A study of the problem solving strategies used by expert and novice designers

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Thesis Summary

This research project focused upon the design strategies adopted by expert and novice designers. It was based upon a desire to compare the design problem solving strategies of novices, in this case key stage three pupils studying technology within the United Kingdom National Curriculum, with designers who could be considered to have developed expertise. The findings helped to provide insights into potential teaching strategies to suit novice designers.

Verbal protocols were made as samples of expert and novice designers solved a design problem and talked aloud as they worked. The verbalisations were recorded on video tape. The protocols were transcribed and segmented, with each segment being assigned to a predetermined coding system which represented a model of design problem solving. The results of the encoding were analysed and consideration was also given to the general design strategy and heuristics used by the expert and novice designers. The drawings and models produced during the generation of the protocols were also analysed and considered.

A number of significant differences between the problem solving strategies adopted by the expert and novice designers were identified. First of all, differences were observed in the way expert and novice designers used the problem statement and solution validation during the process. Differences were also identified in the way holistic solutions were generated near the start of the process, and also in the cycles of exploration and the processes of integration. The way design and technological knowledge was used provided further insights into the differences between experts and novices, as did the role of drawing and modelling during the process. In more general terms, differences were identified in the heuristics and overall design strategies adopted by the expert and novice designers.

The above findings provided a basis for discussing teaching strategies appropriate for novice designers. Finally, opportunities for future research were discussed.

Key words: design education, protocol analysis, design methods, cognitive styles, design process.

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Bryan Lawson (1979) describes the six phases of a design project: enthusiasm; disillusionment; panic; search for the guilty; punishment of the innocent; praise for the non-participants.

In this 'design' project, I certainly started with enthusiasm, but also suffered the feelings of disillusionment, panic and guilt in equal quantities at key stages in the project. I am sure that at sensitive times I punished both my colleagues and family. However, the time has now come to praise the non-participants, all of whom contributed greatly to the completion of this thesis.

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Chapter 1 - The Nature of the Problem

The curriculum in secondary schools within the United Kingdom has undergone enormous change during the past twenty years. The subject area currently known as Design and Technology has probably changed more than any other area of the school curriculum during this period of time. The changes have not been merely in terms of content and subject knowledge, but have challenged the basic philosophy of the subject and hence the teaching and learning methods associated with this philosophy. This has resulted in a fundamental move from tasks in which the focus was upon products and artifacts to an approach which is now much more process-orientated.

Originally, this area of the school curriculum was based within traditional craft subjects of woodwork, metalwork and technical drawing. Over a period of time, these have been continually modified to incorporate a pedagogy in which pupils play a much more active role in their own learning. That is to say, an approach in which pupils identify and solve design problems which are related to real human needs. This contrasts with the craft-based teaching methods in which pupils manufactured artifacts from standard drawings provided by the teacher.

The first modifications of the craft-based approach came as a limited opportunity for designing was provided in syllabuses related to a single material, such as 'Design in Wood' and 'Design in Metal' within General Certificate of Education (GCE) and Certificate of Secondary Education (CSE) courses. It was also possible to find more innovative approaches which were perhaps closer, in philosophical terms, to current courses. For example, the University of London introduced a GCE option in "Design and Technology" in the early 1970s. In the late 1970s the West Midlands Examination Board introduced a CSE subject called "Design

Studies" which would fit comfortably under the attainment targets put forward for National Curriculum.

In 1985 the National Criteria for the newly-formed General Certificate of Secondary Education (GCSE) in Craft, Design and Technology (CDT) were published (DES, 1985). The aims for these programmes were based upon an understanding that any course in Craft, Design and Technology should reflect the complex abilities required to exercise control over the man-made environment but the common core of activity was identified as designing and communicating, making, testing and evaluating. It will be seen in the discussion of the National Curriculum how closely this common core relates to the attainment targets for Design and Technology capability.

Within the GCSE National Criteria three subject areas were identified under the umbrella heading of CDT:

CDT: Design and Realisation
CDT: Technology
CDT: Design and Communication

These successive changes have recently manifested themselves in the development of Technology as an important subject within the National Curriculum. In other words, over a short period of time the subject area has changed from one which was based upon practical skills and of low status in many schools, to one which is now mandatory for all pupils in state schools between the ages of 5 and 16. The implications of the National Curriculum for Design and Technology are discussed in Chapter 2 of this document.

Two 'profile components' have been identified in the National Curriculum Statutory Orders under the general heading of Technology. The first of these is Design and Technology Capability which comprises four attainment targets. These attainment targets are derived from an interactive model of the design process which involves firstly, the identification of a need or opportunity. Secondly, it involves generating a design proposal based upon the need identified. The third attainment target focuses upon the planning and making required to realise the design proposal. The final attainment target involves the evaluation of the solution generated. However, it is recognised that evaluation is continuous throughout the design process.

The second profile component is Information Technology Capability in which there is a single attainment target.

However, even before the National Curriculum has been fully implemented, doubts have been expressed about its effect upon pupil learning. Her Majesty's Inspectorate (HMI) reported (TES, 1992) that only 59% of lessons observed in design and technology were judged to be of a satisfactory standard. The report commented: "Schools have devoted a great deal of time and effort to considering assessment and recording in D&T but few have developed satisfactory policies and practices in either D&T or IT." As a result, new proposals for the National Curriculum subject of technology are currently being considered (DfE/Welsh Office, 1992).

There is also concern about whether the new curriculum adequately prepares pupils for the world of work. Comparisons have been made between the vocational education provided within other parts of Europe and the general educational policy, which is implicit in the United Kingdom's National Curriculum (Halsey et al, 1992).

This new curriculum has faced teachers with the problems of developing new skills and understanding over a wide area. These include understanding and knowledge of a much broader range of materials and processes, greater understanding of technological concepts and knowledge, the introduction of new technologies such as electronics and computer aided design and manufacture, and new approaches to graphic communication.

With the introduction of the new curriculum the role of the teacher changes from that of a provider of knowledge and expert advice related to craft-based teaching, to the more generic role implied by the National Curriculum statements of attainment and programmes of study for design and technology. Linked to this is the development of subject skills and teaching methods appropriate for the new curriculum.

The subject area of Design and Technology has evolved without the research base evident in some other subjects. For example, Science education has a well-established tradition of research promoted through organisations such as the Association of Science Education (ASE). The annual conference of this organisation has for many years provided a focal point for the delivery of research papers. On the other hand, Design and Technology, which has had a much lower status within the education system, has promoted the subject through events such as the International Exhibition for Design and Technology which is held annually at the National Exhibition Centre. This event acts mainly as a trade fair with the purpose of promoting products and curriculum materials to support Design and Technology education.

However, in recent years there has been an emphasis on lectures and seminar groups. The annual research conference in Design and Technology at Loughborough University is also helping to develop a research base which could inform curriculum decisions in the subject area. In spite of these recent initiatives, the research base is still rather limited. This point was highlighted in the interim National Curriculum report for Design and Technology.

> "Indeed, one interpretation of our task is that of contributing to the establishment of a tradition and the setting of appropriate standards in this new curriculum area where there is at present little in the way of a developed and professionally well-tested body of school experience upon which to draw. This is not to say that we have not received and been considerably assisted by valuable evidence from many sources; we have also benefited from observation of good practice in primary and secondary schools and from knowledge of relevant curriculum developments presently taking place. But design and technology lacks a research base in pupils' understanding and learning such as is available in the cases of mathematics and science."
>
> Design and Technology
> Interim Report 1988

The comments above relate to research into Design and Technology education in general terms. The need for research into the relationship between design methodology and teaching and learning strategies has been evident for a number of years. Cross (1982) concluded that further research was needed in this complex area:

> "We need more research and enquiry: first into designerly ways of knowing; second into the scope, limits and nature of innate cognitive abilities relevant to design; and third into the ways of enhancing and developing these abilities through education."
>
> Cross (1982)

What therefore is the motivation for research in this area? The Assessment of Performance Unit (1987) puts forward a number questions which are raised by traditional models of design processes :-

> "All these models have been helpful guides to the 'staging posts' in the activity for many teachers who have been seeking to establish design and technological activities in schools. However, many teachers who recognise the central importance of the procedure, have found some difficulty in fitting the models to what pupils actually do when they get involved in a project. The neat subdivisions of the procedure present an attractive but artificial interpretation of the activity. Does the generation of ideas really precede making - or is making (in model form) one way of generating ideas? Does research really precede specification - or does the specification of the problem help one to see what needs to be researched? Is evaluation concerned with a concluding judgment - or does it occur constantly throughout the whole project? How could we ever move forward if we are not constantly evaluating where we are at present?"
>
> Kelly et al (1987)

Thomas and Carroll (1979) suggest that there are two distinct but related reasons why we are interested in studying design problem-solving. The first is to understand more fully how people think, and the second is to understand how to help them to design better. Cross (1990) suggests that understanding the nature of design ability can better enable design educators to nurture its development in their students.

Akin (1979), in an architectural context, puts forward three reasons for exploring the design process. First, it is necessary to understand intuitive-design to predict the performance criteria useful in developing appropriate tools for machine-design or design-methods. Second, better understanding of intuitive-design processes is essential if students of architecture are to be freed from the esoteric and inefficient methods of training used in the traditional design studio. Finally, making the design process more explicit will no doubt influence the way professional designers design, formulate problems, and evaluate products.

The work of the present author in secondary schools and teacher training establishments has also led to the generation of a number of questions which form the basic motivation to extend research in the area of design problem solving. The questions evolve from the premise that understanding the *nature* of design problem solving will enable design educators to develop teaching and learning strategies which will help to *nurture* its development in students.

The questions can be categorised under three main headings:

1 The process of designing

* What happens mentally when we solve a design problem?

* Is it possible to externalise a large portion of thinking?

* Is it desirable that we should? Could it provide a useful teaching/learning strategy?

* What is the place of imagery within the design process?

2 Novice v expert design strategies

* Do 'novice' designers use similar strategies to 'expert' designers?

* Are current models of expert design realistic? Do they equally apply to 'novice' designers?

3 The impact upon teaching and learning strategies

* Are educational models of the design process accurate? Are the models implicit within examination assessment criteria also accurate and realistic?

* What unique educational experience can be provided through design problem solving?

* Would increased understanding of design problem solving by teachers enhance the learning experience of pupils?

* Given a particular model of the design process, what are the most suitable teaching strategies?

* Should the teaching strategy be linked to the natural learning strategy of the pupil?

* Do pupils solve design problems in spite of the teaching strategy?

* Can problem solving strategies be learned and thus enhance problem solving capacity/potential?

These questions, based upon the professional experience of the author, provide the basic motivation for the research project. However, it would seem to be necessary to focus more accurately upon the underlying issues.

The problem at the heart of this project can perhaps best be summarised by using a version modified by the present author of the approach adopted by Mayer (1981). :-

HOW The scientific analysis of human behaviour is central to cognitive psychology. It is therefore important to build upon hunches and intuition about the way novice designers solve problems through the development of scientific methods to observe mental activity. This will involve the development of precise analytical tools for breaking down mental activities into measurable parts.

WHAT The object of the study is the mental processes and structures used by novice designers to solve ill-structured problems. Mental processes refer to what is going on inside the mind when a problem is solved. The way knowledge is stored and used to perform the task relates to mental structures.

WHY The main goal is to arrive at descriptions of internal cognitive events which are as clear and accurate as possible so that human behaviour embodied in solving ill-structured design problems can be understood and predicted more accurately. This could help the development of alternative teaching/learning strategies.

From the foregoing discussion of these issues, it is possible to identify a number of statements and questions with which the research project will be concerned and hence which will provide a focus for the investigation:

1 To what extent and why do novice designers vary in the way they process information during design problem solving?

2 Do experienced designers tend to work in different ways when solving ill-structured design problems? That is to say, do some, as suggested by Tovey (1986) generate almost complete solutions either by rapid construction or from past experience; do other subjects identify sub-problems and discuss alternative sub-solutions within the problem; will others develop a number of sub-problems and partial solutions using a combination of the first two methods?

3 Is it the case that greater knowledge of the ways in which pupils solve design problems can help in the development of appropriate learning and teaching strategies? Will the development of this information help in determining the most appropriate teaching/learning strategies?

4 Protocol analysis is one research method which has been used for research into problem solving behaviour. Is this method applicable to the study of the design process?

5 Which other research methods are appropriate for looking at the more qualitative aspects of design problem solving?

In design and technology education research needs to take two directions. First of all, theoretical understanding of the relationship between design methodology and teaching and learning strategies needs to be enhanced. And secondly, there is a need to build a methodical empirical base for this aspect of the subject. However, this is a complex area for research and potential problems can be identified. For example, one of the difficulties of undertaking research in this area was highlighted by Kimbell et al (1991):

> "The value-laden nature of design and technology required us to adopt a humanistic approach that respected the value positions and autonomy of pupils whilst at the same time resulting in reliable and useful data."
>
> Kimbell et al (1991)

In the field of professional design, Schon (1988) suggested that there was a need to understand what professional designers know and how they reason. He was especially interested in exploring how design rules and types function in skilled designing.

It therefore appears that within this research project there is a need for a range of methods for yielding data which will enhance conceptual understanding of the process of design as well as providing an empirical base for pedagogical planning and decisions.

Chapter 2 - Review of Literature

2.0 Introduction

The purpose of this section is to review literature from a range of apparently diverse subject areas and to draw together common elements which underpin the project. This will provide a basis to inform and develop the research.

It seems clear from a survey of the literature that there is little, if any, research which integrates all of the areas central to this project. However, there are a large number of existing studies in individual areas and, to some extent, in limited combinations of these

Relevant studies can be found in several diverse areas. First and primarily there is the education literature which has to do not only with the design of curricula but also with methods of teaching and the management of learning.

Secondly, there are studies which address the design process itself as practised by experienced and skilled professionals. These focus on the methods and styles used by practitioners. Little has been done on the acquisition of such expertise or on the differences between novices and experts in this field.

A third area which is likely to yield valuable insights is that of experimental cognitive psychology where there has been much research activity directed towards elucidation of the mental processes underlying problem solving in general and in particular domains.

All these have a bearing on the present research project which must eventually focus on the practical aim of providing a sound theoretical base for the development of teaching and learning strategies designed to initiate, develop and enhance the acquisition of design skills and knowledge in school pupils.

The review provides an opportunity to focus upon a number of interrelated issues, for example, the relationship between protocol analysis and design and technology education, or the way in which these two elements relate to teaching and learning strategies. The final section of the chapter attempts to draw together the main strands of the literature review.

2.1 Design and Technology Education

In reviewing the literature which documents the development of design and technology education, it is important to concentrate upon evolving 'models' of the design processes which have informed design and technology in the schools. Craft approaches were mainly based upon the creation of teacher-determined products and have evolved to approaches in which the process of designing plays a more significant role.

The work of the Department of Education and Science (DES) {now called the Department for Education -DfE} is important in this respect, as is the literature and research generated by the Assessment of Performance Unit (APU). Finally, the review focuses upon text books and journal articles originating in the United Kingdom and abroad.

