, particularly in the design of canals and railways. The formal relationship between large-scale maps and the drawings of civil engineers is a close one.

Even more influential was the Royal Navy. The Marxist historian Eric Hobsbawm has

characterised it as 'that very commercially minded and middle class organisation'. It certainly was one of the first really effective bureaucracies in Britain. Ever since the early years of the Eighteenth century, the Navy Board had required that a model and plan for each of its ships should be prepared for the records. The standardised layout and simple conventions of these ships draughts remained unaltered until the advent of steam on a large scale in the 1830s. A very substantial collection of such drawings is preserved in the National Maritime Museum at Greenwich. Amongst them can be found the first ships draughts that are indisputably designs for ships rather than drawings of ships that have already been built. These draughts contrast vividly in style with those in the text books of the period and it is instructive to compare a Royal Navy drawing with the superb technical plates in *Architectura Navalis Mercatoria*, the great Swedish publication on naval architecture produced by Hendrik Chapman in 1768. Chapman's plates, engraved by his nephew Lars Gobman, are a brilliant exposition of the principles of ship design: the Navy draughts are to communicate to shipyards the design of a particular ship to be built there. It is the more utilitarian stream of drawing that now developed rapidly in Britain.

What was needed to make perspective and projective drawing a part of the everyday work of engineers was a greater closure between the worlds of manufacture and learning. The first development of steam power happened in an isolated setting where mine owners worked with metalworkers of practical genius. Thomas Newcomen, who had designed and built the first viable steam-powered atmospheric pumping engine as long ago as 1712, was not in the mainstream of Eighteenth century intellectual life. The intellectuals in fact belittled his achievement and wrongly attributed it to others or ascribed his success to luck. What Newcomen used was his carefully acquired tacit knowledge of metalworking and ephemeral forms of setting out. He used templates, jigs and models just as he used construction techniques that were well-established to the point of being almost medieval in their rugged simplicity. The only drawings we have of the resulting engines were made by scholars or travellers after they had been built. They seem to have seen them more as curiosities than anything else. Certainly their drawings are inaccurate in many technical details.

By the end of the century the situation had changed. The scene was set by three things:

- 1 The emergence of an intellectual climate that valued and sought after utilitarian application of theoretical knowledge;
- 2 Improvements to steam engine design and manufacture which decisively extended its commercial application and so hugely increased investment and demand;
- 3 The specific abilities and background experience of James Watt, the Scots engineer who contributed most to early steam engine design and who was responsible for the first recognisably modern engineering drawings.

The appearance of engineering drawings as a fully-fledged medium for communication in the engineering industry coincides appropriately with the establishment by Matthew Boulton and James Watt of the first specialist factory in the world for the construction of stationary steam engines. This happened in 1773 when the partners founded the Soho Manufactory in Birmingham and revolutionised the original Newcomen design by the application of a separate condenser. It was this technical development that made steam power commercially viable.

James Watt's personality, education and historical situation meant that he was well fitted to codify drawing practice. His background was unusual in that it combined a practical training and apprenticeship to an instrument-maker with involvement in natural philosophy (as science was then known) at Glasgow University. Thorough, methodical and dour he drew together the threads of architectural, technical, scientific and military and naval draughtsmanship to turn them into an effective means for design, development and production control.

These personal characteristics found a congenial setting in Birmingham. The English West Midlands in which Watt worked was at the end of the Eighteenth century no provincial backwater. It was, on the contrary, a dynamic centre for intellectual as well as commercial speculation. Under the auspices of Josiah Wedgwood and Erasmus Darwin, Charles's grandfather, it was the meeting point of science and industry. In the famous Lunar Society - to which Watt and Boulton both belonged - it had one of the leading philosophical clubs of the time. At its meetings, famous men met one another in small groups, exchanged ideas and hotly debated techniques for progress in society, natural philosophy and manufacture.

To complete the industrial picture it is important to ask why Boulton and Watt needed drawings and how they used them. In order to understand this, it is necessary to visualise the engines that Watt designed and the factory in which they were made. At this early stage, the Boulton and Watt Manufactory was not like a modern engineering works, turning out complete and finished pieces of equipment. These stationary pumping engines for mines and blowing engines for iron smelting depended on the construction of a house to hold the working parts in the correct relationship with one another. Many of these parts were 'bought-in'. For example, George Wilkinson the ironmaster and his rivals, the Darbys at Coalbrookdale, competed for Boulton and Watt contracts for the production of cylinders. Many of these parts would go straight to the site - sometimes as far away as the United States - without ever coming to Birmingham. In this situation drawings were essential. Watt used them for three different purposes:

- 1 As project drawings to decide the particular form of each new engine and to be the basis of a contract with the client.
- 2 As outline production drawings for ordering the necessary parts and raw materials from outside the works, eventually to be combined with fittings made inside.
- 3 As a means of controlling the work on site where bricklayers and carpenters would be required alongside specialist fitters from Boulton and Watt.

This interpretation is borne out by inscriptions on the drawings and by the fact we know that the Darbys and Wilkinson built complete Boulton and Watt engines for themselves from drawings supplied.

LTC Rolt, one of Britain's leading technical historians, has described the enormous amount of work that Watt had to undertake:

It must be emphasised that there was no standardisation in the Soho engine business. Each engine was designed individually to the customer's requirements and the introduction of detail improvements was continuous. Only occasionally did a chance conjunction of orders make it possible to produce identical sets of cylinders and working gear. Consequently the amount of design work which fell on Watt's shoulders was immense.

Before 1781 Watt executed all the necessary drawings himself. Between then and 1790, when a drawing office was at last established in the factory, he worked in his own house with only one assistant, and ex-surgeon called John Southern.

Although Watt and Southern had established basic principles that were to hold good for many years, there were great differences of style and technique separating them from the work done in the 1830s and 1840s. By this time, in Britain, drawing offices had become the main institutions in which engineering design was carried out and engineering drawings had become the normal means for developing ideas and controlling production. These later drawings are far more sophisticated than those produced by Boulton and Watt. Often coloured, they also display

evidence of formalised conventions. The projections used are more uniform and the approach is based on better theoretical knowledge. How did this happen?

It is not possible to ascribe these changes to any single event. Rather they are to do with the continuing ferment of ideas in engineering, to the hugely increased scale of industry and to the emergence of characteristic forms of industrial organisation and administration. Step by step there evolved from Watt's work alone, through his joint work at home with Southern, first small groups of draughtsmen and finally well-organised, recognisably modern drawing offices.

The work also became international. French approaches to drawing did eventually influence British practice and draughtsmen in the United States used both these European sources to develop their own conventions.

To get a picture how these interactions actually occurred it is useful to take the example of Robert Fulton, the American engineer who designed the first commercially viable steamship to sail on the Hudson River. It is possible to see how he and other engineers worked on an international scale and so were able to draw together on a day-to-day basis the various national traditions of drawing.

Fulton believed wrongly that it would be possible to patent his application of steam power to boats. To this end he prepared a remarkable series of drawings for the American patent office. Completed in 1809 and 1811 these show many differences with Boulton and Watt drawings. Fulton had been trained as a portrait painter at the Academy in Philadelphia and it is clear that his personal skill as a draughtsman partly explains the quality of his drawings. However, they foreshadow the drawing styles that became usual in the next decade.

