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Models of Design and Technology and their Significance for Research and Curriculum Development

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Abstract

Modelling is the activity that is central to designing, and is therefore central in the designing of a school curriculum. The models of designing and of the curriculum that are formed shape both the evolution of the curriculum and its subsequent evaluation. A brief introduction charts some of the reasons for the evolution of simplistic models of designing and notes some of their dangers. The nature of problems in design and technology is discussed. Some theoretical difficulties in expressing ideas about design and technology are noted and hence the consequential merits of an empirical approach are made evident. The rigorous analysis of good practice should play an important part in research and curriculum development in design and technology, but it is crucial to recognise that such analysis will be influenced by the viewpoint (models held) by the analyst.

Introduction

Art and Design has represented a particular area of the design field in general education for many decades. However, it is only since the 1970s that designing has been struggling to emerge as an essential element of 'technological studies'. Earlier syllabuses were centred on craft-based technologies, like woodwork and metalwork. At A' Level these syllabuses developed some designing competences in relation to these materials, but they were initially driven by the development of craft skills. Technical issues were also represented at A' Level by syllabuses such as Elements of Engineering Design and at O' Level by Engineering Workshop Theory and Practice. Again particular designing competences were being developed at A' Level founded on substantial prior craft learning. It can be argued that such designing competences grew 'naturally' out of prior craft learning and there were no significant attempts to develop generic models of designing that might provide a unifying theoretical framework for such design activities. The notion of such generic models was a result of wider movements, which had their origins in the three substantial projects completed in the 1970s: the Keele Project (Keele University, 1971) and Project Technology (Loughborough University, 1971) and Design in General Education (Royal College of Art, 1979).

These projects each had wide-ranging but different aims. The Design in General Education project set out to identify the nature of designing (in the context of general education) and where contributions were being made to design education in the curricula of general education. Designing was broadly identified as being associated with the creation of the material culture with contributions from a number of school subjects. Consequently it was cognitive modelling which was identified as being central to designing. The Keele Project was a re-examination of craft-based teaching and learning with a particular agenda to enhance their status in schools. Such low status was (and remains) a result of the unsound separation of 'mind' and 'body', the 'ghost in the machine'. (Ryle, 1949) Cognitive modelling linked to traditional craft subjects could clearly provide the way forward that was being sought. Engineering had been lamenting its absence from general education for many years prior to the establishment of Project Technology and the Loughborough project set out to establish its place in general education and develop appropriate curricular resources. The end result was a somewhat uneasy co-existence between these movements and the establishment of Craft, Design and Technology (CDT), as well as the potential for much confusion. The models employed to introduce the meaning of 'designing' and 'technology' to schools had superficial similarities and with enough simplification became 'the design process', to which reference is now commonly made. The drive to make progress in establishing a place for such activities in school curricula had placed political expediency significantly ahead of epistemological complexity: a lowest common denominator was sought and found.

However, such epistemological complexities will not just go away and the difficulties associated with the nature of the phenomena addressed and the knowledge, skills and values employed in their resolution still remain. Significant questions now need to be asked. For example, what place has actually been found for 'design', 'craft' and 'technology' in UK secondary schools? Has the 'coming of age' to which Kimbell referred in a previous Editorial (1999, pp.3–4) been established at the price of unacceptable compromise? It is, of course, more comfortable to believe that recent curriculum initiatives have resulted in 'forward progress', but is it necessarily so? Answers to such questions will depend on the analysis of outcomes, but this is not a neutral activity. Analysis begins by deciding on the questions to be addressed and, therefore, the questions that will not. It proceeds by gathering evidence relating to the questions posed, and such 'gathering' will be selective and governed by the analysts' views of what is important. The position reached will in part be a result of the evidence, but will also be

influenced by the analysts' aims, objectives and methods. Research targeted at addressing such issues will be highly problematic, unless, of course, political expediency, which tends towards begging the questions, is again pursued.

The nature of problems in design and technology

Design problems are wicked problems (after Rittel and Webber, 1974). The implications of this for designing and designerly activity have been extensively discussed by Roberts (e.g. 1993).

> It is (we say) a problem-centred activity (which is not to say that it is a problem-solving activity). If we consider the question, When, or What is a problem? we might respond: 'A (design) 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.