Technology, as described in the National Curriculum, has gone through a number of stages of development. The roots of the new subject can be traced back to the craft-based subject of Handicraft. This evolved over a number of years to Craft, Design and Technology (CDT). HMI (1977) summarised the difference in philosophy between the earlier and the later approaches :-

> "The principal aim of Handicraft was the physical and emotional development of boys, mainly through the gradual acquisition of skills. CDT extends this to

> provide a fuller experience in which cognitive development features more strongly. Its central aim is to give girls and boys confidence in identifying, examining and finally solving problems with the use of materials."
>
> HMI (1977)

During the 1970s, the nature of CDT was gradually refined as a clearer philosophy for the subject was established. The DES (1980) defines CDT as :-

> "The initials CDT stand for 'craft, design and technology'. This label is applied to a range of learning that goes on in school workshops. Taken separately, each of the words 'craft', 'design' and 'technology' means something different. So do the traditional subject labels 'woodwork', 'metalwork', 'technical studies' and many other terms that identify practical studies in the school curriculum. Yet they are all part of the family of practical activities which give pupils experience of designing and making. Unfortunately, the English language has no single word like 'literacy' or 'numerary' which might be used to denote competence in working with materials. But even if there is no one word there is an acceptance, in British education that boys, and to an increasing extent, girls in schools should discover the physical and aesthetic qualities of materials, acquire the skills to shape them and perhaps, above all, learn to plan and to execute work of their own design."
>
> DES (1980)

During the 1980s, the introduction of GCSE, which merged GCE and CSE courses, provided an opportunity for the further refinement of the philosophy of the subject. For the first time, national criteria were produced for attainment in all GCSE subjects. The National Criteria for GCSE (DES, 1985) put forward the following aims for CDT courses :-

> "The aims of any course in Craft, Design and Technology should reflect the complex abilities required to exercise control over the man-made environment but the common core of activity can be identified as designing, making, testing and evaluating. Although

> these skills and the related value judgments are common to all courses in Craft, Design and Technology, the 'knowledge' content of differing courses will vary. To make provision for the range of activities it is necessary to offer examinations to cover particular areas of study which will have in common the central aims of Craft, Design and Technology as a subject."
>
> DES (1985)

In order to achieve these aims, the subject was divided into three separate parts. Each was available as an individual GCSE subject and indeed pupils could take all three if the school option system allowed. They were all, however, based upon the same National Criteria :-

CDT: Design and Realisation
CDT: Technology
CDT: Design and Communication

The concept of National Curriculum was formulated during the latter part of the 1980s. Technology was identified as a foundation subject at an early stage in these developments. It was the fourth subject to produce statutory orders and consequently its status was enhanced within the education service. However, a much broader base was being developed for the subject. Two main profile components were identified under the umbrella heading of technology. The first, Design and Technology capability which comprised four attainment targets:

AT1 - Identifying needs and opportunities
AT2 - Generating a design
AT3 - Planning and making
AT4 - Evaluating

The second profile component was Information Technology capability, which was a single attainment target.

However, in the Interim Report for National Curriculum (DES,1988) and in the proposals to the Secretary of State (DES,1989) the subject still had the subject title of Design and Technology :-

> "The inclusion of Design and Technology as a foundation subject in the National Curriculum is a recognition that the capability to investigate, design, make and appraise is as important as the acquisition of knowledge. Pupils' ability to respond effectively to new needs and opportunities by the designing and making of original or better products will be important to them personally, but will also be an essential condition for the future prosperity of our business and industry."
>
> Design and Technology Report, 1989

It was in the National Curriculum Council Consultation Report (NCC,1989) that the title of Technology first appeared with recommendations for the two profile components mentioned above. However, the major thrust was clearly in the Design and Technology component and it is with the attainment targets generated for this area that this research is concerned.

It is clear from the general framework for the National Curriculum that the design and technology element will be an important area of experience within the school curriculum. Considerable resources will be invested in assessment and testing. This is central to the concept of National Curriculum. The Task Group on Assessment and Testing (TGAT) Report (DES,1987) puts forward the view that schools must be more accountable to individual parents about the attainment of individual pupils. It is also suggested that National Curriculum test scores are aggregated so that parents can compare one school with another. In other words, schools will have to provide parents with much more detailed information about the attainment and learning of their pupils in all National Curriculum subject areas. Linked to this will be other forms of accountability such as teacher appraisal which is now mandatory for all school teachers (The Education [School Teacher Appraisal] Regulations 1991).

Whilst these are general aims of the National Curriculum, it is clear that Technology as a foundation subject is part of this process. However, there are real concerns about our knowledge of the nature of pupil learning within the complex area of Design and Technology. This concern is articulated in the Design and Technology Interim Report (1988).

> "But design and technology lacks a research base in pupils' understanding and learning such as is available in the cases of mathematics and science."
>
> DES (1988)

However, in section 1.12 of the same report a tentative conception of the cognitive processes involved in design and technology is put forward:

> "In so far as the cognitive processes involved in design and technology are understood today, there is a further characteristic which merits attention. As opposed to scientists, who are concerned to explore and understand what is, designers and technologists are concerned with what might be, the conception and realisation of 'the form of things unknown'. In describing their work, they talk of 'seeing with the mind's eye'. This is literally a visionary activity, a mode of thought which is non-verbal and which has been characteristic of design and technology throughout history. Such imaging finds its representation in drawings, diagrams, plans, models, prototypes and computer displays and simulations, before its eventual realisation in a product, which may be an artifact, system or environment. It is a distinctive aspect of creative thinking of designers and technologists, different from and complementary to verbal modes. Its development should be an important aim of design and technology education in all schools."
>
> DES (1988)

It suggests therefore that the frameworks for the design process embodied in the National Curriculum have been developed from the experience and expertise of a number of individuals involved in Design and Technology education. It seems to recognise that there is a need to develop further research in this complex area.

The National Curriculum had clearly laid out the attainment targets, and programmes of study for the complex area of design and technology. It is clear that the four attainment targets - identifying needs and opportunities; generating a design proposal; planning and making; and evaluating - are linked to the overall process of designing which is central to this project :-

> "The attainment targets - now four in number - are derived from design and technological processes and their holistic and iterative nature. The programmes of study specify the knowledge, skills and processes which pupils must be taught across a range of contexts to enable them to achieve the attainment targets."
>
> DES(1989)

However, the review of the Statutory Orders for Technology (DfE,1992) further considered the concerns raised by HMI which are discussed in chapter 1. The new proposals to the Secretary of State for Education and the Secretary of State for Wales recommend just two attainment targets:

Attainment target 1 - Designing
Attainment target 2 - Making

> "The arguments were finely balanced but we concluded that two attainment targets, one on **Designing** and the other on **Making**, would be sufficient to define the essential nature of the subject, be familiar groupings to teachers, and simplify assessment."
>
> DfE (1992)

It can therefore be seen that the new attainment target 1 is the central focus of this research.

2.2 Design methodology within the context of schools

Conceptions of the design process implied in the statements above have become more sophisticated as the subject has developed. They provide some indication of the supposed thought processes undertaken by school children as they solve ill-defined design problems. Consequently, they also give some indication of the teaching and learning techniques associated with design and technology.

A number of descriptors of the design activities have been put forward as the subject has evolved. At the simplest level, the activity can be described as a linear progression. A schematic representation is given below (Kelly et al, 1987) :

Figure 1 - a linear framework for the design process (Kelly et al, 1987)

Other frameworks developed as design teachers became more experienced at working in a problem solving way. The diagram below

(Kimbell, 1986) describes the activity as cyclical, on the assumption that evaluation must be related to the initiating problem and also recognising that the process may not operate in a linear way:

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Figure 2 - a cyclical framework for the design process (Kimbell, 1986)

An extension to this description of the cyclical framework suggests that the elements are more interactive (Kimbell, 1986):

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Figure 3 - an interacting design loop (Kimbell, 1986)

Kimbell et al (1991) seem to recognise that whilst these descriptors can provide useful frameworks for assessment, they may also lead to an artificial interpretation of the activity. It could be argued, for example, that the framework for teaching and learning strategies that they provide is too simplistic to take into account all of the diverse components of this complex process.

Kimbell et al put forward the view that as soon as we begin to perceive the outline of a task, pictures or images of solutions start to appear in our minds. Initially these images or ideas are likely to be ill-defined and will undergo considerable development. As thinking progresses towards a solution, innumerable potential routes and ideas are investigated in moving towards an optimised solution.

They refer to this determined change as modelling. This is a conscious capacity that can be based on both thought and practical activity. This interaction of ideas in the mind with their expression in the concrete world is a common feature of all design and technology.

The model they put forward illustrates this interaction of mind and hand. The authors contend (Kimbell et al, 1991) that this inter-relationship between modelling ideas in the mind and modelling ideas in reality is the cornerstone of capability in design and technology. They describe this as 'thought in action' in which internal images in the mind's eye are expanded and developed through concrete expressions which allow for the examination of the reality of an idea.

This framework of the design process is shown in figure 4:

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Figure 4 - The APU model of interaction between mind and hand (Kimbell et al, 1991)

The frameworks described above illustrate developments over the past fifteen or twenty years in the subject which is today known as design and technology. They provide insights into the problem solving behaviour of novice designers as perceived by those involved in teaching and developing the subject. They also illustrate the frameworks upon which assessment procedures have been developed in both National curriculum and external examinations. Moreover, they imply teaching and learning strategies for the subject of design and technology and consequently provide the basis of the concerns expressed in chapter one. Concerns about interpretations of these frameworks are summarised by Jeffrey (1990):

> "Indeed it is well known that pupils' design folios, 'written up' at the end of a project, can be made to describe a logical, systematic procedure which has more to do with the assessment framework than the actual development of design ideas in the project."
>
> Jeffrey (1990)

One of the central aims of this research is to provide empirical evidence to contribute to this debate.

2.3 Design methodology within the context of professional design

Cross (1984) highlighted the dearth of literature in the field of design methodology :

> "The development of this relatively new field of design methodology has been conducted principally through means such as conferences and the publication of research papers. There is only one general textbook of design methods, by Jones (1970), and only in 1979 was there established a comprehensive, academic, international journal in the field, the journal of *Design Studies*."
>
> Cross (1984)

The situation has improved in recent years, but there is still a great shortage of textbooks in this area. Consequently, most up-to-date information comes from conference papers and journal articles. The journal *Design Studies* is still the most important forum for discussions of this topic.

Research into the way designers work has been gradually growing over the past thirty years. Cross (1990) arranges these research methods in order from those with direct contact with designers to the more abstract and theoretical:

* interviews with designers
* case studies of particular design projects
* observations of designers at work
* protocol studies of design activity

* laboratory experiments based upon selected features of design ability
* theorising

Research into design methodology has further developed understanding of the nature of design problem solving. Some of this work has focused upon the nature of cognitive processes used in design problem solving. This literature has helped the development of this research.

Amongst professional design practitioners, research has been directed at analysing the nature of design activity. J Christopher Jones (1970,1981) produced one of the early texts in the area of design methodology. He started by asking the question, "What is design?". The responses from design practitioners of the 1960s provides an interesting insight into the complex nature of design:

> "Finding the right physical components of a physical structure." (Alexander,1963)
>
> "A goal-directed problem-solving activity." (Archer, 1965)
>
> "Decision making, in the face of uncertainty, with high penalties for error." (Asimow, 1962)
>
> "Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform prespecified functions with the maximum economy and efficiency." (Fielden, 1963)
>
> "Relating product with situation to give satisfaction." (Gregory, 1966)
>
> "The performing of a very complicated act of faith." (Jones, 1966)
>
> "The optimum solution to the sum of the true needs of a particular set of circumstances." (Matchett, 1968)

"The imaginative jump from present facts to future possibilities."
(Page, 1966)

The responses from professional designers illustrate the problems of defining such a complex process. The updating of Jones's text in 1981 provides an understanding of developments in the area of design methodology during the 1970s. Jones describes the difficulties of using the methods successfully. He indicates that many of them take much more time than some designers are prepared to spend on them. He also suggests that, at the other extreme, it is possible to get 'drowned in data' and consequently lose sight of the purpose of the activity. The points raised by Jones illustrate the need for rigour in the teaching of design methods, but at the same time ensuring that the processes enhance design problem solving experience.

From the author's experience, the issues described above need to be considered in the context of 'novice' designers. Design methodology is an under-researched area within design education. Models of the design process have gradually become more refined as assessment techniques have become more sophisticated. However, little is known of the cogniiive strategies employed when novice designers solve ill-structured design problems.

A range of research has been undertaken with expert designers into the nature of the design process. The traditional analysis - synthesis - evaluation framework has been challenged by a number of researchers. Hillier et al (1984) proposed a conjecture-analysis description of the design process in which the designer is perceived as developing a solution conjecture which is subjected to analysis and evaluation (Roozenburg and Cross, 1991). This contradicts the traditional model in which analysis was seen to precede synthesis.

Roozenburg and Cross also describe the work of March (1984) who argues that "solution concepts are produced not by inductive or deductive reasoning, but by 'productive' reasoning." March suggests a framework for design comprising presuppositions - conjecture - analysis - evaluation.

Darke (1979) indicates that designers do not start with a full and explicit list of factors to be considered or predetermined performance limits in a design problem. She suggests that they have to find a way of reducing the variety of potential solutions to the problem to a small class of solutions that is cognitively manageable. This, Darke indicates, is achieved by fixing on a particular objective or small group of objectives by a process of subjective judgment rather than logic. Darke refers to the major aims as 'primary generators' which give rise to a proposed solution, which in turn make it possible to clarify the detailed requirements as the conjecture is tested.

Darke refutes the analysis-synthesis-evaluation model and instead suggests that the model described below is more likely to be used in practice:

Generator

*

Conjecture

*

Analysis

Walker and Cross (1976) suggest that designers concentrate on generating a satisfactory solution fairly quickly, rather than a prolonged analysis of the problem. Simon (1975) described this as satisficing in which the aim is to produce any one from what is probably a large range of satisfactory solutions rather than one hypothetical optimum solution.

Walker and Cross (1976) further suggest that the designer's task is to synthesise the solution by seeking or imposing a 'primary generator' which both defines the limits of the problem and suggests the nature of possible solutions.

Other literature has referred to individual differences in cognitive style. Cross (1985), using the theories of Pask and Scott (1972) and Guilford (1967), suggests that people differ in the basic cognitive styles that they bring to any learning task. Their learning programmes can be severely impaired if they are mismatched with teachers who prefer, or teaching programmes which impose, a different learning style. He suggests that one of the most important differences in learning style appears to be that categorised as serialist (fig 5) versus holist (fig 6).

A serialist prefers to learn by proceeding in logical small steps, tries to get every point clear before moving on to the next, and pursues a straight path through the learning task avoiding any digressions:

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Figure 5 - a serialistic design strategy (Cross, 1985)

A holist proceeds much more broadly, picking up bits of information that are not necessarily logically connected, and learning things 'out of sequence'. A holist prefers to learn by having things presented in different ways, and approaching ideas from different viewpoints:

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Figure 6 - a holistic design strategy (Cross, 1985)

Cross also suggests that another distinction that has been made between cognitive styles is that between convergent (fig 7) and divergent (fig 8) thinking. Convergent thinking is primarily concerned with taking information and producing or 'converging' on, a single correct answer to the problem:

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Figure 7 - a convergent design strategy (Cross, 1985)

In contrast, divergent thinking is not concerned with the one correct answer. Instead, the emphasis is on a person's ability to generate a wide range of answers; the response is a divergence or expansion rather than one single answer:

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Figure 8 - a divergent design strategy (Cross, 1985)

Cross draws attention to a third distinction between styles of thinking in terms of focused or 'rigid' thinking (fig. 9) and flexible thinking (fig. 10):

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Figure 9 - a focused design strategy (Cross, 1985)

Figure 10 - a flexible design strategy (Cross, 1985)

Cross quotes other researchers (Pask and Scott,1972; Hudson,1967; Witkin, 1969) who contend that the more one is able to identify differences in perceptual and cognitive patterns in people, the more one is able to devise appropriate teaching strategies to cater for such differences. These researchers suggest that 'cognitive maps' reflecting the pattern into which people's cognitive characteristics fall would be one way of of identifying the features of individual learning styles. This 'map' could then help to disseminate how a person might best be taught.