At the end of the Eighteenth century the United States lacked the technical expertise of Europe and it was in search of this that Fulton came to Paris following Napoleon's assumption of the Consulship in 1799. He obtained some support for his experiments and was able, in the summer of 1803, to try out a steamboat on the Seine. It reached a speed of 2.9 m.p.h. going upstream and could be steered efficiently. To get a better engine Fulton had to look to England. At this time only Boulton and Watt could provide suitable motive power. He wrote to them in 1803 but they refused to supply an engine. This may be because war had broken out again between Britain and France and British officials would not approve a request from an American with an address in Paris.

After secret negotiations in Amsterdam, Fulton came to England in 1804. Lord Stanhope helped him obtain the export licence for an engine. The government may now have felt more inclined to grant it since he had helped at Portsmouth to supervise the construction of a torpedo. At all events, the engine was eventually made and first successfully drove the Clermont (later renamed North Star) on the Hudson on 17 August 1807.

In *The Art of the Engineer*, Ken Baynes and Francis Pugh comment on the significance of Fulton's travels for drawing and show that they were not unique (4):

[Central to the development of steam-powered ships] was the use of a new form of machine drawing, already apparent in Robert Fulton's patent applications, which was rapidly to become an essential medium of communication between growing numbers of engineers, mechanics and draughtsmen.

It is not easy to trace the moment of its adoption in Britain but among the diverse sources the most influential was the theoretical work then emerging in France as a result of the founding of L'Ecole Polytechnique. Fulton was

certainly exposed to this climate of theoretical enquiry during his stay in Paris, and it pervades every aspect of his steamboat project, including his sketches and patent applications, but his work had little influence on British engineers. This cannot be said of another outsider, the Frenchman Marc Isambard Brunel whose early enthusiasm for civil engineering, which led to his brief appointment as Chief Engineer of the State of New York in the 1790s, points to his having been taught the theories of Gaspard Monge during his training for service in the French Navy in the late 1780s.

Baynes and Pugh point to Marc Brunel's association with Henry Maudslay as one route along which drawing styles may have been transmitted. It was Maudslay that made the block-making machines designed by Brunel and he soon became Britain's leading maker of machine tools. Maudslay's workshop was to become a training ground for many young engineers. Among them were Joseph Clement, engine-builder and maker of precision machine tools; James Seawood, marine engineer and inventor; Richard Roberts, locomotive engineer and inventor of the self-acting spinning mule; Joseph Whitworth, the greatest British machine-tool manufacturer of the nineteenth century; and James Nasmyth inventor of the steam hammer.

It is an extraordinary roll-call. This one small workshop trained a body of engineers that might do justice to a university department. It is clear that these men inherited much of their love for an orderly and precise approach to design from the early experience of working for Maudslay. His high regard for the art of drawing was widely disseminated by their work throughout British engineering.

Marc Brunel himself believed training in draughting to be essential for an engineer and encouraged his more famous son, I K Brunel, to master mathematics and drawing. The young Brunel showed drawing talent when he was only four years old and had mastered Euclid by the time he was six! Later his father encouraged him to make a survey of the English seaside town of Hove, sketching the buildings there just as he had done years before in his youth in Rouen. Marc insisted that this habit of drawing was as important to an engineer as a knowledge of the alphabet.

The Maudslay influence was repeated in the railway field by Robert Stephenson & Co. When Robert joined with his father George, Edward Pease and Michael Longridge to found the first specialist locomotive factory in the world at Newcastle in the North of England they inevitably took on also the role of pioneer teachers. The post of head draughtsman already existed in 1829 and the drawing office was organised on efficient hierarchical lines. Apprentices and their fees are specifically mentioned in the Memorandum of Agreement which founded the company. J G H Warren, the company's historian, records correspondence dating from 1836 where Robert Stephenson complains of the thankless task of training these apprentices. They have no sooner come into the office and 'become acquainted in every detail with our plans' than 'they leave and carry away what has cost us a great deal of money and more thought'.

Surviving work from the Stephenson office differs in a number of ways both from the early Boulton and Watt drawings and also from the more flamboyant coloured locomotive drawings dating from the 1840s onwards. (Fig 3) They are sober and workmanlike, using tinted washes in grey and sepia but no other colours. It looks as though this style was, in its turn, influential in the United States for a number of very similar railway drawings are preserved in the Smithsonian Institution. This is hardly surprising since Robert Stephenson was visited by most of the early Nineteenth Century railway engineers. Although British locomotives were never a success in the United States they had, at this primitive phase of development, a seminal role to play. Between 1829 and 1841 over one hundred and twenty crossed the Atlantic. At least twenty of them came from Robert Stephenson & Co.

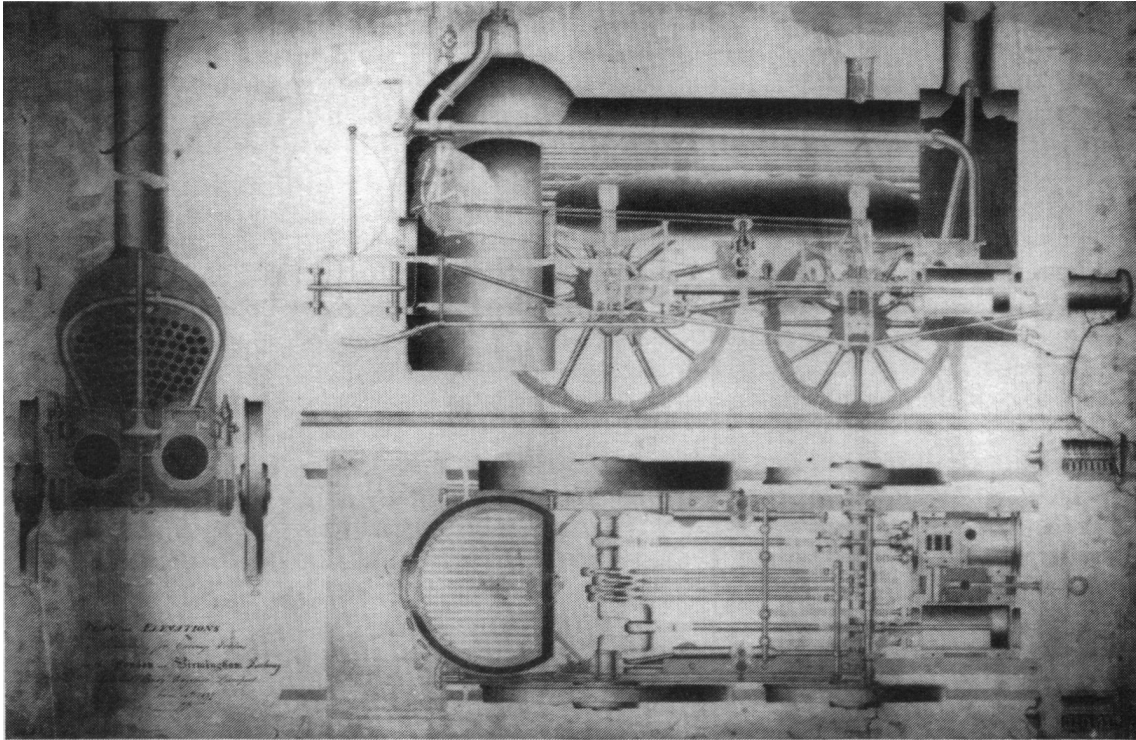


Figure 3. An early monochrome drawing showing a 2.2.0 locomotive for the London and Birmingham Railway. It was built by Edward Burly of Liverpool. The drawing is dated 1837. (Reproduced by permission of the Welsh Arts Council, from The Art of the Engineer exhibition. The drawing is in the Collection of the National Railway Museum, York.)