> Designing is a problem-centred activity, but it is distinguishable from other sorts of problem-solving activity by the fact that it is chiefly concerned with 'ill-defined problems' (wicked problems). In this context, the '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 system requirements and provisions to match one another. The problem is obscurity about what the requirements might be, ignorance as to what sort 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 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'. (pp. 3-5)

If 'design and technology' (read as a composite noun) only incorporated designerly activity in this sense, then there would be no more to say. However, design and technology in practice is not so pure. The problems which pupils investigate in design and technology are commonly a combination of 'defined' and 'ill-defined' elements. This has been hinted at in the writing of Thistlewood. (1990)

> ... there is another component of design teaching to be acknowledged – technology, or rather technologies. This is of course fundamentally necessary learning. It *directly* embraces methods of manufacture and fabrication, from handicraft to mechanical and industrial processes; and it also *indirectly* deals with technologies that are 'packaged' in product design. For example, audio-visual home entertainment systems, within a given range of performance, consist of similar technology, packaged as variations on familiar themes. The same is true of all manner of domestic appliances. Because there is often a surprisingly loose fit between contents and container, the latter may be designed independently in education as it often is in professional life. But educational opportunities are lost if pupils are encouraged to be impressionistic about, say, the internal workings of a washing machine. (p. 19)

Design and technology in the UK very much reflects this idea of directly embracing methods of manufacture and fabrication and indirectly embracing packaged technology. Technologies like electronics and mechanisms are often seen as packaged technology. These aspects of problems are often essentially well-defined with clear statements of performance requirements and consequently suited to a systems analysis approach (a linear model of the defined requirements, generate ideas, select, manufacture, evaluate type). Hence teachers can determine the 'wickedness' of the overall problem through the combination of defined and ill-defined problems which they allow and, thereby, achieve some control of pupil projects (consider for example, electronic circuits in vacuum formed cases). This theoretical position is embodied in the textbook written for A'/AS' Level design and technology (Norman *et al*, 1990), both in the designing and technology chapters.

RESEARCH

Technological areas that have a direct impact on form – e.g. materials processing – are treated differently from those that are often viewed as packaged technology. A detailed discussion of these matters can be found in Norman. (1997)

Hence, design and technology can be seen, in much practice (and not necessarily inappropriately) as addressing ill-defined problems and well-defined problems in some combination. This has been recognised in recent work by Doornekamp. (1997)

> Problem-solving is a central theme in technology in basic education. Pupils learn how to solve technical problems.
>
> These problems can be characterised as open-ended or as constrained problems. They are the extremes on a continuum: they are the alpha and the omega. Between them, is a great variety in problems which are less open-ended or less-constrained.

Avoid, for the moment, the easy conflation of 'technical problems' and the 'wicked problems' of Rittel and Webber: consider the commonality of their structural features. The apparent similarities have clear implications for the kind of approaches that can be pursued.

Rittel and Webber explained the difficulties very clearly in their paper concerning wicked problems.

> ... in order to *describe* a wicked-problem in sufficient detail, one has to develop an exhaustive inventory of all conceivable *solutions* ahead of time. The reason is that every question asking for additional information depends upon the understanding of the problem – and its resolution – at that time. Problem understanding and problem resolution are concomitant to each other. Therefore, in order to anticipate all questions (in order to anticipate all information required for resolution ahead of time), knowledge of all conceivable solutions is required...
>
> The formulation of a wicked problem *is* the problem! (1974, pp. 273-4)

This is clearly a description that would apply accurately to design problems, but it is the next quotation in relation to this, which really exposes the key issue.

> This property sheds some light on the usefulness of the famed 'systems-approach' for treating wicked problems. The classical systems-approach of the military and the space programmes is based on the assumption that a planning project can be organised into distinct

phases. Every textbook of systems engineering starts with the enumeration of these phases: 'understand the problems of the mission', 'gather information', 'analyse information', 'synthesise information and wait for the creative leap', 'work out solution' or the like. For wicked problems, however, this type of scheme does not work. (1974, p. 274)

Design and technology teachers might like their students to be engaged in open-ended problem-solving (i.e. ill-defined or wicked problems), but that alone would hardly be a realistic curriculum; (the ability to address, effectively, such classes of problems might however be a legitimate performance objective). Every problem being undertaken by every student would have no definite formulation, no stopping rule, no easy means of assessment, would require a unique method etc. This was the essence of the difficulties that forced the revision of the 1990 version of the UK National Curriculum in 1995. Whatever the merits of engaging in design activities that consisted solely or largely in wicked problems, the resulting curricula would be very difficult to conceive or manage. Pedagogical practice is inevitably constrained in its constituent teaching and learning situations. Good practice in design and technology education enables pupils of all ages to engage with problems with both defined and ill-defined aspects, and this is one aspect of its unique contribution to school curricula. Problem-solving in science and mathematics, however, is more concerned with well-defined problems.