Tovey (1986), through an analysis of the practical activities which designers undertake, suggests that in solving design problems designers use a combination of 'analytical serial thinking' and' holistic synthetic thinking'. He puts forward three strategies which seem to be employed when solving design problems.

Quoting Lloyd Jones (1984), Tovey describes a 'serial analytic strategy' as an approach to design using a planning grid, or matrix of lines as a basis for geometrical decision making of an interactive and recursive kind. He suggests that such a system generates a complexity which could not be imagined in the mind's eye (fig. 11):

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Figure 11 - a serial analytic strategy (Tovey, 1986)

Secondly, Tovey describes a serial analytic-holistic strategy (fig. 12) as one in which the use of holistic thinking is seen as the initiating strategy for the design process. An overall concept, lacking in detail, provides the framework for the subsequent more detailed thinking:

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Figure 12 - a serial analytic-holistic strategy (Tovey, 1986)

Finally, Tovey discusses an holistic synthetic strategy which is concept-led and makes great use of visual, tacit and intuitive thinking. He describes a student project based upon this strategy in which there was little need to evaluate alternative proposals explicitly. The initial concepts seemed to have already been through an evaluative filter:

Figure 13 - a holistic synthetic strategy (Tovey, 1986)

2.4 Cognitive Psychology

Introduction

There has been a great deal of research within cognitive psychology into different aspects of problem solving. In this section, the first aim is to explore some of the general principles of this work. Secondly, the focus will be upon the nature of design problems and design problem solving. It will then be important to look at the cognitive models which underpin experimental research in this area. A detailed examination will then be undertaken of different aspects of protocol analysis, with a particular emphasis on the use of this technique for the study of design problem solving. The major focus of this research is within this area.

The experimental study of the role of insight in problem solving began with the Gestalt psychologists and was pioneered by Duncker (1945), Kohler (1929) and Wertheimer (1959). They defined the process of problem solving as a search to relate one aspect of a problem to another, which results in structural understanding. That is to say, the ability to comprehend how all parts of the problem fit together to satisfy the goal. Mayer (1977) suggests that this involves new ways of organising the elements of the problem situation so that the problem can be solved. Greeno (1978) concludes that while the studies conducted by Gestalt psychologists provide numerous interesting examples of thinking processes that were analysed insightfully, few general principles emerged that could lead to a solid body of theory.

Behavioural and Associationist psychologists have taken a different approach to the analysis of problem solving. Greeno (1978) suggests, in explaining this approach, that a problem occurs when the response needed to achieve some goal is less strong than other responses, or when several responses are required and it is unlikely that they will all be performed. This approach emphasised the need for problem solvers to perform a variety of responses that are relatively improbable.

Mayer (1981), in providing a framework to discuss behaviourism, notes that cognitive psychology has the following characteristics: Its subject matter is human or rational; its methods involve the scientific analysis of mental structures and processes; and its goal is the understanding of human behaviour.

Looking at the first of these issues Mayer suggests that whilst behaviourism has its goal as the understanding of human behaviour, there is no attempt to understand the internal processes that underlie behaviour. Secondly, he indicates although behaviourism is committed to the rigorous methods of science, the techniques differ from those used in cognitive psychology. Finally, Mayer argues that the major difference between behaviourism and cognitvism concerns what should be the subject matter of psychology. He quotes the work of psychologists such as Skinner (1953) who argue that since mental events cannot be directly observed they can never be legitimate objects of scientific study. Thus suggesting that the subject matter of psychology must be restricted to behaviour which can be directly observed.

Mayer (1981) defines cognitive psychology as the scientific analysis of human mental processes and memory structures in order to understand human behaviour. He describes the four major tools of cognitive psychology as the analysis of the human information processing system, cognitive processes, cognitive structures and strategies.

More recently problem solving has been analysed using the concepts of information processing. This approach assumes that a human being is a processor of information, with the cognitive processes represented as either a sequence of mental processes or operations performed on information in the subject's memory, or a sequence of internal states or changes in information that progress towards the goal (Mayer, 1978). The aim is to define more precisely the processes and states that a particular subject is using to solve a particular problem. This should then provide a list of the exact sequence of operations.

Before looking in detail at the information processing system and the cognitive models based upon this approach, it would seem necessary to first of all examine the nature of problems and problem solving.

2.5 The nature of problems and problem solving

A range of research has focused upon the cognitive aspects of design problem solving. The aim of this section is to define the nature of design problems and design problem solving so that the unique characteristics can be taken into account during the development of the research and also during the discussion of the research findings.

Mayer (1977) suggests that a problem has certain characteristics. First of all, givens. That is to say, the problem is in a certain state with certain conditions, objects, pieces of information, and so forth being present at the onset of the work on the problem

Next goals - the desired or terminal state of the problem is the goal state, and thinking is required to transform the problem from the given to the goal state.

Finally, obstacles - the thinker has at his or her disposal certain ways to change the given state or the goal state of the problem. The thinker, however, does not already know the correct answer; that is, the correct sequence of behaviours that will solve the problem is not immediately obvious.

Mayer goes on to clarify this definition by stating that any definition of a problem should consist of three ideas that (a) the problem is currently in some state, but (b) it is desired that it be in another state, and (c) there is no direct way to accomplish the change.

Newell and Simon (1972) put forward the view that a person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it.

Reitman (1965) generated four categories of problems according to how well the given and goal states are specified. First of all he describes problems that have a well-defined given state and well-defined goal state. Secondly, problems that have a well-defined given state and poorly defined goal state. Third, those with a poorly defined given state and well-defined goal state. Finally, problems which have a poorly defined given state and poorly defined goal state. It is within the latter category that design problems will usually be found.

Gick and Holyoak (1985) also differentiate between well-defined and ill-defined or ill-structured problems. Well-defined problems are often those with a single correct solution. For example, problems found in mathematics or science. Ill-defined problems are problems with an indefinite number of solutions.

Simon (1978) proposes that there is no precise boundary between problems regarded as well-structured and those that are ill-structured. He suggests that there is a continuum from problems like the Tower of Hanoi to problems like designing a house. However, he says there are certain features which distinguish the second group from the first.

First of all, the criterion that determines whether the goal has been attained is both more complex and less definite. Second, the information needed to solve the problem is not entirely contained in the problem instructions, and indeed, the boundaries of the relevant information are themselves very vague. Finally, there is no simple 'legal move generator' for finding all of the alternative possibilities to each step.

Findler (1981) also puts forward three reasons for the ill-structure of design problems. He suggests that the measure of good attainment is multidimensional and fuzzy. He also puts forward the view that a detailed knowledge of facts 'outside the universe of problem definition' is required for the solution. Finally, he suggests that alternative courses of action often cannot be enumerated and evaluated in a systematic manner for lack of general guidelines.

Walker and Cross (1976) suggest that design problems are not like scientific or mathematical problems which generally require the logical proof of a hypothesis or theorem. These design problems have a number of features. First, they do not have a single correct solution (as a crossword). Second, they are not like problems of the artist or composer who work principally to satisfy self-imposed goals/objectives. Third, it is impossible to 'prove' that the solution has arisen logically from the requirements set - at best it is possible to demonstrate a coherent connection between the solution and the problem. Fourth, although a designer's individuality influences a solution, there is limited scope for the exercise of this individuality because of the constraints placed by the requirements of the client or user.

2.6 Information processing framework of human problem solving

Newell and Simon (1972) describe behaviour during problem solving as an interaction between an information processing system, the problem solver and the task environment, the latter representing the task as described by the experimenter. They suggest that in approaching the task, the problem solver represents the situation in terms of a problem space; which is a way of viewing the task environment. Newell and Simon indicate that the three components - information processing system, task environment and problem space - establish the framework for the problem solving behaviour.

Simon (1985) describes the basic characteristics of the human information-processing system. He proposes that apart from sensory organs, the system works almost entirely serially, one process at a time, rather than in parallel fashion. This is reflected in the narrowness of its momentary focus of attention. The elementary processes are executed in terms of milliseconds and the inputs and outputs of these processes are held in a small short-term memory (STM) with a capacity of a few (4-7) symbols or chunks. He suggests that the system has access to unlimited long-term memory (LTM). The time required to store a new chunk in LTM is in the order of seconds or tens of seconds.

Simon indicates that problem solvers exhibit no behaviour that requires simultaneous rapid search of disjoint parts of problem space. Instead behaviour takes the form of a sequential search, making small successive accretions to the store of information about the problem.

The system parameters relate to the capacity limit of LTM and in terms of STM the limits on the speed of processing rather than on what processing can be done. The organisational characteristics of LTM have to be considered alongside these processing parameters.

Norman (1985) discusses his dissatisfaction with the conventional view of information processing. He describes a basic conceptualisation in which intellectual processes are the result of the operation of several separable systems: sensory-perceptual systems, central processing (thought), memory and response output (motor control). Sensory transducers feed a steady stream of information about the environment to some of the processing structures where the information in analysed, interpreted and fed to a response system which controls body movements and speech sounds.

Norman illustrates how these considerations have led to the view of the human as composed of separable subsystems of information processing mechanisms:

> "perceptual systems (including pattern recognition), motor or output systems, memory systems, and systems for internal reasoning and deduction, which includes thought, problem solving and language."
>
> Norman (1985)

He summarises the components in figure 14 shown below.

However, Norman concludes that there is more to human intelligence than the cognitive system. He suggests that the science of cognition cannot afford to ignore these other aspects and uses examples from an aeroplane disaster and classroom behaviour to illustrate his argument. The latter example will be discussed in the final section of this chapter.

Figure 14 - The human information processing system (Norman, 1985)

Ericsson and Simon (1985) further develop the models generated by Newell and Simon. They put forward two hypotheses. The first and most general suggests that human cognition is information processing.

The second hypothesis indicates that information is stored in several memories each having different capacities and accessing characteristics. The first has several sensory stores of very short duration. The second is a short term memory with limited capacity and/or intermediate duration. The third is a long-term memory with very large capacity and relatively permanent storage, but with slow fixation and access times compared with other memories.

Ericsson and Simon suggest that due to the limited capacity of STM, only the most recently heeded information is accessible directly. However, a portion of the contents of STM are fixed in LTM before being lost from STM, and this portion can, at later points in time, sometimes be retrieved from LTM.

2.7 Protocol analysis

It would seem important to determine how these definitions link to the experimental study of problem solving. The research approaches which are relevant to this study concern the development of verbal protocols as a means of analysing the cognitive strategies and processes used to solve problems. The majority of this work has been in the area of well-structured problems. However, there has been a significant range of research which has focused upon using verbal protocols to analysis the cognitive strategies and processes used when solving ill-structured design problems. In this section, research using well-structured problems will be considered. In the next section, the focus will be upon the use of protocol analysis in a design context.

The models of Newell and Simon (1972), Simon (1978) and Ericsson and Simon (1985) have provided a framework for research using the information processing theory of human problem solving. Protocol analysis has contributed to the development of this theory. Central to this theory is the notion that thought is both the process and product of information processed by the brain. One method which is frequently used to gain information about the course of the cognitive processes is to probe the subjects' internal states by verbal methods (Ericsson and Simon,1984).

Verbal protocol analysis involves asking humans to solve problems and talk aloud as they work. The early work in this area by Ernst and Newell (1969) and Newell and Simon (1972) analysed verbal protocols in order to abstract the strategies the subjects used to solve problems. The researchers tried to specify this strategy in precise detail in order to develop a computer program which simulated problem solving strategies identified in humans.

Ericsson and Simon (1984) discuss how concern for the course of cognitive processes has revived interest in finding ways to increase the temporal density of observations so as to reveal intermediate stages of the processes. They analysed in depth the way in which verbal methods can be used to probe the subjects' internal states in order to gain information about the course of the cognitive processes.

Ericsson and Simon identify two forms of verbal reports as being the closest reflection of the concurrent processes. Foremost, they suggest, are concurrent verbal reports - 'talk aloud' and 'think aloud' reports - where the cognitive processes, described as successive states of heeded information, are verbalised directly. This is illustrated in figure 15.

Ericsson and Simon claim that cognitive processes are not modified by these verbal reports. They also claim that task-directed cognitive processes determine what information is heeded and verbalised.

The second type of verbal report which Ericsson and Simon report is the retrospective report. They suggest that a durable memory trace is laid down of the information heeded successively while the subject is completing a task. When the task is completed, this trace can be accessed from STM or retrieved from LTM and verbalised. They suggest that retrospective reports based on LTM will display some of the kinds of error and incompleteness that are familiar from experimental research on memory. They conclude that both kinds of reports are direct verbalisations of specific cognitive processes.

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Figure 15 - States of heeded information in cognitive process (Ericsson and Simon, 1985)

Eckersley (1988) suggests that the essence of verbal methods rests on the following premises. First of all, verbalised cognitions can be described as states that correspond to the contents of short-term memory (i.e. to the information that is in the focus of attention). Information vocalised is a verbal encoding of the information in short-term memory. The verbalisation processes are initiated as a thought is heeded and is a direct encoding of the heeded thought and reflects its structure. Units of articulation can correspond to integrated cognitive structures. Pauses and hesitations are good predictors of shifts in processing of cognitive structures

So when can we trust a verbal report? What factors determine the veridicality and usefulness of verbal reports?

Smith and Miller (1978) raise three questions. First of all, the question of relevance. Second,the question of testability and third, the question of completeness.

Nisbett and Wilson (1977) reported several situations in which people seemed unaware of stimulus factors that determined their responses. They suggest that only the product of the mental processes was accessible to consciousness; the process whereby the choice occurred was not open to introspective report.

Smith and Miller (1978) and White (1980) put forward the view that the distinction between mental processes and verbal products has never been clearly drawn.

Ericsson and Simon (1984) put forward some of the issues which must be dealt with if we are to use subjects' reports as fundamental data in psychological experiments. The first issue relates to the suitability of subjects' verbalisations as scientific data. Secondly, they discuss the problem of extracting data from subjects' behaviours. They also look at how the encoding of behaviour into data can be made objective and univocal, so that the resulting data will be "hard" not "soft". They further express the need to be explicit about the theoretical presuppositions that are necessarily embedded in the encoding process. Finally, they suggest that there is a need to specify the processes which allow us to go backwards from the data to the behaviour and thence to inferences about the subjects' thought processes.

Eckersley (1988) suggests that a small but emerging school of thought in psychology proposes that under controlled conditions, individuals (when trained to concurrently verbalise their thoughts) can reveal a remarkably accurate picture of their cognitive processes while engaged in problem solving.