By the time of the Great Exhibition in 1851 the engineering industry and with it engineering drawing was well-established in Europe and America. The hectic days of technical invention and industrial innovation had been transformed into an orderly, institutionalised process. The drawing office had become the nerve centre of design, development, research and production control in all engineering companies. Fine draughtsmanship was expected. Apprentices were trained in it and text books now existed to explain how to do it.

At this point it is useful to step back and to attempt to answer two questions. First, is it possible to say why engineering drawings took the form they did? And second, did the Nineteenth century engineers themselves recognise the crucial importance of draughtsmanship as a modelling medium capable of separating craft from industrial means of production?

The body of work that can properly be described as 'engineering drawing' as distinct from 'technical illustration' such as that found in the Encyclopédie is far from homogeneous. It ranges from the slightest sketches to elaborate and carefully coloured sets of presentation drawings. This variety is essentially functional. It relates to the differing demands of, for example, initial design, where ideas are not yet resolved, to production where exact and complete instructions are required. A basic 'typology' of drawings appears to have emerged early in the development of the engineering industry and by the 1840s it was well established. The same typology is, in fact, still evident today.

At least five distinct categories have emerged clearly:

Designers' Drawings

These relate to the stage in development when the engineer is considering broad alternatives and putting forward outline schemes. They are frequently found in notebooks kept by senior engineers and are often very individual in style. It is usually this kind of drawing that people have in mind when they say that something was 'designed on the back of an envelope'. A characteristic of these drawings is that they leave vague those parts of the design which the designer is not concerned with at the time. They normally highlight those aspects of the design which are particularly difficult or novel. Professor Bruce Archer has suggested that designers operate in a way that is analogous to a movie camera, changing focus and definition from one part of the design to another, allowing the various parts to affect one another until sharp definition is achieved throughout. Engineers' notebooks tend to confirm this theory.

Project Drawings

Like designers' drawings these show proposals in broad outline. However, they are not personalised; instead they are produced according to accepted rules and conventions, usually by the drawing offices of established companies. They are often drawn to a relatively small scale.

Production Drawings

These are perhaps what most people think of as engineering drawings. Typically, they conform to a sequence starting with a general arrangement drawing and covering every detail of the product to be manufactured. In the earliest days the sequence was frequently very incomplete and concentrated on those parts that were unusual in some way. As industrial organisation increased in sophistication so did the number of drawings needed to control production.

Presentation and Maintenance Drawings

Many of the finest drawings which now survive are presentation drawings, that is, drawings made of the product after it had been finished. Frequently they are the work of skilled

draughtsmen, based on measurements taken by apprentices as a part of their training. In shipbuilding these are known as 'as fitted' drawings and they record the changes in design made while the ship was being built. In the case of the great private locomotive builders in Britain, the term 'contract drawings' was used. These were complete sets of drawings that formed the basis of the contract with the customer. In some of these marvellously finished drawings there is clearly an element of industrial pride and public relations, but they also served a practical purpose. They were used as reference when a machine needed maintenance or modification and many have later additions recording the changes that were made.

Technical Illustrations

These are illustrations for technical or popularising books that use the conventions of engineering drawing. In the Nineteenth century, they reached a very high level of skill and presentation.

The first engineers, like all designers, needed a modelling system or 'language' in which to conceive their schemes and to command the subsequent work of production. For this purpose they frequently used written specifications and descriptions but any such literary or verbal form is inadequate when faced with the problem of defining a three-dimensional reality that is highly specific. The only possible way to do that is to use a visual form of communication incorporating signs and symbols that are as 'readable' as the words in a sentence. For engineers this is precisely what the conventions of the engineering drawing eventually became. By 1902, when Hawkins published his text book on Mechanical Drawing in New York, he was able to write that 'drawing constitutes a universal language, to acquire which is a matter of importance, for by its use one is able to illustrate the form and dimensions of an object, device, or utility, in very much less time, and far more clearly, than by a verbal description'.

The ability to do this is at the root of engineering, and without its existence it is hard to imagine that the technological revolution of the Nineteenth and Twentieth centuries could have taken place.

The vital importance of engineering drawing, and its role in management, was well-recognised by Nineteenth century designers and manufacturers. Writing in 1835 On the Economy of Machinery and Manufacturers, Charles Babbage, the British mathematician and inventor, made its significance explicit (5):

When each process has been reduced to the use of some simple tool, the union of all these tools, actuated by one moving power, constitutes a machine. In contriving tools and simplifying processes, the operative workmen are, perhaps, most successful; but it requires far other habits to combine into the machine these scattered arts. A previous education as a workman in a peculiar trade, is undoubtedly a valuable preliminary; but in order to make such contributions with any reasonable expectation of success, an extensive knowledge of machinery, and the power of making mechanical drawings are essentially requisite. These accomplishments are now much more common than they were formerly; and their absence was, perhaps, one of the causes of the multitude of failures in the early history of many of our manufactures.

Babbage gives what are basically utilitarian reasons for the importance of drawing. But their interest and meaning go beyond this. There is in them an excitement and intensity that comes from their function as a medium for creation. They are about what might be. They are wrestling with future possibilities. They are attempting to give form to uncertainties. Again, this is something that was well understood in the nineteenth century. Men like Watt and Maudslay were interested in drawing for this reason and, as a result, believed that it should be of