Some difficulties in expressing ideas about design and technology

Progress can be made in defining the nature of the problems addressed in design and technology using language, but there are other areas – e.g. their resolution and appropriate pedagogy – which are more problematic. This paper presents the view that the distinctive nature and the boundaries of design and technological activity are functions especially of:

•   the kinds of problems addressed

•   the knowledge, skills and values employed

and are also influenced, if not entirely determined, by institutional constraints.

In so doing, the paper is distinguishing design and technology from the sciences and the arts and reinforcing the subject's claim to a prominent place in school curricula. However, reference is not being made to 'a' or 'the' design process. The existence of such a singular process has been previously

questioned (e.g. Norman and Roberts, 1992), and there is growing research evidence that it is a myth (Welch and Lim, 1998). Such research is being undertaken largely as a result of the widespread misinterpretation of models of designing, which are often presented as diagrams. Designing does not take place in a linear sequence and never did. The nature of designing as a reflective conversation between 'internal' cognitive models and 'external' representations was accurately described by Schön (1983), and Baynes and Roberts (1984) described human cognition as a process embracing...

> ... all those processes of perception, attention, interpretation, pattern recognition, analysis, memory, understanding and inventiveness that go to make up human consciousness and intelligence'. (p. 8)

It was never realistic to expect it to be possible to model such a complex human activity by a linear model derived from the methodology of systems analysis. Even design loops and spirals, with or without feedback paths, can never hope to be an accurate representation: models must differ from their subject phenomena. Their originators may or may not have seen them as some kind of complete description of designing, but they could never be so. It is interesting to note our first experience of teaching about models of designing in a new module piloted with final year industrial design undergraduates (in 1997/98). It began with lectures describing six or seven models of designing and a discussion of the intentions of their authors. The students were then invited to either present their choice of a model which best represented their understanding and experience of designing or to develop their own and justify it. One student (out of thirteen) presented a linear model close to one that had been described: the others developed their own. These all had aspects which were as convincing as those referred to in lectures, perhaps the most interesting being a modified map of the London Underground developed by Luke Sicinski. Diagrams, by themselves, are clearly not sufficient models to depict or to clarify the meaning of designing.

Of course, models of designing are not necessarily solely visual (i.e. non-linguistic) representations; they may also incorporate language. But can the language associated with such models ensure their clarity? Saxton and Miller reported a study of the language used to describe designing in 1996. They found that even:

> ... when design teachers are talking about 'design' activities there is evidence that they do not all share the same understanding about the nature of these activities. (p. 118)

This is, of course, to raise further questions: to do with the language used in models of design activity and the meta-language of discourse (*about* design activity).

A study reported by Hine (1997) is targeted similarly at the difficulties that the lack of a shared (meta-language) vocabulary might have for teaching and learning. Hine has developed a methodology for capturing what pupils and teachers say that they understand by 'technology'. The resulting profiles have two characteristics divided into six areas which, if nothing else, serves to demonstrate the complexity of the phenomena or of the concept that an individual is trying to convey when the word 'technology' is used. Interpretations of the meaning of the subject area are equally complex and the findings of the recent study by Hopper and Downie (1998) are not surprising.

> What the research has highlighted is that teachers have no clear model of the interrelationship between technological capability and the co-processes which bring capability about. (p. 57)

However, the positive findings of this study are the more remarkable and encouraging in the current context.

> The examination of the data generated by the various complementary strands of the small scale research has provided sufficient evidence to support the following conclusions:
>
> I) that practising teachers are able to confidently and spontaneously define the knowledge, skills, concepts and personal attributes which enable learners to become technologically capable;
>
> ii) that there is a significant level of agreement between experienced teachers with regard to the definition of the essential components of technological capability;
>
> iii) that practising teachers rely on past practice and experience rather than promote the development of the essential components of technological capability which they have earlier identified. (ibid, p. 57)

It would appear that experienced teachers know what they are doing, but may have some difficulties saying exactly how they do it, which is a classic example of the distinction

RESEARCH

made by Ryle (1949) between *knowing how* and *knowing that*. It is actually unsurprising in that, if you imagined conducting a survey of a few hundred competent, experienced cyclists concerning how they rode their bicycles, you are unlikely to find out very much about the fundamental physics (propositional knowledge or knowing that), which makes riding a bicycle possible. It is, in any case, by no means certain that teachers (or anyone else for that matter) ever can have a clear model of the interrelationship between technological capability and its associated teaching and learning (as Daley explained in 1984).