Ericsson and Simon (1984) set forth the hypothesis that verbal behaviour is to be accounted for in the same way as other behaviour, that is, by developing and testing an information processing model of how information is accessed and verbalised in response to stimuli. They surveyed a wide range of different verbal reporting tasks to show how they can be accommodated within this framework, and also to show how their model can be used to resolve some of the controversies that have arisen about the interpretation of verbally reported information.

In discussing the completeness of verbal reports, Ericsson and Simon conclude that information heeded during the performance of a test is the information that is reportable; and information that is reported is information that is heeded. They also suggest, in discussing the inferences which can be drawn from verbal data, that here is evidence from research that "verbal reports are not in the least epiphenominal but are highly pertinent and informative about subjects cognitive processes and memory structures".

Eckersley (1988) suggests that protocol analysis offers the community of design scientists a potentially effective method for the controlled observation and experimental analysis of design problem-solving behaviour.

The essence of the theory rests on the following premises (Ericsson and Simon, 1984). First of all, verbalised cognitions can be described as states that correspond to the contents of short-term memory. In other words, to the information that is in the focus of attention. Second, information vocalised is a verbal encoding of the information in short-term memory. Third, verbalisation processes are initiated as a thought is heeded. Fourth, verbalisation is a direct encoding of the heeded thought and reflects its structure. Fifth, units of articulation can correspond to integrated cognitive structures. Finally, pauses and hesitations are good predictors of shifts in processing of cognitive structures.

Eckersley (1988) suggests that few research projects have used protocol analysis as a tool to analyse design problem solving behaviour. Akin (1979) used protocol analysis to 'explore the process of design as it is manifested in the behaviours of human designers'. He suggested that protocol analysis was especially suited to his purposes for several reasons :-

(i) it provides a context in which task environment, such as design, can be explored in its entirety, i.e. in aggregated form;

(ii) a priori experimental hypotheses about the task environment are not essential;

(iii) it can provide rich data in the form of verbal protocols as well as reaction times and/or visual cues.

2.8 Protocol analysis and design problems

A number of research projects have been conducted using the process of protocol analysis to explore the nature of design problem solving.
Akin (1979) conducted one of the first research projects based upon the use of protocol analysis within a design problem solving context. He collected data on problem solving behaviour as a single architect talked aloud when solving a complex design problem. Akin was concerned that the problem behaviour graph derived would contain large gaps of missing data and therefore lack completeness and veridicality. He therefore based his codification upon the work of Miller et al (1960) which put forward the notion of 'plans' as a means of codifying operations used when problem solving. Miller et al defined plans as hierarchal processes,

or schemata, that control the order in which a sequence of operations is to be performed.

The schemata put forward by Miller et al, and used by Akin in his study, included:

Instantiation
Generalisation
Enquiry
Inference
Representation
Goal-definition
Specification
Integration

Akin concludes that his research challenges the analysis-synthesis-evaluation cycle which lies at the heart of most normative design methods. He suggests that 'analysis' is part of virtually all phases of design. Similarly, 'synthesis' or solution development occurs as early as the first page of the protocol. Not all solutions, he maintains, arise from an analysis of all relevant aspects of the problem. Instead, cues in the environment are sufficient to evoke a precompiled solution in the mind of the designer. Indeed, Akin suggests that no quantifiable model is complex enough to represent real-life complexities of the design process. Hence the reason for designers 'satisficing' their solution. That is to say, they pick a solution which satisfies an acceptable number, rather than all, design criteria.

Eckersley (1988) used protocol analysis to examine the design processes of two experienced interior designers and three junior level university design students. From observation of the video taped design protocols generated by his subjects, he identified eight verbalisation-types:

Literal copy
Paraphrased copy
Inference
Intentions/plans
Move
Search
Specific assessment
General assessment

A model to represent the design task-related verbalisations in a hierarchy of information structures was developed in which the eight types of verbalisation are shown as a subset of all verbalisable cognitions. These verbalisable cognitions are, in turn, shown as a subset of all cognitions passing through the short-term (STM) and working memories (WM) of the subject.

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Figure 16 - Model of information structures in design (Eckersley, 1988)

As a basis for his research, Eckersley used a problem adopted from Carroll, Thomas and Malhotra (1978) in which the space designer must move seven characters around a schematic office space to accommodate 19 functional requirements. Eckersley was attempting to control, to some extent, the structure of the problem so as to ensure a certain baseline of comparison between problem solvers

Eckersley concluded that designers vary significantly in the nature and amount of information processed during problem solving and also in the behaviours used during the process. He suggests a number of areas for further research. For example, experiments to assess the degree to which design heuristics flourish and using protocol analysis to examine expert versus novice approaches to design problem solving. He also suggests that educationally, protocol analysis could have potential as a diagnostic tool, or as an instrument to show the 'form' of problem solving.

Chan (1990) used protocol analysis to explore the cognitive mechanisms involved in architectural design problem solving. He was specifically concerned with the way design constraints operate throughout the process.

Chan describes the components of problem space found in architectural design problems. First of all, a set of design units which is either given by the clients as the design programme or brief, or is generated by the designer at an intermediate problem state. Second, a set of operators which is not specified by the clients but is part of the designer's knowledge base. The operator is anything that changes the knowledge state. Third, a set of design constraints that is specified by the designer. Finally, a goal in which the designer finds an object satisfying all of the constraints.

A cognitive model was developed by Chan to illustrate a designer working on a problem space and searching for a solution. He indicates that by taking a set of design units and retrieving its associated schemata, design solutions for a particular goal can be generated and tested. He suggests that by repeating the process the design problem gradually moves toward the final goal. Chan's general model of the design process and cognitive model of design problem solving are shown below:

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Figure 17 - A general model of the design process (Chan, 1990)

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Figure 18 - Cognitive model of design problem solving (Chan, 1990)

Chan concludes that his study confirms design solutions are generated by means of activating design constraints and associated rules in memory. He also suggests that design ability is determined by the ability to select rules in schema as well as the ability to develop new schema to test newly generated design units.

Schon (1988) analysed for patterns of reasoning and use of design rules the protocols of seven practised designers who all undertook a common design exercise. This design exercise was based upon the 'footprint' of a building and was intended to be simple enough for designers to complete in an hour or two. He suggests that it was realistic enough to be reminiscent of actual design practice.

In discussing the tensions in the theory of designing, Schon puts forward the view that designers appear to build up their knowledge in a cumulative fashion, developing knowledge in one design episode and carrying it over to the next. He suggests that designing is not primarily a form of 'problem solving', 'information processing' or 'search' but a kind of 'making' which is made up of several layers moving from a very general view of designing to a more specific one.

Schon suggests that in order to formulate a design problem to be solved, the designer must frame a problematic design situation. That is to say, set its boundaries, select particular things and relations for attention, and impose on the situation a coherence that guides subsequent moves. He describes the notion of design worlds as environments entered into and inhabited by designers when designing. The objects of the design world provide 'things to think with'. He proposes that these design worlds are constructed not only through the shaping of materials but through the interlocking processes of perception, cognition and notation.

In accounting for the cumulative generality of design knowledge and the designer's capacity to generate new understandings in response to the uniqueness of a particular design situation, Schon indicates that this has led to the adoption of the notion of 'type'. Type is knowledge which is neither in the general or specific sense. This functions in a general way and promotes rich imagery which can generate sequences of moves and hence guide designing. Schon argues that by invoking a type a designer can see how a possible design move might be matched or mismatched to a situation, even when designers cannot say with respect to what feature there is match or mismatch.

Schon goes on to discuss the way in which rules employed in design reasoning are derived from types and subjected to test and criticism by reference to them. He suggests that the ability to apply a rule correctly depends on familiarity with the underlying type. He concludes that there is a two-way interaction between design types and design worlds.

Stauffer and Ullman (1988) compared six investigations, based upon empirical data, in which the mechanical design process was evaluated by studying human designers (Marples, 1961; Ramstrom and Rhenman, 1965; Mitroff, 1967; Lewis, 1981; Waldron and Waldron, 1987; Ullman, Stauffer and Diettrich, 1987). All but the study by Ullman, Stauffer and Diettrich were based on data taken by making observations or by taking retrospective reports of design engineers.

The Ullman et al study was based upon verbal protocol analysis. The goal of the research was to develop a complete set of operators sufficient to describe the mechanical design process, a representation adequate for the task, and to identify strategies used to explain the operator sequence. They conclude that designers appear to progress from systematic to opportunistic behaviour as the design evolves. They also suggest that sketching and drawing play a crucial role in the organisation of the process.

Carroll, Thomas and Malhotra (1979) reported on two studies involving an analysis of design problem solving. The first experiment concerned an observational study of an actual client-designer work session. A transcript of the session was made and the analysis revealed a systematically structured interaction in which the overall problem is decomposed into subproblems, each of which is smaller and somewhat more well-structured than the overall problem.

The second experiment of Carroll et al was based in a laboratory and the client role was simulated by an instruction booklet with a student taking the role of the designer. The protocols illustrate that the subjects spontaneously structure the elements of a design problem into sub problems the nature of which is systematically related to aspects of the problem structure. The researchers found that there was a high intersubject agreement as to how the decomposition into subproblems should proceed.

Lawson (1979) conducted an experiment in which students of architecture and science developed verbal protocols as they solved a colour block problem. The results suggest that while the scientists were selecting the blocks in their question in order to discover the structure of the problem, the architects were proceeding by generating a sequence of high scoring solutions until one proved acceptable. Lawson also indicates that the science students operated a problem-focused strategy, while the architecture students adopted a solution-focused strategy.

2.9 Heuristics

The development of protocol analysis provided researchers with opportunities to consider general strategies used in problem solving situations. Akin (1979) disaggregated the design process into higher level strategies or processes. Mayer (1981), following the work of Simon (1971) describes these strategies as heuristics which are rules of thumb or general plans of action. In cognitive psychology, a basic strategy or heuristic for searching through problem space is means-ends-analysis. Mayer describes means-ends-analysis as beginning with a clearly specified problem space with the problem solver generating goals and attempting to find operators to satisfy each goal. If a particular goal cannot be satisfied, a sub goal is created. Only one sub goal is worked on at a time.

Mayer considers the three general sub goals which can be used in means-ends-analysis. He suggests that the three may be used repeatedly in a problem, but at any given point only one can be used at a time:

1 Transform state A into state B.
2 Reduce the difference between state A and state B.
3 Apply operator Q to state A.

These subgoals are shown in the diagram below.

Mayer also describes the process in terms of Push-Down Pop-Up Goal Stack. He suggests that in problem solving, a person begins with the goal of transforming the given state into the goal state. This is a *Transform A into B* subgoal(1). The top goal (1) is put in the stack and a difference D is found. The next subgoal might be *Reduce the difference D.* The top goal (1) has not yet been solved so it stays in the stack and subgoal (2) is put on top of it. In order to accomplish subgoal (2) an operator must be found and applied. This could mean that operator Q is found and the problem solver proceeds to the next subgoal (3) - *Apply operator Q to state A.* Subgoal 3 is then put on the top of the stack. If the subgoal can be accomplished, subgoal (3) can be popped off. This also satisfies subgoal (2), so it pops off. Subgoal (1) is reinstated and a check must be made to see if state A is different to state B. If so, a new subgoal (4) is pushed in.

The three subgoals used in means-ends-analysis and the push-down pop-up goal stack are illustrated in figures 19 and 20.

Figure 19 - Three subgoals in means-ends-analysis (Mayer, 1981)

Figure 20 - Push-Down Pop-Up Goal Stack (Mayer, 1981)

Mayer (1977) describes another heuristic as hypothesize-and-test. He puts forward a basic model to account for the hypothesis testing process which consists of:

the sampling idea that the subject samples one hypothesis (or sample of hypotheses) from a pool of all possible hypotheses which may be correct, incorrect or irrelevant;

the no-memory idea that if the hypothesis results in correct classification of an instance it is retained, otherwise it is replaced in the pool and a new hypothesis (or hypotheses) is selected (Mayer,1977).

Mayer also describes the strategy of induction which refers to a situation in which the thinker is given a series of examples and must 'leap' to the creation of general rules.

Akin (1979) found that the more familiar forms of search strategies observed during his research were;

(i) hypothesize-and-test
(ii) induction
(iii) means-ends-analysis
(iv) hill climbing
(v) pattern matching

Akin describes hill climbing as a search strategy in which search starts from any point in the problem space. All subsequent design operations try to move this point closer to the goal, or solution, state. Success or failure depends on whether the initial point selected is one that is potentially capable of leading to a satisfactory solution.

Akin (1979) was also able to identify two major strategies for design; pre-sketching and sketching. He suggested that the characteristic schemata used in the pre-sketching phase were enquiry, instantiation and inference. In the sketching phase he identified the main schemata used as specification, integration and enquiry.

Akin put forward some deterministic patterns for strategies used within the pre-sketching phase. First of all he suggests that problem documents are used to activate conceptual knowledge; later, visual knowledge is activated; and finally, physical representation of the design problem is formed.

Within the sketching phase, 'hill climbing' is identified as a major control structure. Hypothesise and test, induction, means-ends-analysis, and pattern matching are also identified as the more familiar forms of search strategies observed. Unique forms of heuristic seen include, obvious-solution-first, divide-and-conquer, pre-compiled-solution, and most-constrained-first.

de Bono (1982) discusses the strategy of pattern matching as a process in which the mind (in perception) provides a means whereby incoming information gets organised into patterns. Once a pattern has been formed then the mind no longer has to analyse and sort information. All that is required is enough information to trigger the pattern.

Akin (1979) was able to identify a number of unique forms of heuristic search within the protocols analysed during his research project:

(i) obvious-first-solution
(ii) divide-and-conquer
(iii) pre-compiled-solution
(iv) most-constrained-first

These heuristics, or general rules of thumb, will need to be considered during the development of the research plan.

2.10 Experts and novices

There has been a limited amount of research into comparing the problem solving behaviour of expert and novice designers. Work has also been undertaken in the areas of physics and chess. This research is considered below.

Byrne (1990) asked his students to evaluate self-recorded audio tapes of a design process. He was concerned with ways in which students could be made to benefit from an analysis of their thoughts that were verbalised and recorded while solving a graphic design problem. This task was based upon a 'layout' problem and was attempted by ten students in a design methods class.

Students were asked to address the following questions:
"How efficient was one's process? How does one's protocol differ from that of an expert layout designer?"

Byrne also reports upon the work of Kampren (1983) in which protocols were taken from an 'expert' and 'novice' designer. Krampen undertook an operational analysis of each protocol which identified a number of subphases:

Problem solver 1 (novice)
Definition of problem
Possible choice for solution
Simplification
First solution attempt
Reiteration and second attempt
Third attempt
Verification and presentation
Summing up difficulties of problem
(8 stages)

Problem solver 2 (expert)
Familiarisation with problem
Clarification by sketching

First solution attempt
Verification and rejection
Second attempt
Presentation of solution and correction of minor mistakes
Verification
(7 stages)

Krampen noted a number of differences between 'expert' and 'novice' designers. For example, he suggested that an 'expert' problem solver may not try out all possible operations and combinations of operations but will concentrate upon those that will transform the problem state to a solution state. He also states that an expert designer finds out quickly which are the promising strategies which bring him closer to the final solution.