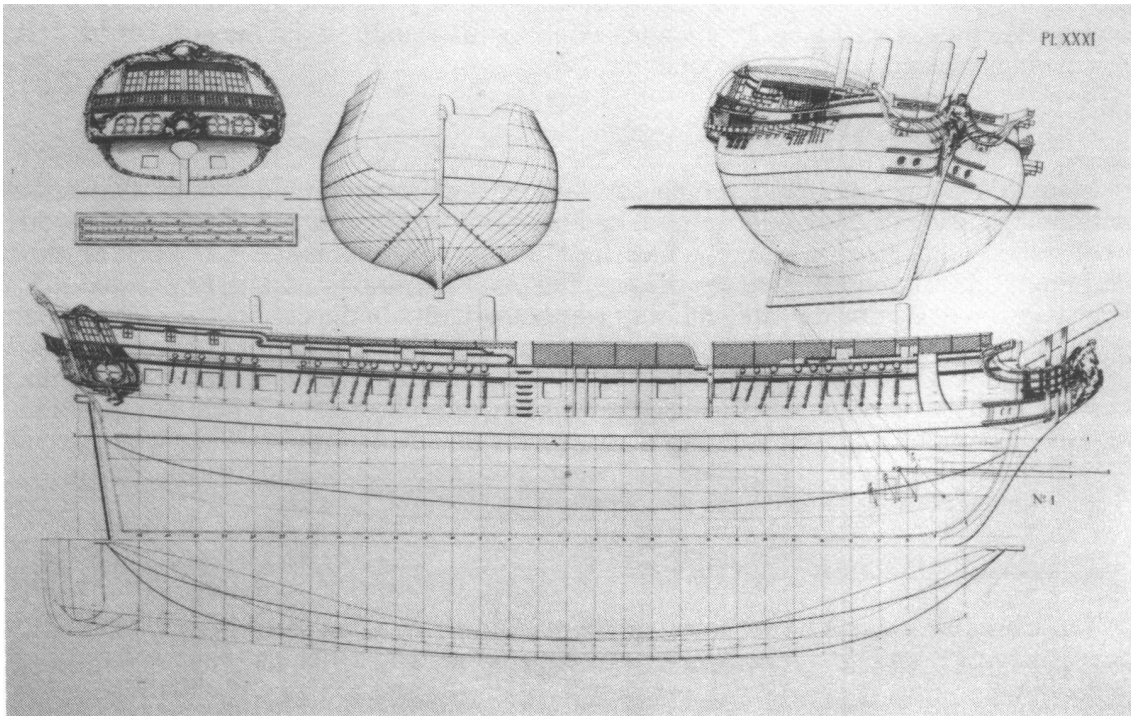


Figure 4. One of the splendid plates from Hendrik Chapman's Architectura Navalis Mercatoria published in 1768. It shows the Lines of a French 40-gun frigate (Reproduced by permission of the Welsh Arts Council from The Art of the Engineer exhibition. In the Collection of the Statens Sjöhistoriskz Museum, Stockholm)

high quality. The linkage between clarity of concept and clarity of depiction was recognised as was the connection between 'fluency' of drawing and 'fluency' of invention. By the middle of the Nineteenth century, the pioneering companies had already developed a sense of history and took steps to preserve their early drawings. Scott Russell, in his book on ship design published in 1864, looked back to Hendrik Chapman's drawings in *Architectura Navalis Mercatoria* (Fig 4) and recognised them as exemplary pioneering work in his own field, not only for their content but for the quality of their draughtsmanship.

It is evident that engineering drawing was a particularly exact expression of the ideals, interests and aesthetic sensibility of the late Eighteenth and early Nineteenth centuries, not only for engineering but for a more elusive 'spirit of the times'. It is this close cultural involvement that goes to explain both the excellence of mechanical design between 1829 and 1850 and the obsessional perfection of many of the drawings that the age produced. When James Nasmyth, Maudslay's pupil who invented the steam hammer, gave evidence to a British parliamentary committee in 1836 he stressed 'the entire reconcilability of elegance of form with bare utility' and in his *Autobiography* defined engineering as 'the application of common-sense to the use of materials'.

For Nasmyth there was an almost magical significance in geometry and in the perfecting of a small range of geometrical forms. This same passion is also something which comes through in engineering drawings from the first half of the Nineteenth century. It shows how they reflected ideology as well as utility, or rather how they gave visible expression to the aesthetic ideology of utility. In a striking passage Nasmyth set out the basic elements of machine design (6):

Viewing abstractedly the forms of the various details of which every machine is composed, we shall find that they consist of certain combinations of six primitive or elementary geometrical figures, namely, the line, the plane, the circle, the cylinder, the cone, and the sphere; and that, however complex the arrangement, and vast the number of parts of which a machine consists, we shall find that all may be as it were decomposed and classed under these six forms; and that, in short, every machine, whatever be its purpose, simply consists of a combination of these forms, more or less complex, for the attainment of certain objects and performance of required duties.

This brief statement by Nasmyth contains the whole programme for engineering drawing as a modelling medium for design and production control in the Nineteenth century. His clarity of purpose and his almost puritan insistence on simplicity and commonsense may not have been the attitude of all engineers but they continued to be most at home with the line, the plane, the circle, the cylinder, the cone, and the sphere and to devote their drawing skill to representing them in the classic viewpoints of plan, elevation and section. It was practical, it worked. And its aesthetic perfectly matched the passionate rationalism of their utilitarian philosophy.

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Of Models, Modelling, and Design: An applied Philosophical Enquiry

PHIL ROBERTS

The discussion in this paper is derived from a strand in a series of enquiries conducted into design phenomena and into design educational activity. It is intended as no more than a contribution towards an agenda for more specific enquiry into the nature and functions of models and modelling, and towards the construction of a practitioners' theory. The enquiry was phenomenological in its general orientation and, more particularly, applied philosophical in its approach.

Let me first locate the discussion: it is in design education; more specifically, it is in Curriculum studies and, even more specifically, it is in the area of Design Curriculum studies. If 'design education' is a term which is indicative of potential paradigmatic change, it is understandable that design educational theory is embryonic. Theory construction is at the stage only of the formulation of models. But a theoretic framework is in sight. If turbulence is symptomatic of paradigmatic change, or of paradigmatic competition, the absence of a generally accepted language of discourse - or even vocabulary - which would enable practitioners of different specialist communities to talk with, as distinct from past, each other is similarly no surprise. In the formulation of new paradigms, innovators necessarily construct theory and a new language: the paradigms that practitioners 'inhabit', and by means of which indeed they exist, are to a large extent predicated on specialist languages. But the languages of differing constituencies are distinctive even though they may employ the same words. It is no surprise that the members of 'old' traditions and the constructors of new ones have difficulty in making contact with each other; the surprise would be if it were otherwise.

The need to develop a shared meta-language of discourse across the areas of design practice is also evident. The need for sustained scholarly and research effort is also apparent. There is, for instance, at the heart of the National Curriculum (NC) Design and Technology documentation a model of activity which has the character of a procedural model. Because of the legislative status of the Education Reform Act and its subsequent Orders - as distinct from its academic or theoretic well-foundedness - it is possible that the central model will become part of a new orthodoxy. Yet it is an inadequate and inappropriate model which may therefore further hinder understanding of how designerly activity, in fact, occurs and of how design thinking and technological ability develops. The relations between the model and the realities to which it is in reference are not well represented in the NC documentation. A simple model at a high level of generality together with a range of complementary lower-level models - the latter having greater specificity and stringency - would have been more appropriate. This, however, is to run too far ahead of the discussion; the NC Design and Technology documentation simply illustrates or adds to the scholarly agenda rather than resolves it.

It is convenient to use questions as a framework for this discussion. The first is: What human capacity is central to the conduct of design activity? Alternatively put, the question might be: How is it possible to design at all? (which is a matter very different from a concern with a theory or with a procedural model of how to design).