> To talk of propositional knowledge (knowing that) in this area, or to make knowledge claims about the thinking processes of designers, may be fundamentally wrong-headed. The way designers work may be inexplicable, not for some romantic or mystical reason, but simply because these processes lie outside the bounds of verbal discourse: they are literally indescribable in linguistic terms. (p. 300)

Hence attempts to model designing through natural language may prove just as problematic as using non-linguistic representations. All models in this field, whatever their format and medium, are essentially allusive. The reason that teachers rely on past practice and experience is that know-how can be demonstrated and passed on from more experienced practitioners to new entrants to the profession. The need nevertheless remains to develop a better language of discourse, a better knowledge of the capacity for design (cognitive modelling), and a better understanding of the nature and status of modelling as the 'language' of designing.

These difficulties of expression associated with pursuing a theoretical study are what lead towards the crucial role of empirical approach. To quote an earlier paper by Norman:

> Design curricula embracing associated technology have been developed for all ages in most countries and cultures, but they have not been subjected to rigorous analysis. Discussions tend to focus on what might be taught and how (e.g. McCormick, 1997), but why in a particular sequence and the relationship of such a sequence to the general educational development of the child have been rarely addressed. It could be assumed that such design curricula represent good practice, the strands related to technological knowledge, skills and values identified and what is found mapped onto what is known

concerning the development of human cognition. Such an analysis would reveal both matches and mis-matches – the matches might reinforce current theoretical positions in both fields – and the mis-matches could lead to new theoretical developments in either. (1998, p86)

Such an agenda represents a massive task, but such analysis of empirically developed good practice might be the only effective way forward, because of the difficulties associated with expressing knowledge and ideas concerning design and technology.

A topic of considerable current concern is the complexity of the relationship between knowledge developed in science and mathematics and its use in design and technology. In the recent Maurice Brown Memorial lecture, McCormick argued:

> ...that we need to examine again what we mean by capability and in particular to look at the role of knowledge. The argument has a number of strands. First that we cannot continue to use models of capability that rely on processes that exist independent of knowledge. Second, that the use of knowledge particularly from science and mathematics is more complex than the injunction in the National Curriculum ... presents it. Third we need to examine the nature of the knowledge that is used in technological activity, and to explore qualitative knowledge. (1999, p. 5)

A theoretical discussion of the nature of technology for design can be found in Norman (1998), but it is possible to go further through the analysis of empirically developed good practice. As an example of what could be done, consider the work of the ASE/DATA Science with Technology Project, which was reported by Jim Sage in 1996 (pp. 66-73). Following an investigation of good practice in schools fifteen units were produced covering technological areas including electronics, energy, human factors, food and textiles. These were favourably reviewed in the Summer 1996 edition of *The Journal of Design and Technology Education* (pp. 179-189). Sage makes the following statement concerning 'Stage 3' of the process for planning collaborative work in schools.

> *Stage 3*
> Identify strands of conceptual development that run through the subjects involved and employ strategies that support the effective transfer of understanding from one subject to another (ibid, p. 70)

A collection of case studies concerning this process could make a valuable contribution to our knowledge and understanding of good

RESEARCH

practice in relation to technology for design. The analysis of the 'transfer of knowledge' or, even, the transferability of knowing and knowledge from one domain to another has hardly begun. It is an urgent topic, not least because of the glib though largely rhetorical assumptions that it is, apparently, non-problematic. ('Transferability of skills' is another slogan awaiting analysis.)

A further possibility would be the analysis of the use of a resource pack concerning kites developed by Norman for teaching design and technology at Key Stage 3 (which will be available early in 1999). This pack supports existing good pedagogic practice in relation to technology for design, but should facilitate the teasing out of some of its detailed aspects: thus helping in its articulation. Its analysis would therefore be centred on the key assumption that teachers 'know how' and would be a step towards aspects of 'knowing that', albeit with the recognition that it is probably theoretically impossible to complete such a journey in the area of design and technology. Good pedagogical practice must be presented through a series of illustrated case studies, rather than a statement of a priori principles from which it can be derived for any particular circumstances.

An illustration and conclusion

McCormick set out to understand children's problem-solving processes and reported his early findings at the International Conference on Design and Technology Educational Research and Curriculum Development (IDATER) in 1993. In reporting findings concerning a teacher's approach the following comments were made:

> The teacher we studied was aware of the need to keep in mind all of the processes required by the National Curriculum. She had decided for the kite-making project to emphasise the processes concerned with 'generating ideas' and 'evaluation', and the practical activity of using materials. She stated that she did not want the overall process to be seen as a rigid linear sequence (hence pupils were to "evaluate throughout"), but was concerned in addition to emphasise creativity. By this she meant encouraging the children to experiment with materials and to try out ideas without any preconceived notions of a final product. However, in pupils' minds the over-riding impression of the project, and of technology generally (both in and out of school), was essentially of 'making', and learning outcomes in D&T were described as skills related to making. The children appeared to be largely unaware of the design process. In an interview six

months after the project the teacher expressed concern about the National Curriculum processes and felt some conflict between teaching the design process and encouraging learning in Art that she valued i.e. creativity. It is therefore unsurprising that the pupils' perceptions would not include these processes.