Akin (1990) in considering the necessary conditions for design expertise suggested that "novices used declarative knowledge to find a path to a solution, using a generate and test procedure; while experts chose a series of actions which they knew from past experience would work in certain cases." He indicates that the acquisition of expertise consists of "transforming declarative knowledge into a procedural one."

Akin also indicates that expertise embodies several cognitive abilities. The first is concerned with organising information in the mind so that it is possible to recognise creative and unusual solutions. The second is the ability to work in uncharted territory without getting lost. The third relates to the ability to develop heuristic procedures which translate passive knowledge into active exploration.

There is other evidence of novice-expert differences in the field of physics (Heller and Reif, 1984; Larkin, 1983,1985; Chi, Feltovich, and Glaser, 1981; Chi, Glaser and Rees, 1983). In solving problems it is suggested that experts build more complete representations because of the extra knowledge they have available. They also solve problems four times faster than novices even though they spend more time analysing and understanding the problem. Novices tend to move to seeking solutions very early in the process, whilst experts elaborate the representation of the problem by selecting appropriate principles that apply to a situation. In other words, the experts move forwards to a solution and the novices tend to work backwards from a solution. Eysenk and Keene (1990) suggest that novices lack a large repertoire of relevant schemata for solving problems and so find it difficult to link problem situation to principles. In the absence of such knowledge they fall back on more domain-dependent heuristic knowledge, such as means-end-analysis, similar to that used in puzzle problems. Eysenk and Keene also report on the work of Lambert (in press) on comparative models of physics skills in which LTM is a distributed memory from previous problem situations. He showed that this computational system could produce solutions that correspond to those generated by human experts.

De Groot (1965,1966) compared the performance of chess grand masters, experts and novices. He found that grand masters used prior knowledge to exclude irrelevant moves. Chase and Simon (1973) suggested that chess players were using specific, heuristic knowledge for evaluating moves and sequences of moves

2.11 The Role of Drawing/Modelling

A number of research projects have analysed the role of drawing within the design process. Schenk (1991) in looking at this aspect, based her research programme on interviews with observers, the observation of drawing practice and the analysis of designers drawings. She suggests that designers use drawing throughout the analysis and development of the design solutions. Schenk comes to the conclusion that although the graphic design process contains procedures of analysis, synthesis and evaluation, it is clearly **not** the three-stage linear process described in some early models, but involves many 'feed-back loops'.

Schenk also differentiates between the use of drawing for analysis and first stage ideas and the stage of synthesis and development. For the former she puts forward the view that:

> "the use of drawing is a very significant aid to the analytical and first ideas of a designer's work. It helps designers to assemble their first thoughts and a fluent free-ranging drawing style can enable a designer to explore a greater number of ideas quickly, with economy of effort."

Schenk suggests that in the synthesis and development phase drawing is the key to relating the elements together:

> "The designer's need to resolve a visual idea in more detail in order to make decisions about its appropriateness prompts a change in the pace and style of drawing activity and during the course of synthesis and development, a shift of attention from concept to format can be seen to take place."

Kimbell et al (1991) highlighted the difficulty in assessing communication skills and tried to discriminate between good communication and good design and technology. Their study focussed upon the way in which the various aspects of communication supported the interactive development of ideas. The quality of communication, including written, 2D drawing and 3d models, was split into four categories. The first of these related to the **complexity** of the message. The second focussed upon the **clarity** of the message. The third assessed the **confidence** demonstrated in the communication. The final category looked at the **skill** employed in the presentation.

Tovey (1986) indicates three principal functions of design drawing. Firstly, to facilitate the design process; second to externalise the process and thus allow others to participate; and third to communicate design proposals to others. Tovey goes on to describe three types of drawing which are used with higher education students within the first two categories:

* representational drawings: concept drawing; ideas drawings
* diagrammatic drawings: schematic; abstract
* measured drawings: elevational; 3D (planometric, isometric etc.)

Tovey claims that these drawings overlap, and although they may all be used in either the analytical phase or as part of synthesis, the representational drawings tend to be of greater use in a synthetic-holistic design strategy and the diagrammatic drawings more usable in a serial-analytical design strategy. He suggests that any of these types of drawings may be used in the initial stages of visual thinking in the design process, when the physical form of the design conjecture is being first derived.

2.12 Teaching/learning strategies

So far, the review of literature has focused upon design and technology education, design methodology and cognitive psychology - particularly the use of verbal protocols to probe subjects' internal states in order to gain information about the course of cognitive processes (Ericsson and Simon, 1984).

The focus in this section is upon teaching and learning strategies. First of all the issues of cognitive science will be related to the classroom. Then literature concerned with the teaching and learning strategies related to design methodology will be considered. This literature will be used to help develop and inform the findings of the research.

Norman (1985) attempts to relate issues of cognitive science to the classroom. He suggests, in an ideal world, that in order to make a point or get a body of knowledge across the teacher must construct a mental model of student knowledge, match the model of the student with that of the desired endpoint, determine the strategy for presenting the information not currently held by the students, and go forth and teach.

> "An information processing model of the teacher. Starting with educational goals, the teacher compares those goals with the current state of classroom behaviour and knowledge and uses an instructional strategy appropriate to the situation. The teacher continually monitors the classroom behaviour and modifies the instructional strategy, or knowledge being taught accordingly. This is the feedback model of instruction. The 'current state' implies, among other things, a model of student knowledge and behaviour. This model of a teacher is common to modern instructional theory. It is probably necessary, but by itself, it fails to be a useful predictor of classroom behaviour."
>
> Norman (1985)

This approach is illustrated in figure 21:

Figure 21 - An information processing model of the teacher (Norman, 1985)

Norman goes on to suggest that anyone who has actually taught in a classroom knows that this description provides only the most idealistic view of real behaviour. He puts forward a further model which takes into account that pupils are in a social setting, interacting with one another, acutely aware of each other and of the overall classroom behaviour.

> "The classroom behaviour is the result of a combination of interactions. Each student responds to the behaviour of the classroom, as well as to the internal goals of satisfying other students, the teacher and self needs. So too with the teacher. The teacher and students are modelled by something akin to the previous model, but understanding of their behaviour requires understanding of the entire interaction. The classroom is a system of individual actors."
>
> Norman (1985)

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Figure 22 - Classroom behaviour as a result of interactions (Norman, 1985)

If, as Norman suggests, the classroom is a 'system of individual actors', then the design studio or workshop can equally be described in this way.

Students of design and technology are often solving individual design tasks, each of which has an indefinite number of solutions. The role of the teacher in managing these interactions is central to the promotion of learning in students. The introduction of mandatory programmes of teacher appraisal provide a means of reviewing classroom interactions. Mathias and Jones (1988,1989a) point out that the ultimate purpose of teacher appraisal is to enhance the quality of pupil learning. Used creatively it can help to focus upon the needs of individual pupils.

2.13 Teaching/learning strategies related to design methodology

SEAC (1990) puts forward a model for learning through design and technology. Their survey has shown that there are two distinct aspects of capability in Design and Technology that need to work together as pupils tackle a task. First of all, reflective capability, which is concerned with thinking around the task and seeing and reflecting on the issues that bear on the task. And secondly, active capability, which is taking action on the task to develop proposals for new artifacts, systems or environments. They describe these dimensions in terms of conceptual understanding and the modelling and communicating facility.

Figure 23 - The dimensions of capability (SEAC, 1990)

Kimbell et al (1991) propose that as this developmental process continues the thinking gets deeper, clearer and more detailed as the clarity of expression shows up what is and what is not possible.

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Figure 24 - Reflective and active ability (Kimbell et al, 1991)

Kimbell et al conclude that in terms of reflective capability, girls generally outperform boys, although where they are set in a more active test structure boys' performance is much improved. When looking at active capability differences girls were seen to outperform boys in terms of proposals made for manufacture.

What do these models and conclusions suggest about teaching and learning strategies? To what extent can designing be taught? It seems that in the United Kingdom education system the teaching of design methodology has been undertaken in a simplistic way. It has often been based upon the assumption that designing is a linear process which all teachers of design and technology understand. Consequently, few resources have been allocated towards in-service training related to design methodology.

Nevertheless, even in a professional context, design methodology is a relatively new discipline. One of the first publications from J Christopher Jones (1970) provided "a first attempt at understanding and describing the new design methods that have appeared in response to a world-wide dissatisfaction with traditional procedures." Jones suggested that the interest in methodology in the 1970s was not limited to designing but could also be seen in other industrial activities such as management, production engineering, accounting and marketing.

In the 1981 version of Jones's book ways of using the design methods are discussed. Jones suggests that few people are prepared for the rigour with which it is necessary to follow a design method if it is to make any difference to the ways of setting about designing. He discusses how there is a tendency to let even simple ideas, like brainstorming, degenerate into being something not usefully different from the kind of undirected chatting and 'research' that takes place in any design office. This seems to raise questions about the appropriate way of teaching design methodology, particularly with students in the secondary age phase.

Cross and Roy (1975) further developed the work of Jones in their booklet 'Design Methods'. A range of specific design methods are suggested to suit a variety of situations. These are illustrated below (figures 25 and 26). The manual also contains detailed descriptions of each design method.

Figure 25 - Choosing a design method (Cross and Roy, 1975)

Figure 26 - Routes through the methods (Cross and Roy, 1975)

Implicit within the work of Jones(1970,1981) and Cross and Roy (1975) is that design thinking methods can be taught. de Bono (1982) suggests that there are two choices associated with this debate. One is based upon the premise that thinking is like walking or breathing and there is nothing that can be done about it. The other suggests that thinking is a skill like driving a car, juggling, cooking or skiing which some people will be better at than others, but everyone can acquire a reasonable amount of skill if he or she wants to. In other words, thinking can be taught and by implication design thinking can also be taught. de Bono describes a number of activities for developing these skills.

There have been few studies on the subject of design methodology for school pupils within the secondary age phase. It seems in the early literature that it was assumed that understanding of design methodology would be implicit in teachers who had been involved in the teaching of the traditional craft-based subjects.

Literature aimed at secondary pupils tended to focus upon providing linear models of the design process together with a general list of considerations for the 'novice' designers. For example, Yarwood and Dunn (1979) provide the model shown below (Figure 27) as a framework for teachers and pupils.

Figure 27 - A design process (Yarwood and Dunn, 1979)

Gradually, the design methodology aspect of the literature for secondary school pupils became more detailed and specific. Breckon and Prest (1983), for example, provided teaching materials which extended the linear models provided in the late 1970s. Kimbell et al (1987) put forward a series of exercises aimed at developing design skills. These included activities such as 'brainstorming', 'looking elsewhere' and 'chance connections'.

McMillan et al (1987), in a publication entitled 'CDT Starting Points and Design Strategies' which was sponsored by the BP Design Fellowship, discussed the use with secondary school pupils of specific design methods such as brainstorming, morphological analysis, checklists, and survey and research. This work seemed to have been based upon activities within the 'expert' design context by authors such as Jones (1981) and Cross and Roy (1975).

Kimbell and Wheeler (SEAC/EMU) (1991) suggest a range of teaching strategies in their paper entitled 'Negotiating Tasks in Design and Technology'. One technique is concerned with starting with half-developed ideas and they put forward two ways in which this strategy can be used:

(i) by providing a visual image or 'concept model' of how a solution to the task might work. This is intended to act as a starting point for pupils and to provide the focus for detailed design development;

(ii) by providing a list of criteria that highlight certain features of how a successful outcome might have to perform. This is intended to focus the range of possibilities and generate purposeful activity in a very short time-frame.

Kimbell and Wheeler also discuss the strategy of starting with the appraisal of real products, using group discussions as a starting point for action and the use of contextual stimulus material.

So it can be seen that during the 1980s and 1990s gradual development and understanding in the area of design methodology took place. The introduction of a National Curriculum in Technology for all pupils between the ages of 5 and 16 has extended the need for further understanding of teaching strategies related to design methods. This is illustrated by the recommendations for the review of the National Curriculum in Technology (DfE, 1992). Perhaps these rapid changes show that there has never been a greater need for self-reflection of teaching methods. However, at times of great change within the education system how can time be found to consider teaching and learning strategies? Mathias and Jones (1988, 1989a, 1989b, 1989c, 1989d) suggest that the introduction of teacher appraisal (H M Government, 1991) could provide an opportunity for teachers to give greater consideration to the teaching and learning processes. They suggest that there is a need to give some ownership to teachers of the processes of classroom observation, which is a mandatory requirement within teacher appraisal, so that appropriate teaching and learning strategies can be developed. This would allow teachers to consider some of the important and complex issues discussed in this chapter in a non-threatening environment. This potential is further considered in the concluding chapter.

The task in this research has been to draw together the range of issues discussed in this chapter into a single project so that an under-researched area can be explored. The range of literature sources has included material from design education, design methodology and cognitive psychology. The literature sources from all these areas have helped the development of a research approach related to the development of conceptual and empirical understanding of the design problem solving strategies used by expert and novice designers. This has helped to bridge a gap in current research by attempting to enhance theoretical understanding of the design process demonstrated by expert and novice designers as well as providing useful methodological discussion.

To summarise, the purpose of of this research project has been to:-

(i) disaggregate the design process to provide general insights into the differential processes used by 'novice' and 'expert' designers in solving ill-structured problems;

(ii) present illustrative case studies or protocols of individual 'expert' and 'novice' designers;

(iii) explore the implications of the findings for teaching and learning strategies;

(iv) consider ways in which the research methods might be used for the diagnosis of faulty or ineffective procedures.

Chapter 3 - Research Method

3.0 Introduction

The purpose of this section of the report is to describe and justify the research methods generated for this project. It has been noted that there has been little, if any, previous research in this explicit area. The justification is therefore of particular importance as a major part of the project will be to modify existing instruments and develop new research approaches.

The research methods therefore had to be capable of addressing the issues which are central to the problem outlined in chapter one. In other words, they had to provide opportunities for comparing the behaviour of expert and novice designers. They also had to provide a basis for considering the teaching and learning strategies which are appropriate for novice designers.

The research methods generated for this project have resulted from an analysis of work carried out in two separate disciplines - design methodology and the cognitive psychology area of information processing. The research strategy therefore had to have credibility in these two disciplines.

The chapter is divided into a number of parts. First of all, alternative research methods have been discussed. Second, the research plan has been described and justified. The development of the coding schedule has been discussed and the process of transcribing, segmenting and encoding the verbal protocols has been reported. The nature of the task has then been discussed and the sample population for the project has been outlined. Finally, the arrangements for collecting data have been summarised.

It should be noted, however, that the research method evolved during two distinct stages of data collection. It has therefore not been possible to describe all aspects of the research plan in logical detail. It will therefore be necessary to refer to Chapters 4 and 5 to obtain a full understanding of the research method.

3.1 Potential research methods

A number of possible research methods were considered for this project. Most of these originated from the field of professional design. As stated above, little research has been undertaken into the problem solving behaviour of novice designers. In order to discuss potential research methods, a framework put forward by Cross (1990) was used. Cross arranged these in order from those stemming from direct contact with designers to the more abstract and theoretical.