Central to the act of designing is the capacity to conceptualise and represent ideas, aspects of present realities and future possibilities. 'The mind' (we say) makes use of a variety of forms of knowing, and makes transformations between the modes of conceptualisation and representation. Envisaging-what - or cognitive modelling - is externalised and manifested in such familiar media and forms as words, drawings, plans, maps, 3-dimensional models,

prototypes. Work carried out in the Design Education Unit of the Royal College of Art indicated something of the nature and status of cognitive modelling:

The conduct of design activity is made possible by the existence in man of a distinctive capacity of mind, analogous with the language capacity and the mathematical capacity. This is the capacity for cognitive modelling. A person acting in the role of designer or appraiser of designs forms images 'in the mind's eye' of things and systems as they are, or as they might be, and evaluates them and transforms them so as to gain insights into their structure and into the likely quality of fit between alternative conceivable configurations and the interaction of perceivable requirements. (...) Cognitive modelling is not limited to spatial configurations. Aspects such as colour, texture, sound, flavour and anything else relevant to the system can be imaged and manipulated. Cognitive modelling is independent of language or symbol systems, but when appropriate, the concepts modelled can be translated into or supplemented by language or notational terms. The image is usually externalised through models and simulations, such as drawings, diagrams, mock-ups, prototypes and, of course, where appropriate, language and notation, or it can be embodied in the construction of or the enactment of the emerging responses. These externalisations capture and make communicable the concepts modelled. (1)

Cognitive modelling does not have the status of language as a linguist would define language; there are too many untested propositions for such a claim to be sustained. With that caveat in mind, however, 'cognitive modelling' can conveniently be referred to as the essential language or cognitive medium of designing and, by extension, of design educational activity. Hence it might be reasonable to expect to find explicit references in course descriptions to the development of the capacity for cognitive modelling. Illustrative instances of such expectations within the descriptions of courses' learning objectives might be, for instance:

- ... to develop the ability to present and represent ideas in two- and three-dimensional forms and media;
- ... to develop the ability to make transformations between the symbolic forms in which an idea is conceived and the forms in which it might best be represented;
- ... to develop the ability to choose and use the symbolic form and media most appropriate to the purpose, the task, and the audience.

A scrutiny of several hundred course descriptions in art, CDT, technical/engineering drawing shows neither any such intention nor expression - either implicit or explicit. And this finding applies both to single subject courses and across design-related subject courses. In view of the centrality of cognitive modelling in design-related activity this is interesting because surprising.

This absence of explicit attention and intention can be discerned, along with other issues, through a reflection on models and modelling. It is convenient to consider a model that is to do with design educational activity: it is a model within the language of discourse: that is, in the discourse about designing and its associated phenomena.

The model, Figure 2, is derived from schools-based practice. It uses four perspectives on the design-educational activity. These are deployed by means of four role-views: those of the designer, the maker, the user, and the observer. Figure 1, below, describes the roles:

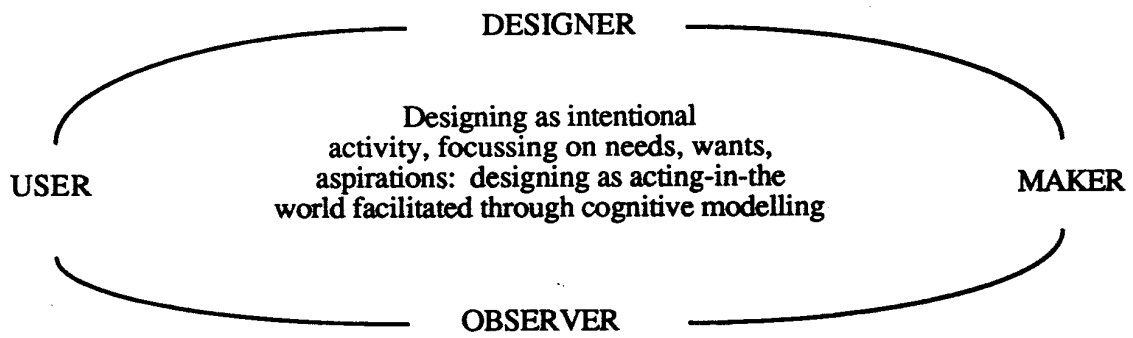


Figure 1: Four Roles (the Designer, the Maker, the User, the Observer) offering complementary perspectives on learning-through-designing

The four role-views are intended to provide working perspectives towards the better comprehension of design and technological activity and of cognitive modelling.

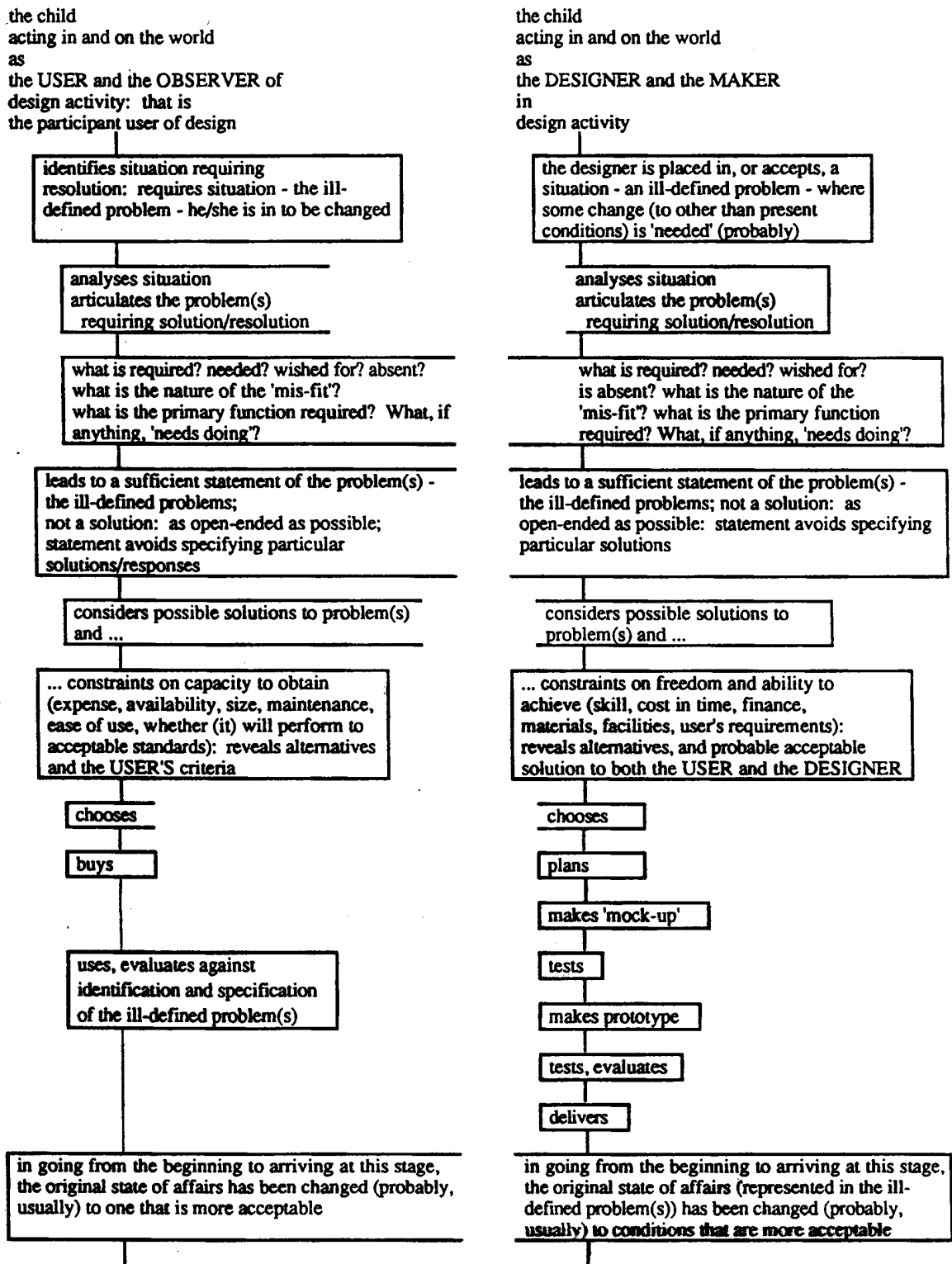


Figure 2: A model towards understanding the nature of design educational activity