This conflict in aims led to a lack of explicit treatment of the processes. The lessons over the eight weeks of the project followed the usual sequence of processes:

- defining a reason for a kite (a need)
- generating four designs
- modelling in 2-D and 3-D
- evaluating these models and modifying
- planning the making (using a full-scale 2-D drawing)
- making the kite
- evaluating and modifying the kite
- carrying out the final evaluation.

Despite this there was little reflection on them and no explicit discussion of the overall process. This was in part a deliberate pedagogic strategy on the teacher's part. In order to prevent the pupils becoming focused upon a final product prior to being creative with their initial ideas, she tended to 'reveal' the process implicitly as the class went through the various stages of the project. This reflected the belief that this stage of exploration was critical if pupils were to apply understanding of the materials from an informed and experienced position. Hence creative experience of the materials was seen as a pre-requisite of a good solution. Rather than being devalued by the teacher, the design process to an extent became secondary to other learning she considered more fundamental. (pp. 9-10)

This passage, together with the remainder of the paper, are interesting for a number of reasons. In the present context it is remarkable for exemplifying the goodwill towards 'the design process' on the parts of both the teacher and researcher. The teacher seems to be fully aware that the 1990 National Curriculum was built on sand, but nevertheless willing to attempt to teach 'the design process', albeit 'implicitly'. The researcher is seeking evidence of the explicit teaching of 'the design process', despite, surely, more than a suspicion that it was an invention. However, by this point in its history, the myth had taken such a hold that

views like the following from the National Curriculum Design and Technology Working Group were commonly held.

> Another feature of progression is the ability to reflect upon practice and from this make explicit the concepts, procedures and strategies involved so that these can be carried over and applied consciously to new design and technological situations. (p. 9)

McCormick was clearly right to look for evidence, but equally right in his conclusions.

> Models of the design process which identify clear sub-processes that link in some holistic process, do not reflect the complexity of how pupils undertake 'design and make' tasks, or what is involved for teachers working across disparate areas of the technology curriculum. (op. cit p. 11)

Nevertheless, the doctrine of 'the design process' as a transferable skill is beginning to take hold. Given that 'the design process' exists in its own distinctive right, such arguments are a feeble justification for teaching expensive design and technology. As a transferable skill 'the design process' could be taught in another subject with equal effect and 'transferred' to design and technological activities (were they to remain): the managerial logic of the ill-conceived 'transferable skill' would be, however, to teach 'it' in the cheapest curricular subject and, in any event, avoid unnecessary duplication.

Looking again at the evidence which McComick gathered, we might choose to accept the teacher's proposition that 'this stage of exploration was critical if pupils were to apply understanding of the materials from an informed and experienced position'. Neither, the interpretation of the evidence, nor its gathering, were focused on in this agenda, but it could have been. In the design and technology area, research and curriculum development are hampered by myths and ideology masquerading as established facts.

In concluding we return to one of the questions posed earlier. Has a place actually been found for any of 'design', 'craft' and 'technology' in UK secondary schools? Do designers, craft experts and engineers visiting schools see their professional knowledge, skills and values reflected in current practice in design and technology? Should any or all of them be able to? It all rather depends on what is being claimed for the subject as part of education in the next millennium. Is design and technology some kind of pre-vocational training experience? A problem-solving

panacea perhaps? A mind-expanding, creative experience? Is there a vision for design and technology in general education? If nothing else, there is considerable good practice in classrooms and its analysis is the most likely way of making progress. 'Top down' approaches have been tried with limited success and much could be gained by returning to primary sources, and leaving the story-telling behind.

IDATER is held annually at Loughborough University (August 23-25 in 1999, see http//:www.lboro.ac.uk/idater/ for further details). For all the reasons stated in this paper and because of our continuing close partnership with schools, practising teachers are particularly welcome. Research and curriculum development are important issues for all educational professionals, and it is important to achieve the widest possible participation in establishing research agendas and collaboration in carrying them out. This is not a call for teachers to become academic researchers (although several are registered for MA and MPhil degrees). Teachers are already busy in their professional roles and in professional development. However, the sharing of their collective knowledge of practice is an aspect of such professionalism and crucial to the success of future research and curriculum development in design and technology.

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RESEARCH