The first approach involves interviews with designers. This is a retrospective technique in which the subject is asked to recall the events of the design process either at key stages or when the design is completed. Stauffer and Ullman (1988) describe a number of research projects which use this approach (Marples, 1961; Ramstrom and Rhenman, 1965; Lewis, 1981; Waldron and Waldron, 1987). Ericsson and Simon (1985) also discuss the potential of retrospective reports (Chapter 2) and conclude that they can provide accounts of cognitive processes. However, in this project data will be collected from both expert and novice designers.The latter group may lack the confidence and experience to use this method.

Another research method involves the development of case studies of particular design projects. This could involve observing all aspects of the design process, including design folios and the final outcome of the process. This is similar to the role of teachers within the National Curriculum (DES,1990) who conduct formative assessment during the designing process and who are also involved in the summative assessment of the work produced during the project. It would seem to be important in this research project that some use is made of the drawings and products of the design task (Tovey, 1986; Kimbell et al, 1991; Schenk, 1991).

A third method is based upon protocol studies of design activities. This involves training designers to talk aloud as they solve design problems. The verbalisations are recorded and then transcribed, segmented and coded, before being analysed. This method is discussed in detail in Chapter 2. It is a process which seems to provide opportunities to generate empirical data whilst basing the activity in a real design and technology context.

Another research method involves laboratory experiments based upon selected features of design ability. Lawson (1979) conducted an experiment with architecture and science students which examined problem-focused and solution-focused design strategies. Whilst these approaches can provide detailed insights into specific aspects of behaviour, they are not really broad enough for examining the more general aspects of behaviour demonstrated by expert and novice designers.

Finally, theorising has been used to research into design problem solving behaviour. Simon (1969), March (1976), Schon (1983) and others have provided interesting theories related to topics such as design, science and logic, forms of reasoning and epistemology. All of these researchers have added to understanding about the processes of designing. However, there seems to be a real need to further develop the empirical research base related to the behaviour of expert and novice designers. An approach based mainly on theorising can therefore be discounted at this stage. Nevertheless, the conclusions of previous research could provide a framework for considering the behaviour of expert and novice designers.

3.2 The research plan

Three main research approaches have therefore been incorporated into the research plan. The first perspective is that of information processing in human problem solving. One approach uses the analysis of verbal protocols to gain information about the course of the cognitive processing by probing the subjects' internal states. It involves the recording of problem solvers concurrent verbalisations under controlled conditions. A model of the data in terms of the presumed processes is then developed. This is followed by the encoding of portions of the verbal protocol to the previously defined categories in a model of dynamic cognitive processes. Linked to this approach is a consideration of the heuristics which are identifiable within the verbal protocols,

A detailed discussion of this approach is provided in Chapter 2. Ernst and Newell (1969), Newell and Simon (1972) and Ericsson and Simon (1984) in justifying this approach claim that verbal behaviour can be accounted for in the same way as other behaviour. That is to say, by developing and testing an information processing model of how information is accessed and verbalised in response to stimuli. Eckersley (1988) suggests that protocol analysis can provide a controlled method for analysing design problem solving behaviour. Akin (1979) illustrates the way in which protocol analysis can be extended to consider the general plans of action or rules of thumb used by designers.

The second perspective of the research plan is concerned with using a framework of conclusions from previous research in order describe the behaviour of expert and novice designers. This involves the analysis of the video material and verbal protocols in order to describe behaviour in terms of the general design strategies adopted by the problem solver. This framework allows for the research data to be compared with the findings of prominent researchers in area of design methodology such as Cross (1985), Pask and Scott (1972), Guilford (1967), Krampen (1983), Darke (1979), Lawson (1979) and Kimbell et al (1991).

The third perspective of the research plan involves analysing the drawings and models produced during the design activity. This allows for consideration of issues such as the way drawing is used to support thinking, the style and nature of the drawing and also the use of modelling to support thinking. Previous research (Tovey, 1986; Kimbell et al, 1991; Schenk, 1991) has provided interesting insights into design problem solving behaviour by analysing the role of drawing within the design process. As it is such an important aspect of the assessment of novice designers, it can provide in this research project an extra dimension of design problem solving behaviour.

It can therefore be seen that the research plan is based upon a process of triangulation which will look at design activity from three different perspectives. The research draws upon literature of previous research projects from both cognitive psychology and design methodology which have looked at these three approaches independently. It therefore provides an opportunity to draw these three perspectives into a single research project in order to develop broad-based protocols of the design problem solving behaviour demonstrated by expert and novice designers.

What follows is a more detailed description of each of these research approaches. The coding frameworks developed for each approach have also been discussed.

3.3 Research approach 1 - protocol analysis

Protocol analysis is a technique devised to infer the information processing mechanisms underlying human problem solving behaviour. This technique has been based upon the work of Newell and Simon (1972), Ericsson and Simon (1984), Eckersley (1988), Akin (1979), Miller et al (1960) and Chan (1990).

The cognitive process model described below (Figure 30) provided a framework for interpreting the verbal data. This processing model represents the verbalisations related to a design task in a hierarchy of information systems. Verbalisable cognitions are shown as a subset of all cognitions passing through the short-term memory (STM) and working memory (WM) of the subject (Eckersley, 1988).

Cognitive processes can be seen as a sequence of internal states successively transformed by a series of information processes. That is to say, processing takes the form of sequential search, making small additions to the store of information about the problem. Information is stored in several memories each having different capacities. Information recently acquired is kept in STM and is directly accessible for further processing. Elementary processes are executed in terms of hundreds of milliseconds and inputs and outputs of the these processes are held in a small STM with a capacity of few (4-7) symbols or chunks.

The system has unlimited access to to long-term memory (LTM) which first has to be retrieved before it can be reported. The time required to store a new chunk in LTM is in the order of seconds or tens of seconds (Simon, 1985).

To summarise, the essence of the theory of information processing put forward by Ericsson and Simon (1984) rests on the premise that verbalised cognitions can be described as states that correspond to the contents of STM. That is to say the information that is the focus of attention. Second, information vocalised is a verbal encoding of the information in STM and verbalisation processes are heeded as a thought is heeded. Third, verbalisation is a direct encoding of the heeded thoughts and reflects its structure. Fourth, units of articulation can correspond to integrated cognitive structures and pauses and hesitations are good predictors of shifts in processing of cognitive structures.

The processing model used in this project for interpreting verbal data seems to satisfy the criteria put forward by Ericsson and Simon (1984). First of all, the model is as simple as possible. Secondly, it does not incorporate components which are issues of theoretical contention. Finally, the model is robust. That is to say, it is compatible with a wide range of assumptions about human information processing. The model was therefore used as a framework for the development of the coding system.

Research approach 1 - the development of the coding system

It is upon the principles described above that the verbal protocol coding system evolved. This development of a system for coding the verbal protocols went through a number of stages - exploratory data, expert designers, novice designers. Modifications to the coding system were made at each stage and the protocols of the expert and novice designers were recoded at the end of the process using the final coding system.

It was clear from the literature review that a range of operators had been developed for previous research. In this initial stage, the work of four main researchers (Miller et al, 1960; Akin, 1979 ; Thomas and Carroll, 1984; Eckersley, 1988) was analysed using data from previous research by the author (Mathias, 1982).

Thomas and Carroll produced a relatively straightforward coding system based upon the use the problem statement, the outlining, elaboration and testing of the solution, followed by agreement or rejection of the solution:

Goal statement
Goal elaboration
Solution outline
Solution elaboration
Solution testing
Agreement or rejection of solution

Akin (1979), following the work of Miller et al (1960), identified eight plan-like behaviours, or schemata, and defined the inputs, outputs and body of actions needed to convert the input into the output format.

Eckersley (1988) identified eight verbalisation types from the observation of videotaped design protocols generated by individuals engaged in a particular space-planning problem.

The coding systems used in previous research of this type are described in Chapter 2.

General agreement could be found in the coding systems regarding some aspects of the process. For example, referral to the problem statement was categorised as 'goal statement' and 'goal elaboration' by Thomas and Carroll, whilst Akin referred to it as 'specification'. Eckersley used similar statements as Thomas and Carroll - 'listed copy' and 'paraphrased copy'.

'Inference' was identified as an operator by both Akin and Eckersley. 'Integration' was included by Miller et al and Akin. Most researchers identified operators relating to solution outline, testing and validation.

Stage 1 - coding exploratory data (Pro 1 + Pro 2)

As a result of analysing the coding used in previous research, a range of possible codings were developed for piloting on existing data (Mathias,1982). These codings were generated by pulling together common elements from the work of previous researchers discussed above and were also based upon the experience of the author in the assessment of design activities. At this stage, these codings provided a tentative list for trial purposes. It was recognised that the codings did not provide a coherent framework for analysing design problem solving behaviour:

Restatement of the problem
Problem refinement
Goal refinement
Drawing upon knowledge base
Integration of problem information
Analogy
Judgment
Inference
Visual thinking
Modelling
Linking to past experience

Stage 2 - developing the coding system

During the pilot stage with existing data generated by the researcher (Pro1 and Pro 2) a number of the codings were discounted and a framework for encoding transcribed protocols was gradually developed (Figure 28).

Stage 3 - modifying the coding system

The protocols of the expert designers were transcribed,segmented and encoded using the procedures described below (Figure 28). At this point, it was decided that modifications were needed to the coding schedule and the revisions were made as illustrated in Figure 29. The reasons for, and details of, these changes are provided in Chapter 5.

Operators/Plans

A Problem Restatement

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

B Problem Elaboration/Refinement

A statement which extends and interprets information provided in the problem statement.

C Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems

D Holistic Solution Generation

The generation of solutions to the problem from an undetermined or apparent intuitive source.

E Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions.

F Inference

The generation of new information from internal sources. Higher order conclusions, assertions, propositions or justifications not given in the problem statement but generated by the problem solver.

G Information Search

The application of technological or other forms of knowledge to help the development of sub-solutions.

H Solution Validation

The testing and justification of a solution to the problem.

Figure 28 - The initial coding schedule

Operators/Plans (revised form)

A Problem Restatement

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

B Problem Elaboration/Refinement

A statement which extends and interprets information provided in the problem statement.

C Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems

D Holistic Solution Generation

The generation of solutions to the problem from an undetermined or apparent intuitive source.

E Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions.

F Assertions

Assertions from the generation of new information from internal sources.

F1 Inference

Higher order conclusions, assertions, propositions or justifications not given in the problem statement but generated by the problem solver.

G Information Search

The initial application of technological or other forms of knowledge to help the development of sub-solutions.
N.B. subsequent use of this knowledge will be coded under category E

H Solution Validation

Testing, justifying and revising of a solution to the problem.

Figure 29 - The revised coding schedule

Research approach 1(continued) - Heuristics

The heuristics or general plans of actions were also identified within the protocols. They relate to the strategy being used at a particular phase in the problem solving activity. In other words, chunks of the transcript, or groups of operators can be used to identify the heuristic being used to move through the search space. That is to say, they represent an overall strategy which provides a framework for the use of individual operators at specific phases of the activity.

The heuristic descriptions shown below have evolved from the literature review and provide the framework for discussing this aspect of the process:

Hypothesise and test

A basic model to account for the hypothesis testing process consists of :-

the sampling idea that the subject samples one hypothesis (or sample of hypotheses) from a pool of all possible hypotheses which may be correct, incorrect or irrelevant;

the no-memory idea that if the hypothesis results in correct classification of an instance it is retained, otherwise it is replaced in the pool and a new hypothesis (or hypotheses) is selected (Mayer,1977)

Induction

Refers to a situation in which a thinker is given a series of examples and must 'leap' to the creation of a general rule (Mayer, 1977)

Means-end-analysis

A major heuristic is 'means-ends-analysis' in which the present state is compared with the new state that could result from the application of an operator in order to determine whether the new state is closer to the goal. If it is, the 'move' is made : if not, the solver searches for another move that produces a state closer to the goal state. (Mayer,1977)

Hill-climbing

Hill climbing is a search strategy in which search starts from any point in the problem space. All subsequent design operations try to move this point closer to the goal, or solution, state. Success or failure depends on whether the initial point selected is one that is potentially capable of leading to a satisfactory solution.

Pattern Matching

The mind (in perception) provides a means whereby incoming information gets organised into patterns. Once a pattern has been formed then the mind no longer has to analyse and sort information. All that is required is enough information to trigger the pattern (de Bono, 1982).

+

Obvious-first-solution
Divide-and-conquer
Pre-compiled-solution
Most-constrained-first

The verbal transcripts were analysed in order to consider the heuristics most prominently demonstrated by each subject.

The diagram shown below summarises the basic principles of the cognitive model, the classification of verbalisations and the heuristics.

DESIGN PROBLEM

Available sensory information

Recognition

LTM < - > STM

Verbalisation in relation to design activity

Classification of verbalisations:

A - Problem restatement
B - Problem elaboration/refinement
C - Integration
D- Holistic solution generation
E - Solution elaboration/testing
F - Assertions
F1 - Inference
G - Information search
H - Solution validation

Heuristics :

Hill climbing
Means-ends-analysis
Hypothesise and test
Pattern matching
Induction

Figure 30 - The processing model and coding schedules

The model has been extended to provide a broader view of the process of designing. Whilst the information processing model allows for an empirical analysis of the process through the analysis of design-related verbalisations, more qualitative aspects also need to be considered if a broad-based view of the designing processes is to be obtained. This has been achieved by considering first of all the general design strategies used by expert and novice designers, and secondly by considering the role of drawing and modelling within the design process. These help to provide further insights into the verbal protocols.

3.4 Research approach 2 - the general design strategy

Each protocol was described in terms of the general design strategy adopted by the problem solver. The framework for this aspect of the research project was influenced by the work of Cross (1985), Pask (1972), Guilford (1967), Tovey (1986), Lawson (1979), Darke (1979), Krampen (1983) and Kimbell et al (1991). The work of these researchers has been discussed in Chapter 2 and the detail which informs this framework for analysis will be found in that part of the report.

The following framework was used to compare the design strategies of 'expert' and 'novice' designers:

(i) Subjects were compared using the work of Cross (1985), Guilford (1967) and Pask (1972):

Convergent
Divergent
Serialist
Holist

(ii) The definitions of Tovey (1986) were also used as a basis for describing and analysing design strategies:

Serial analytic strategy
Serial-analytic-holistic strategy
Holistic synthetic strategy

(iii) The key words used by Kimbell et al (1991) in comparing and characterising the way in which pupils (novice designers) tackled design problems were used for a similar purpose within this project for both the expert and novice designers:

resourceful, innovative, safe, fluent, predictable, disorganised, genuine, determined, focused, divergent, committed, prolific, preoccupied, methodical, rigorous, rich, exciting, empathetic, ambitious, self-motivating, thoughtful, fully involved, flair, artistic,

(iv) Kimbell et al (1991) contrast between **reflective ability,** which allows thinking around the task, seeing and considering issues that bear upon it and which help to solve the real problem rather than the one that seems the most appealing at the time, and **active ability** which allows action in response to the task resulting in the development of proposals for new artifacts, systems and environments. The behaviour of subjects was compared using these two aspects of design problem solving.

(v) The models of Krampen (1983) were used as a basis for examining the strategies employed:

Novice

Definition of problem

Possible choice for solution

Simplification

First solution attempt

Reiteration and second attempt

Third attempt

Verification and presentation

Summing up difficulties of problem

Expert

Familiarisation with problem

Clarification by sketching

First solution attempt

Verification and rejection

Second attempt

Presentation of solution and correction of minor mistakes

Verification

(vi) The **analysis-synthesis-evaluation** model and subsequent adaptations to this model were used as a basis for comparison.