Figure 2 - itself, incidentally, a model - represents cognitive modelling as active processes and functions which are within, related to, and derived from the design act. As it happens, this model makes considerable reference to artefacts, but this is not to suggest that artefacts are, or should necessarily be, the principal outcome or the principal object of the activity. In this case, the significant status of artefacts is as a possible means towards achieving change, rather than as a necessary end. This is to make a distinction between means and ends which ought to be important with regard to educational purposes. Making use of such a model, then, is not to assume that artefacts shall be made, in order for the activity to count as designerly activity. In this context, the model is, rather, predicated on the notion that designing is essentially concerned with change (or, better, with changing); or with bringing about some intended change both in the agent of the activity and 'out there'.

The centrality of bringing about change as one of the identifying features of designing and of design-educational activity is worth pursuing. Figure 2 presents a view of design activity as having a transitive form: that is the perspective represented by the User and the Observer.

... All design activity involves continual appraisal and reappraisal of the meritoriousness of existing realities and alternative propositions being handled.
... a transitive form of the activity is wholly or largely concerned with the appreciation of states of affairs and with choosing and deciding, rather than with the creation of things and systems. All human beings rely heavily on cognitive modelling in both these forms for the pursuit of their everyday activity. (2)

This transitive mode of design activity is under-valued - indeed, is barely recognised at all - in mainstream definitions of designing, including the conceptions found within specialist groups of design-related practitioners. And yet it represents better the more general case of design experience and activity than does the familiar model which is essentially concerned with the making (but not always with the designing) of artefacts. Appreciation of the transitive mode is of enormous radical significance; and the operational implications would be beneficial. For instance, a particular part of this significance is in the potential for the complete transformation of so-called 'consumer education' in relation to, first, the priority often attributed to the making of tangible artefacts in the design-related school curriculum subjects and, second, the experience of design activity - predominantly transitive for the majority - in the lives of adults. Even more significant is the potential for developing a larger conception of design in schools through the formulation of a model at a higher level of generality: it would have the effect of changing the perceived exemplary status of some established and familiar curricular activities.

The modelling of Figure 2 readily accommodates the production of physical artefacts - and distinguishes between means and ends in so doing - but the functioning of design activity that it represents does not entail them, nor their making. This is so not only in the transitive form but also in the 'making' dimension. When acting in the role of 'the designer' and 'the maker', the child is now disallowed from 'changing his mind' away from an (at some earlier point) anticipated artefact in his or her evolving conception and realisation of the state of affairs which gives rise to the activity.

The phenomena, and the actions and events, that it attempts to provide a model for (incidentally rather than of) are not exclusive towards feelings or emotions. Indeed, the intention is to be inclusive towards them. It is a skeletal peg intended to make design experience more comprehensible and transparent. One function is to offer the possibility of an interpretative perspective on experience. This does not exclude other possible functions within pedagogy: of, for instance, helping pupils understand better the operational aspect of design activity. Or, of helping pupils to gain a better sense of a phenomenon which essentially is not susceptible to description in natural language. The modelling may appear to be descriptive in character but

rather than being primarily descriptive - or, as a superficial reading might even suggest, isomorphic - of the activity, any apparent descriptiveness is towards developing the pupils' analytical, synthesising and reflexive capacities, mediated in design activities. There is, then, no intention to articulate an 'identity' or 'correspondence' model: it is, potentially, informative of the activity rather than representative. That is, the key function is translation: between the language of discourse and the development of operational capability.

In any event, to pursue this latter point more generally, the test of adequacy or of usefulness of a modelling mediated in natural language in the field of design-educational practice does not necessarily consist in its 'imitation' of 'the facts'. To subscribe wholeheartedly to 'imitation' might be to miss part of the metaphoric nature of language and, particularly, the functions of metaphor in modelling. Furthermore, to concentrate on 'imitation' might be to risk a distortion of the phenomena as experientially enacted. It is a modelling for: to be persuasive or useful, a model must differ from the subject phenomena. Models lose life, and as a consequence much of their value, as they gain in identity. Were this not so, the structure of design phenomena would be as obvious as that of the model (making the model redundant). This seems banal once stated, but the widespread failure to recognise it, and hence its significance, is well illustrated in the naive following of 'the design line', or 'the design loop', or the four attainment targets of NC Design and Technology model, as though they provided recipes or descriptions of the structure and the structuring of design-educational activity.

In other words, the failure to understand the nature, the status and functions of models has resulted in widespread confusion between the logic of designing and the logic of the language which is used to refer to or describe designing. Alternatively put again, there is a widespread failure to distinguish between the phenomena of designing and the meta-language of discourse, in which the models are located. One of the strong criticisms of the models of design activity in education, including the one at the heart of NC Design and Technology, is that they purport to be general but are, in fact, particular. (The NC model, it can be argued, sits uneasily between the two levels, and satisfies neither; the effect is confusion.) It is, however, possible to express a model at a high level of generality. Before that, it is necessary briefly to remind ourselves of the distinctive nature of designerly thinking and technological activity. The character of the action is distinguished by its treating, and conjunction, with 'ill-defined problems'.

... (Design) is a problem-centred activity, but it is distinguishable from some other sorts of problem-solving activity by the fact that it is chiefly concerned with 'ill-defined problems'. In this context, the term 'problem' refers to the presently-existing state of affairs; it does not refer to the statement of requirements which a (possible) thing or system is expected to meet. Nor does the term 'solution' refer to the design arrived at. (...) Design problems are described as 'ill-defined' because there is no way of arriving at a provision description merely by the reduction, transformation or optimisation of the data in the requirement specification. By the same token, it is rarely possible to determine whether or not the finished design is 'the correct', 'the only' or 'a necessary' answer to the requirements. It must usually be possible, of course, to establish whether or not one 'proper' answer to the requirements is better or worse than some other 'proper' answer. Where such doubts do not exist, the problem is not 'ill-defined' as might therefore have been resolvable by scientific or mathematical methods rather than designerly methods. (3)

With that in mind, it is possible to conceive of a model at a high level of generality. If we consider the question, 'When is a (design) problem?' we can respond: 'A problem consists in a state of affairs, in which we feel some unease or discrepancy or incompatibility'. The 'problem statement' consists in a description of that state, and it will be, inevitably, an approximate or tentative description; thus:

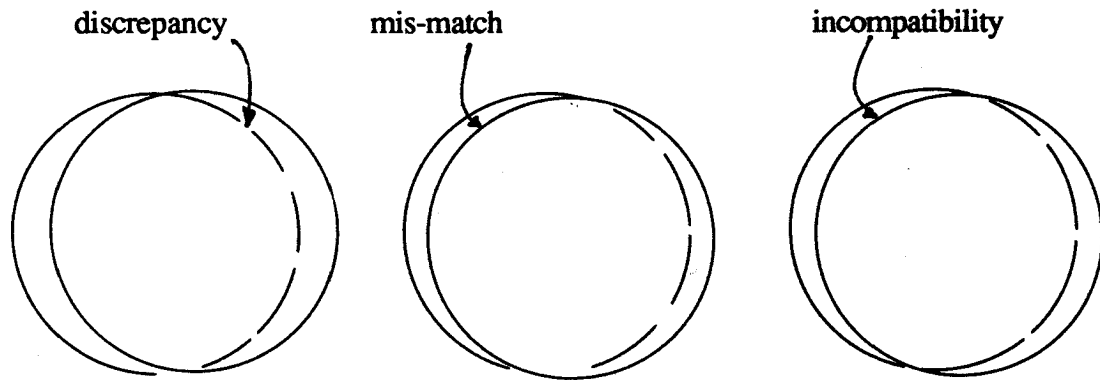


Figure 3: 'When is a problem?'

Figure 4 develops the notion:

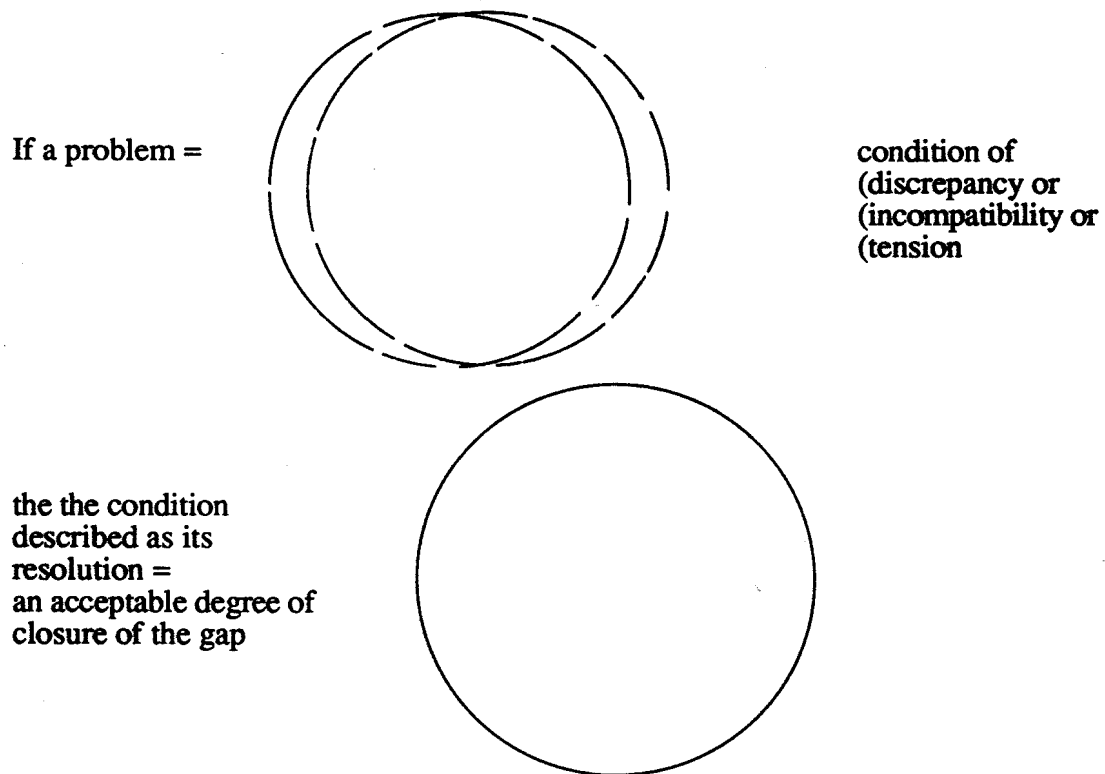


Figure 4: From problem-state to resolution

The central notion is that design and technological activity is concerned with changing (and notice the gerund); or with the achieving of some change. It might be that a change is required

in circumstances 'out there'; it might be some change in the sensibility, or the capability, or the knowledge of the agent of the activity. But change does not entail the production of things, or systems, or environments: the essential focus of designing is on ends, not means. Most models relating to design educational activity which specify that products shall be produced have more to do with means than with ends. That is not illegitimate; but means and ends should not be confused or conflated.

In an educational context, it is then possible to construe design and technological activity as continuing activity, with educative activity construed as continuing process, contained in the addressing a series of overlapping states of affairs grounded in pupils' lived experience.

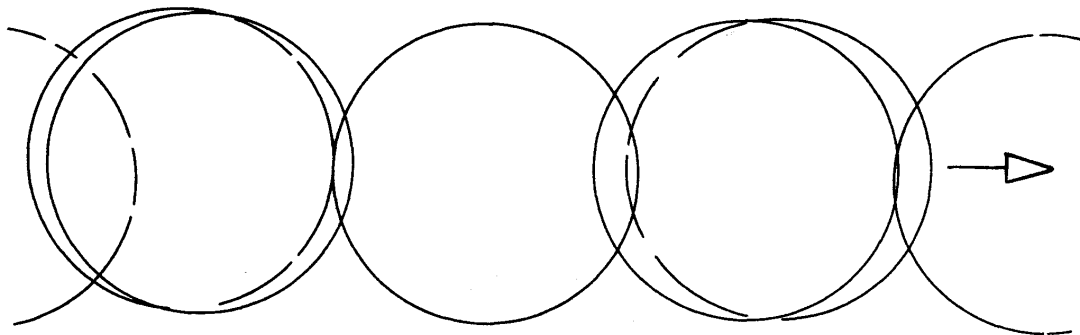


Figure 5: Design and technological activity as learning: Problem solving as continuous process, contained in focussing on overlapping states of affairs

Figures 3-5 provide a model upon which the model provided in Figure 2 may be imposed. Figure 2 may have some initially useful pedagogic functions, but it is more specific than that of 3-5.

In another context, Toulmin noted that some novel method of representation is always at the centre of discovery, helping us to apprehend the phenomena in a new and more fitting manner. (3) That could suggest that one of the functions of modelling can be characterised as cognitively heuristic. On such a view, Figure 2 tends towards a 'translation-correspondence' model, translating between sets of concepts - those of nominal definitions and those of operational functioning.