(vii) The problem-focused and solution-focused strategies identified by Lawson (1979) were considered.

(viii) The extent to which **'satisficing'** and the concept of **'primary generator'** (Darke, 1979) were used was also be considered.

The summary of this framework is provided in figure 30:

1 Convergent/divergent/holistic/serial

2 Serial analytic/serial analytic holistic/ holistic synthetic

3 Key words

4 Active V reflective ability

5 Novice V expert

6 Analysis-synthesis-evaluation

7 Problem/solution focused strategy

8 Satisficing/primary generator

Figure 31 - The framework for considering design strategy

3.5 Research approach 3 - Drawing and modelling

Drawing and modelling have two main functions within design problem solving. First of all, they can be used to help the process of designing. That is to say, they can be used to actively help a designer to develop images and ideas which aid the movement through the search space. Secondly, drawing and modelling can be used to show the product of thinking. In other words, they provide a retrospective record of decisions which have been made during the design problem solving process.

Research in this area has been discussed in Chapter 2. The framework described below has drawn upon the central principles of this work.

The first issue which needs to be considered relates to the use of drawing to aid analysis and first stage ideas. Schenk (1991) suggests that drawing is a very significant aid to the analytical and first stage ideas of a designers work. She differentiates between this and the use of drawing during the synthesis and development stage. Schenk is, of course, referring to the work of expert designers. It will therefore be important to consider this issue in relation to the expert and novice designers who are central to this project.

The following general framework was developed in order to describe the role of drawing within the design problem solving process. It provides a basis for considering how both expert and novice designers use drawing and modelling to support thinking during the development of first ideas, analysis and synthesis. It also provides an opportunity to consider the style and nature of drawing used by expert and novice designers.

1 The use of drawing to support thinking

(i) drawing for analysis and first ideas

* assembly of first thoughts
* rapid exploration of a large number of ideas through free ranging drawing

(ii) drawing for synthesis

* detail to aid decision making
* pace and style of drawing
* shift from concept to format

The second issue relates to the style and type of drawing used within the process. Kimbell et al (1991) analysed the work of 'novice' designers in terms of the complexity, clarity and confidence of the communication. Their work provides a framework for this second element:

2 The style and nature of the drawing

* Complexity of the message

  - the range and depth of issues and proposals communicated

  - the details of how, when and where it would work

  - who would use it

  - and how it would be made

* Clarity in communication

  - the ease of access into the issues and proposals

  - whether there was any confusion

  - do you have to make any assumptions about the ideas expressed?

* confident communication

  - bold, strong style

  - big images and writing

  - use of colour

- flow of ideas

- use of freehand sketches

- interaction of words and pictures

- switching between techniques eg 2D to 3D

The third element of this part of the framework relates to the use of modelling to aid thinking. The APU model put forward by Kimbell et al (1991) illustrates the role of modelling as an interaction between the phases of speculating and exploring and clarifying and validating (see Chapter 2).

In some design activities such as those used by, for example, a potter or wood turner, thinking through modelling may take place throughout the process. It also seems that, to a greater or lesser extent, depending upon the nature of the problem, both expert and novice designers may use the physical manipulation of materials to aid thinking at any stage within the process.

It was therefore important to consider:

3 The use of modelling to support thinking

(i) the use of modelling for analysis and first ideas

(ii) the use of modelling for synthesis

A summary of the framework for considering the role of drawing and modelling within the design problem solving process is provided in figure 32:

1 Drawing for first ideas

2 Drawing for synthesis

3 The style and nature of the drawing

4 The use of modelling to support thinking

Figure 32 - The framework for considering the role of drawing and modelling

3.6 Plan for processing the data

It was planned to process the data for analysis in a number of stages. First of all the verbal protocols were required to be transcribed, segmented and encoded using the schedules outlined in Figures 28,29 and 30. The coding schedule was modified after the collection of data from expert designers. The full method of processing the data is described in Chapter 5. Secondly, the protocols were analysed using the frameworks summarised in Figures 31 and 32. A mapping process was used used to examine the protocols in parallel

The transcription, segmentation and encoding were based upon the criteria:

Transcription

A number of issues needed to be considered during the process of transcription. First of all, the difference in speech patterns between adults and school children. Ericsson and Simon (1984) suggest that the verbalisations of adults can be transcribed into ordinary words. Referring to research by Ochs (1979) they indicate that dictionary words may not adequately describe the verbalisations of young children. However, in this research project the novice designers were represented by pupils at the end of key stage 3 in National Curriculum terms. That is to say, 13-14 year olds. From previous research by the author with this age group, it was felt that transcription would not be a problem. This proved to be true in terms of the protocols generated for this project.

The second issue related to the problem of transcribing 'speech bursts'. Ericsson and Simon suggest that they are difficult to transcribe and may be subsequently difficult to encode. These issues were taken into account during the transcription process.

Segmenting

The second phase of the process involved segmenting or chunking the verbal protocols in preparation for encoding. A number of attempts have been made to define criteria for segmentation. Ericsson and Simon (1984) suggest that cues for segmentation may include pauses, intonations and contours, as well as syntactical markers from complete phrases and sentences. They indicate that if oral prose were completely grammatical, a statement would essentially be a clause or sentence. However, in normal speech, statements are often abbreviated to phrases or even single words.

Smith (1971) attempted to segment on the basis of separating ideas. Goor and Sommerfeld (1975) segmented by three second intervals. Eckersley (1988) used verbal pauses to begin new lines of text and also hesitations and synatically complete thoughts. Eckersley indicated that the great majority of verbalisations were of short duration and usually consisted of a single line before a pause. However, where a single line of data clearly indicated more than one discrete verbal behaviour, he broke the lines into separate chunks. Chan (1990) segmented statements by pauses greater than four seconds. He suggested that a pause time of greater than four seconds indicates that the successive statement probably provides information about a new perceived item. His protocol contained 604 segments.

Kilpatrick (1968) attempted simultaneous segmenting and encoding. However, this is not usual practice in protocol analysis as it is difficult to concentrate upon two contrasting aspects of the protocol.

The previous research described above helped to influence the segmenting method used for this research project. The protocols were therefore segmented using pauses, hesitation and syntactically complete phrases as cues for identifying instances of the general process. On occasions, it was found that single words could provide a basis for segmentation using the criteria described above. In order to improve validity and reliability, an independent segmenter was used during this phase. The details are provided in Chapter 5.

Encoding

During this stage preprocessed segments of the transcripts are encoded using the categories which are based upon the theoretical model. Care must be taken in terms of reliability, so that high inter-coder agreement is reached. However, reliability alone is not enough and problems can arise even when inter-coder agreement is high.

Ericsson and Simon (1984) discuss three possible problems in this area. The first problem concerns biases towards confirmation of the hypotheses. That is to say, if the encoder has knowledge of the hypotheses which underpin the research project, this knowledge can influence the encoding procedure. It is clear that inter-coder agreement, where both parties have knowledge of the hypotheses, may not measure coding validity. In this project it was therefore decided that the second coder would be independent of the project and consequently would not have knowledge of the questions which underpin the research.

The second problem relates to inferences of what the subject must have said, rather than did say. In other words, the assumption that the coder made the same inference as the subject. Often this is not difficult, but it can be a problem when the coder is faced with an ambiguous statement. In order to address this issue it was decided that ambiguous statements would be highlighted so that the researcher and independent coder could discuss and agree the final coding.

Finally, problems exist in restricting the influence of previously encoded information on subsequent coding decisions. That is to say, if each segment is to be treated as an independent datum, then the encoding of that segment must be made on the basis of the information contained in it and therefore independent of the surrounding segments. In this project, both the researcher and the independent coder selected at random segments of the protocol. These were then coded independently with the findings discussed and agreed.

In summary, it is suggested that the reliability and validity of the encoding process was improved through consideration of the issues discussed above. Validity is also affected by the initial identification of codings based on the theoretical models described in Figures 28 and 29. The subsequent evaluation and modification of the coding system also helped to improve validity. This was aided by the piloting of the original coding system on previously collected data. The full details of these processes will be found in Chapter 5.

The mapping process

A mapping process was used in order to look at the protocols in parallel. This provided a template or framework for the analysis which allowed key issues to be identified from the wealth of data embodied in the transcribed protocols. The coding schedule, which can be seen to represent a type of hypothesis for design problem solving behaviour, therefore provided a framework for analysis.

Each element of the schedule was analysed in turn and this provided a framework for discussion within the protocol. The design strategy was then discussed using the framework described in the research plan (Figure 31). This was followed by an analysis of the impact of drawing and modelling upon the process, which is also described in the research plan (Figure 32). Finally, general elements were considered to provide a summary at the end of each protocol.

The actual processing of the data is discussed in Chapter 5.

3.7 The nature of the task

Much of the previous research based upon the use of protocol analysis with design problems has been undertaken by professional architects. Consequently, the design problems used during data collection were mainly related to building design. The task used by Chan (1990) related to designing a three-bedroomed dwelling for a single family. Eckersley (1988) adapted the design problem conceived by Carroll, Thomas and Malhotra (1978) which involved the designer moving seven characters around a schematic office space to accommodate nineteen functional requirements. Akin (1979) used a professional designer to develop a single person dwelling. The desire in each case seemed to be to keep some control over the framework and constraints embodied in the problems in order to facilitate encoding and, in the case of projects using more than one subject, to allow comparisons between problem solvers.

The researcher was concerned with the much broader area of design and technology which utilises design tasks from a wide range of contexts and problem types. It was therefore felt that the design problems used in previous research with 'expert' designers would not be appropriate within the context of this research project. However, it was not immediately clear which type of problem would be appropriate. For example, would the task come from from product, graphic, systems or environmental design? All of which are encompassed within the design and technology syllabus. It was also necessary to consider whether the problem would be open-ended, or closed with tight constraints.

In order to generate tasks suitable for this project it was necessary to analyse problem types and consider the data collection methods and constraints embodied within the tasks.

Six main design problem types were identified:

1 Problems with a convergent brief and tight constraints.

2 Problems which provide opportunities for thinking through modelling.

3 Problems generated from a broad theme.

4 Problems using directed approaches within abroad theme.

5 Totally open-ended problems

6 Problems involving system design.

Problem types 3-6 were eventually discarded as it was felt that they were too broad to control and make comparisons between expert and novice designers. It was felt that the problem need quite tight constraints in order to provide a structure and framework for analysis. However, there were still tensions between tasks for research and tasks used for teaching purposes within design and technology.

A range of video material from APU/Kent (1990) was viewed. Much of this video material focused upon developing contexts for design and technology which could be used as a basis for 'identifying needs and opportunities' (National Curriculum - Attainment Target 1). However, it was felt that it was not possible to use this material for identifying a specific design problem as it focused upon encouraging students to work in a very individual way, thereby making it very difficult to draw general conclusions from the research.

It was therefore decided that it would be important to identify a problem that would:

(i) be broad enough to encourage subjects to work on the design task using their natural cognitive style;

(ii) have some constraints embodied in the problem statement so that comparisons could be made between individual design problem solving strategies;

(iii) allow students to demonstrate genuine design and technology activity.

Analysis of the role of modelling and drawing during the design process was also central to the research methods developed for this project. It was therefore decided to look at this aspect in the first stage of the data collection with expert designers. Subject 2 (Pro 4) therefore undertook a different main problem to Subject 1 (Pro 3).

Problem 1

Choose an appropriate theme and design a board game which has an average play time on no more than twenty minutes. Test a series of prototypes and record the result. If possible include designs for three dimensional playing pieces made from card, together with visually presented set of rules. make suggestions for packaging and advertising.

GCSE - CDT (Kimbell et al, 1987)

Problem 2

Using a sheet of A4 card, design and make a book support which could be used for revision/study and can then be stored in an A4 folder.

Problem 1 was undertaken by subject 1 (Pro 3) and problem 2 was undertaken by subject 2 (Pro4). A practice problem (problem 3), also embodying tight constraints was used in the training programme which preceded the data collection for both subjects. This was subsequently used as the practice problem for the novice designers (Pro 5-7). Problem 3 had been previously used in the collection of the data for the previous research by the author (Mathias, 1982).

Problem 3

Small indicators are required to stand on the desks of a large office to display the name of the person working at that desk. Design a simple neat stand that would suit the purpose, occupy as little space as possible on the desk top but still be such that it cannot be knocked over easily. The letters forming the name are to be 20mm high.

3.8 The sample

Previous research in the area of protocol analysis has utilised very small, deliberately selected samples. This is because of the high density and depth of data collected during the process. This means that generalisations to larger populations are difficult. However, the principal aim of protocol analysis is to develop general descriptions of the design process which add to the knowledge and understanding of this complex issue.

Many research projects have been based upon the collection of data from a single subject (Akin,1979; Chan,1990; Lewis,1981; Waldron and Waldron,1987). The maximum sample size used in previous research seems to be five (Eckersley,1988; Stauffer and Ullman,1988). However, even in these research projects detailed case studies were only developed for part of the sample selected.

This research project has focused two main sample populations - expert and novice designers. A total sample of five subjects was therefore selected from these two areas. This sample comprised two expert designers and three novice designers. It was decided to use a large sample in terms of protocol analysis because the data obtained from novice designers was likely to be less dense than than that obtained from expert designers. The sample was also skewed to the novice designers as previous work has been mainly undertaken with expert designers. Little, if any, previous research has focused upon the use of protocol analysis with novice designers.

Sample 1 - expert designers

Two students taking programmes in design and technology were selected as the sample for this project. At the time of data collection, it was anticipated that both students would obtain a first-class honours degree in design and technology and could therefore represent expert designers within this research project. One student did subsequently obtain a first-class honours degree. The other left before the end of the degree programme to pursue commercially a design project identified during the degree programme. The project was successful in the commercial market and the subject has developed a flourishing business related to product design and development.

It was therefore felt that the two subjects described above were close enough to the models of expert designers described in other research projects (Eckersley,1988; Chan,1990) for comparisons to be made. It was also felt that the subjects related directly to the researchers professional context and would therefore provide the benefit of adding to understanding of the way undergraduate students of design and technology solve design problems:

Subject 1 (Protocol 3) - final year undergraduate student estimated to obtain a first-class honours degree.

Subject 2 (Protocol 4) - second year undergraduate student estimated to obtain a first-class honours degree (subject moved into the commercial domain before the end of the degree programme).

Sample 2 - novice designers

A great deal of consideration was given to the size and nature of the sample of novice designers. The original intention was to select three subjects from three school representing three LEAs. However, the review of literature indicated that research projects undertaken with expert designers had been based upon very small samples because of the density of the data. Also, it was not the intention of the research project to generalise about LEAs or schools, but to develop individual in-depth protocols related to the design problem solving strategies employed by individual novice designers with the hope that this would help to inform general understanding in this complex area.

It was therefore decided to use a sample of three pupils from a single school. All pupils were at the end of National Curriculum key stage 3 :

Subject 3 (Protocol 5) - the subject for Protocol 5 was a year 9 pupil at a a large comprehensive school in the City of Birmingham. The pupil was assessed by the school as being of below average ability in terms of design problem solving. At the time of data collection the subject had just selected Design and Realisation to study at GCSE level in years 10 and 11. The subject was estimated to obtain a grade E in the GCSE.