This reflection on the nature of modelling in natural language and the functions of models may be taken just a little further. Our experience of misunderstandings in, for example, social affairs is a sharp reminder that the words of natural language have no clear cut boundaries to 'their' meanings. Wittgenstein said:

... We might, by the explanation of a word, mean the explanation which, on being asked, we are ready to give. That is, if we are ready to give any explanation; in most cases we aren't. Many words in this sense then don't have a strict meaning. But this is not a defect. To think it is would be like saying that the light of my reading lamp is no real light because it has no sharp boundary. (4)

Our use of words of natural language (in modelling) can bring into focus 'parts' or aspects of our experience, the clarity of whose meaning - a functioning of the focussing - diminishes as the

focus blurs towards the edges. But one man's clear meaning can be another's blurred focus, even within apparently shared experience. In principle, perhaps it is possible to achieve hard conceptual boundaries in an artificial language. The point is this: language cannot represent, unequivocally, our experience; but it can be, and is, useful. If natural language were found unequivocal in the meanings carried by it, or if it were found lacking in tension or ambiguity, it would be found so only by members of a speech community who shared the same narrow set of activities, and whose activities were confined to acts whose meanings were those contained by the language's constitutive definitions. Hence the comparative unequivocality of the formal language of scientific theories. But this absence of ambiguity, or this intended inflexibility, is the feature that makes such formal language unusable by people who are untrained in that language, or who work with subject matter the boundaries of which cannot be confined. The capacity for many possible meanings is intrinsic to evolving natural language: the unfolding form holds blurred boundaries, which is to say possibilities for meanings. And much of designing is, by definition, to do, literally, with the making of meaning. Polysemy is intrinsic and necessary in form-making. The problem, then, of description (in relation to meaning-making) perhaps lies in more appropriately 'matching' one polysemous form (language) against another polysemous form (designing), both of which are situated in an infinity of possibilities.

On this view, the call by some teachers for a 'definitive design vocabulary' - meaning definitions without ambiguity - rather than for a useful meta-language, is misinformed. (In passing, this also offers an insight into the utopian ambition of specifying what shall be the 'knowledge content' of NC Technology.) But in any event, if to learn is to be engaged in the active making of meaning, then learning activity, in general, has a polysemous quality; and the plea by some teachers which appears implicitly to say that this should not be the case appears as a challenging and curious proposition.

However, this is no argument at all for not trying to represent our experience as precisely as the limits and limitations of language usage will allow: we learn to treat with those difficulties as well as live with them. So, we can attempt to achieve a minimal yet firm skeleton, but properly (and especially at this stage of design theory development) be less parsimonious towards its substance in the interests of the potentialities and actualities of meaning-making.

The modelling of Figure 2 presents a conception of design activity as a sub-set of human intentional activity: of acting in and on the world. It also expresses the notion that learning is a function of taking action; that designerly activity is to do with bringing about change; that design educational activity is concerned also with bringing about some change in the capability, the sensibilities, or the awareness in the agent of the activity. And at the heart of the activity is the engagement of the capacity for cognitive modelling. Might reflection suggest any matters of significance for researchers, scholars and for teachers? There are several lines of response.

The first arises from the documentary evidence provided in course descriptions. That is, the development of cognitive modelling ability is not explicitly addressed by teachers of design-related subjects. The status, the nature and the functions of modelling (and of models) appear to be poorly understood and appreciated. Does that matter? The answer must be Yes. The quality and status of the teaching of most of the techniques of modelling in design are much less than their centrality deserve, both within the field and in the public mind (as evidenced in the 'back to the 3Rs' tendency). And the teaching of modelling is certainly less well coordinated than it could be. Partly as a consequence, the relations between the modelling conventions employed by, for instance, art teachers and CDT teachers, are less mutually appreciated than they might be. But the absence of a theoretic base for modelling holds back the incorporation of further modelling techniques and useful concepts that might be taken from studies in artificial intelligence, systems theory, and cognitive psychology. The lack of explicit attention to and knowledge of modelling holds back the development of the design curriculum and design pedagogy.

There is also a major strand of enquiry to pursue via the history of ideas. There is a tendency to think of design as being in some special sense 'visual'. The conception and the expression of ideas, however, do not employ only one symbolic form. We may conceptualise in one mode and express in another - hence the possible objective, expressed earlier, of developing the ability to make transformations between different symbolic forms; and of developing the ability to choose and use whichever symbolic form and media might be most appropriate to particular purpose, task, and audience. This is an area of philosophical-scholarly and operational importance. To present designing as being necessarily predicated on the capacity for cognitive modelling is to say also that design capability is a function of the capacity to understand a physical environment in abstract ways; and that is to accept the intellectual status of design. The relationship between the construing of an environment and the perception of physical objects is a long-standing problem in epistemology. An alliance of enquiry between the philosophical and the operational might lead towards a response to our opening question: How is it possible to design at all?

Another line of enquiry that may perfectly well be pursued by practitioners also arises from reflection upon Figure 2. This line of enquiry would be to do with design-related curriculum subjects in relations to design educational activity. It can be summarised.

First, if the capacity to act intentionally is construed as being central to designing (and to design educational activity) it is necessary to recognise differing modes of action. That is, action in and on the world may be overt or covert. Secondly, it is necessary to distinguish between mindful activity and mindless activism. The alleged superiority of any single and particular mode or manifestation of action is not to be taken as self-evident: the criterion of superiority would be in some relation to the task, purpose, function, context, and their contingency. More specifically, four points follow.

One, overtly witnessable modes and unwitnessable modes are complementary modes of action. The grounds then for asserting that the overt mode should necessarily be regarded as the exemplar, rather than the covert and transitive, are opened up for re-appraisal.

Two, in acting in and on the world, neither the making nor the using of tools is entailed. In a weak sense, it could be said that tools - when and if used - function as instrumental extensions of man's intentional activity. In a stronger sense however, tool-making and tool-using extend man's cognitive capabilities: that is, they are not to be understood as simple modifications of natural objects.

Three, the making of tangible artefacts is not entailed - except in those areas of activity which are constituted in artefact achieving, eg, furniture making. But even there, there are exceptions to this generalisation, and even there the transitive mode is not necessarily inferior to the overt mode which is frequently displayed through artefact production. In terms of curriculum subjects, such a recognition would lead to the proper recognition of Craft, Design and Technology (CDT) as a limited case. Alternatively put, CDT does not provide the paradigm case of designing; nor does art. This is not of course a value judgement: it is a conceptual issue.

Four, while it is important that man makes things and systems, and while it is important to understand how competencies in the making of things and systems may be enhanced, there is a prior question (or, at the least, an accompanying question): Why, or whether, man makes or acts. That is, the prior question is to do with mindful action. The narrowly operational, no matter how complex or simple, is insufficient by itself - and particularly with regard to educative intentions.

All this means that the often asserted or sometimes supposed exemplary status of some particular school subject is not easy to sustain. The brief summarising conclusion is that the development of the design capacity is central to would-be educative activity. The capacity to act with intention is realised and manifested in the functioning of cognitive modelling. In treating with real-world ill-defined states of affairs, cognitive modelling engages, employs, and is constituted in differing modes of conceptualising, symbolising, and presentational systems, according to the subject phenomena, the 'task situation', and the required functions or purposes. The operations encompassed by the term 'cognitive modelling' are necessarily and inevitably complex, and transformational.

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- 4 Wittgenstein, *The Blue and Brown Books*, Oxford: Blackwell 1975, p 27