Subject 4 (Protocol 6) - the subject for Protocol 6 was a year 9 pupil at a large comprehensive school in the City of Birmingham. The pupil was assessed by the school as being of above average ability in terms of design problem solving. At the time of data collection the subject had just selected Art to study at GCSE level in years 10 and 11. The subject was estimated to obtain a grade A/B in the GCSE.

Subject 5 (Protocol 7) - the subject for Protocol 7 was a year 9 pupil at a large comprehensive school in the City of Birmingham. The pupil was assessed by the school as being of average ability in terms of design problem solving. At the time of data collection the subject had just selected Design and Communication to study at GCSE level in years 10 and 11. The subject was estimated to obtain a grade B in the GCSE.

3.9 Arrangements for collecting data

The main requirement in this project was to collect data in the form of a video recording as the subjects talked aloud as they solved design problems. The aim was to transcribe the audio element of the video tapes and then code each segmented element of the transcript.

It was planned to collect data from the expert and novice designers on two separate occasions, which were several months apart. The reason for this was to use the collection of data from expert designers in order to evaluate the coding schedule, the design task and the setting for data collection. This allowed for changes to be made before the collection of data from novice designers. In other words, the first phase of the data collection was planned to be, in part, exploratory.

The process of data collection was therefore planned to integrate with the evaluation and development procedures described above. The process of data collection outlined below therefore consists of a timetable which was established at the outset and which was then modified at key stages in light of the evaluation process:

1 The collection of data from expert designers (TV studio).

2 Transcription, segmenting and coding of the protocols from expert designers.

3 Analysis of the protocols of expert designers in terms of operators, heuristics, design strategies and drawing/modelling.

4 Evaluation of -
   (i) the process of data collection, including the setting;
   (ii) the coding schedules/frameworks;
   (iii) the design task.

5 Modification of the coding schedules/frameworks.

6 The collection of data from novice designers (design studio).

7 Transcription, segmenting and coding of the protocols from expert designers.

8 Recoding of the protocols from expert designers.

9 Analysis of protocols from expert and novice designers.

A number of issues needed to be considered before data collection could start:

(i) **the setting** - a fully equipped television studio was made available for the collection of data from the expert designers. However, at the outset it was felt that this may be too intimidating a setting for the novice designers and an alternative setting was made available. In light of the evaluation of the data collection process with the expert designers, a design studio was subsequently used for the novice designers.

A range of design material was available for each subject and suitable working conditions were provided. The settings are described in detail Chapter 4;

(ii) **the process** - it was anticipated that the collection of data would last between 60 and 90 minutes for each subject and arrangement were made for the specialist facilities to be available for this period of time. Both the researcher and a television studio technician were available throughout the period of data collection;

(iii) **the tasks** - were as outlined in section 3.7;

(iv) **training** - subjects were trained prior to the main process of data collection. The training process is described in Chapter 4.

Full details of the two sessions of data collection are provided in Chapter 4 - Data collection. The practical details of processing the data will be found in Chapter 5.

Chapter 4 - Data Collection

4.0 Introduction

Data collection took place in two main stages. First of all protocols were developed from the expert designers. Some months later protocols were collected from novice designers. The purpose of this section is to describe the process of data collection in terms of pre and post data collection meetings, the setting, training for the subjects and the actual collection of data.

4.1 Collection of data from expert designers

Stage 1 - Pre-data collection meeting

The subjects selected for this project were invited to a meeting prior to data collection to discuss the purpose of the project and also the process of collecting data. Subjects were assured that they were not being assessed in any way. The methods for collecting data were also discussed in detail. In particular, the process of developing verbal protocols was described.

Stage 2 - The setting

The collection of data from expert designers took place in a television studio located in the researcher's place of work. The quality equipment and expertise provided by the studio technician facilitated the production of high quality video material.

Two television cameras were used in this process. The first captured the detail of drawing and modelling. The second focused upon a general view of the subject and provided the inset for a split-screen picture (Figure 33).

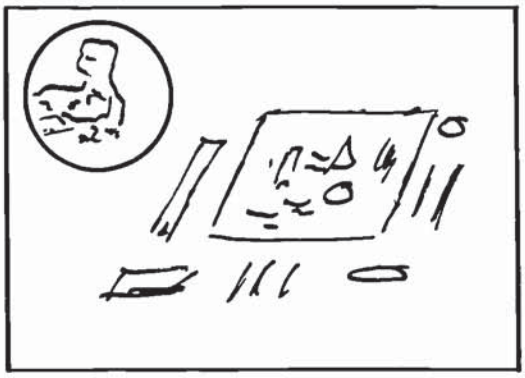

Figure 33 - Split screen video picture

The setting (Figure 34) was chosen because of the need to create a neutral environment which would not provide visual stimulus to aid the problem solving process. It was recognised that the setting may prove to be intimidating for some subjects. However, it was felt that it would not unduly affect the expert designers who were the focus of the first stage of data collection. It was also important to ensure that the opportunity was taken to develop high quality video material.

A range of material was available for the subjects use during the design:

Drawing paper	Knife
Cutting board	Card
Staples	Paper clips
Glue	Pens/pencils etc.
Scissors	Straight edge

The setting

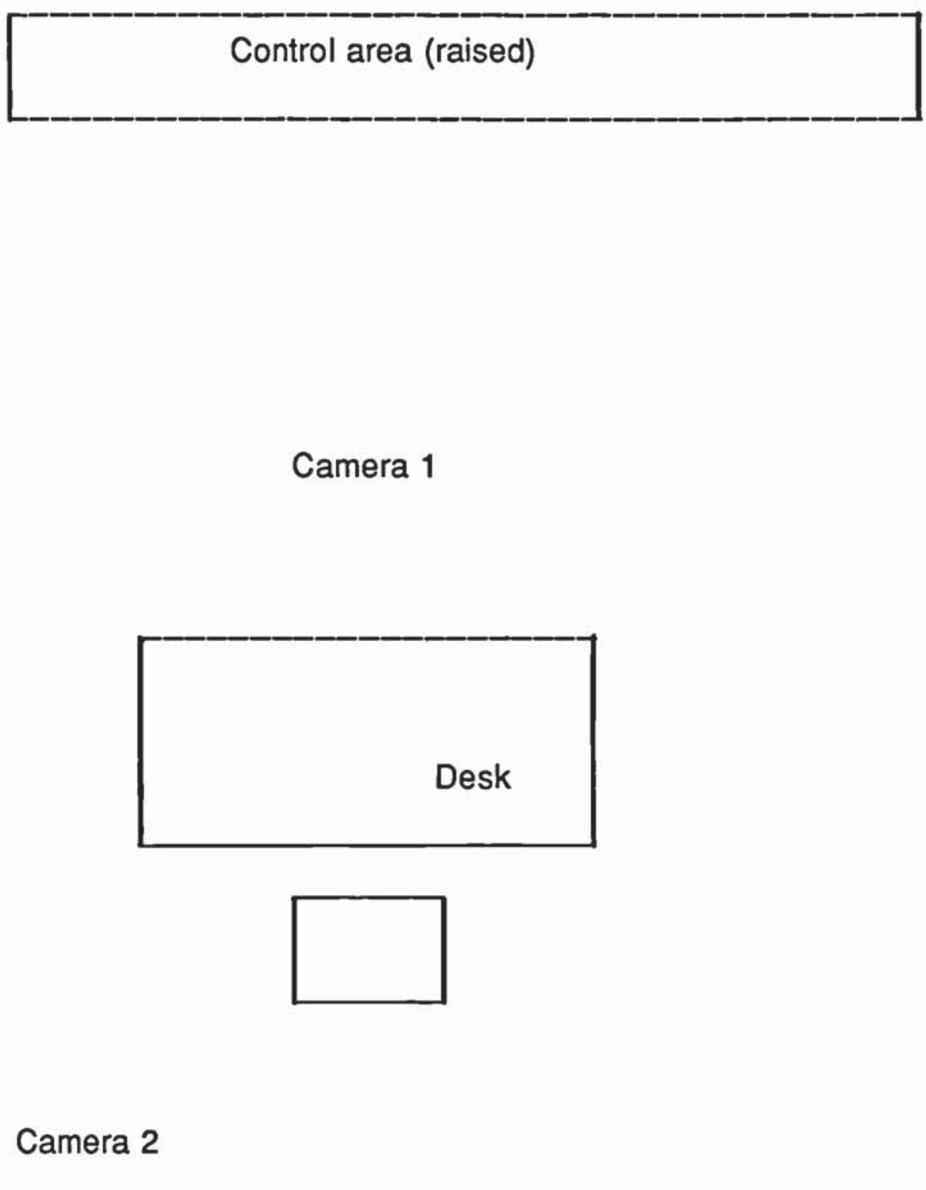

Figure 34 - The setting for the collection of data from expert designers

Stage 3 - Training

The principal aim of this part of the process was to provide warm-up exercises to relax the subjects and acquaint them with the television cameras, microphones and general setting for the task. The process of collecting data was described in detail and the need to talk aloud whilst working was also emphasised. Subjects were then given a practice problem in order to try out the process:

Problem 3

Small indicators are required to stand on the desks of a large office to display the name of the person working at that desk. Design a simple neat stand that would suit the purpose, occupy as little space as possible on the desk top but still be such that it cannot be knocked over easily. The letters forming the name are to be 20mm high.

Subjects were also given the following guidelines to help in the process:

The enclosed design problem can be solved without reference to external sources of information or materials. In other words, it is a self-contained problem which can be solved using existing experience and knowledge.

1 *Study the problem carefully*

2 *Attempt to solve the problem using the materials provided*

3 *Use the drawing paper to record the ideas which you develop (this may also enhance your graphic thinking)*

4 *Try to talk as you design/think. In other words, try to articulate or externalise what is going on inside your mind.*

5 *A video camera will record a general view of the process (including hand gestures etc.)*

6 *A second video camera will record the process of graphic thinking (drawing and modelling)*

Try to relax as much as possible. It is very important that you consciously attempt to externalise as far as possible the images generated in the 'mind's eye'.

During the warm-up exercise, the researcher interrupted the subjects to explain points and to encourage them to keep talking. The training session was not recorded on the video tape produced from the session with expert designers. With hindsight, this was perhaps a mistake as useful additional insights of the problem solving behaviour of the expert designers could have been obtained. The training session for novice designers was recorded on video tape.

Stage 4 - Data collection - main problem

The collection of data from the main problem followed the training session. Before starting, issues which had arisen during the training session were discussed.

Subject 1 (Pro 3) was asked to solve problem 1 (see Chapter 3). This was provided on a separate sheet of paper:

Problem 1

Choose an appropriate theme and design a board game which has an average play time on no more than twenty minutes. Test a series of *prototypes and record the result. If possible include designs for three dimensional playing pieces made from card, together with visually presented set of rules. make suggestions for packaging and advertising.*

GCSE - CDT (Kimbell et al)

Subjects were also reminded of the guidelines provided for the training programme.

During the process there were no interruptions from the researcher, even though a microphone linked the control room and studio. The reason for this related to the effect of interruptions on verbalisation. However, a number of long pauses were observed in the protocol of the subject. Consequently the procedure was evaluated before the collection of data from novice designers.

The session lasted approximately one hour and was recorded in total on a video tape.

Subject 2 (Pro 4) was asked to solve problem 2 (see Chapter 3). This was provided on a separate sheet:

Problem 2

Using a sheet of A4 card, design and make a book support which could be used for revision/study and can then be stored in an A4 folder.

The subject was reminded of the guidelines provided for the training programme.

During this process the subject was interrupted on one occasion. This occurred when it was clear that the subject had misinterpreted the nature of the task. The first part was therefore considered as an extension of the training programme. However, the effect of this interruption on the development of the protocol will need to be considered.

Stage 5 - Post-data collection meeting

Subjects were thanked for their efforts and offered the opportunity to view the video recording of their individual sessions. Both subjects expressed an interest in being informed of the findings of the research project.

Interim evaluation of the data collection process

Prior to the collection of data from novice designers, a number of changes to the process of data collection were made as a result of the evaluation of the first stage:

(i) the coding system was modified. This is outlined in Chapter 3 and discussed in detail in Chapter 5;

(ii) problem 1 was adopted for the main task and problem 3 was maintained for the training programme;

(iii) it was decided that a less formal environment should be used for the collection of data from novice designers;

(iv) it was decided that interruptions may be necessary in order to keep the novice designers talking during the task.

4.2 Collection of data from novice designers

Stage 1 - Pre-data collection meeting

A meeting took place prior to data collection between the researcher and the head of department of the school from which the selected sample came. The purpose of the project and the role of participants was discussed. The head of department was briefed on the information to give to the students. The researcher provided a letter to be sent to the parents of the selected sample.

The subjects were also met as a group immediately prior to the data collection. An attempt was made to generate a fun activity. Students were assured that the process was not part their assessment. Training and data collection took place on an individual basis.

Stage 2 - The setting

It was decided that the television studio would have been too intimidating for the novice designers. A more friendly environment was therefore selected (Figure 35) which related more closely to the teaching space which would be found in the school of the subjects However, care was taken to ensure that the room did not contain visual stimulus material which could aid the design problem solving process. A single television camera was used on this occasion and a microphone was attached to the camera. The television studio technician operated the camera. The researcher sat out of camera view, but in a position to interrupt the subject if this proved necessary.

The same range of materials were available as those provided for the expert designers.

The setting

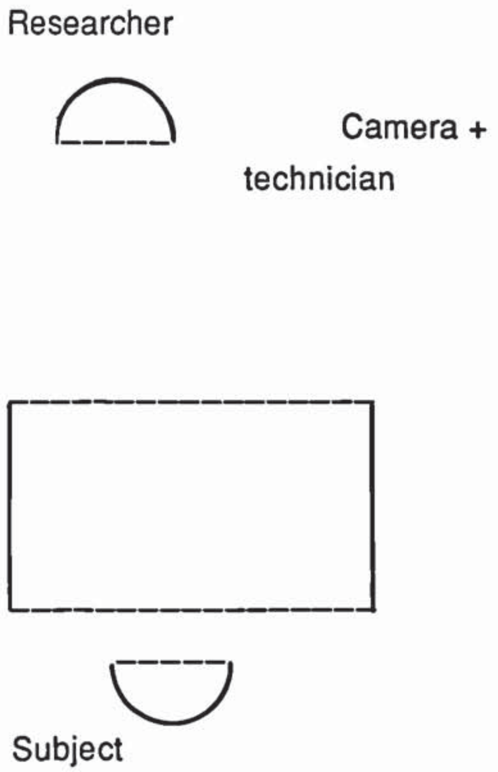

Figure 35 - The setting for the collection of data from novice designers

Stage 3 - Training

As with expert designers, the principal aim was to provide warm-up exercises which would relax the subjects and acquaint them with the television camera, microphone and general room setting. The process was explained in detail to each subject and the guidelines shown below were explained:

The enclosed design problem can be solved without reference to external sources of information or materials. In other words, it is a self-contained problem which can be solved using existing experience and knowledge.

1 *Study the problem carefully*

2 *Attempt to solve the problem using the materials provided*

3 *Use the drawing paper to record the ideas which you develop (this may also enhance your graphic thinking)*

4 *Try to talk as you design/think. In other words, try to articulate or externalise what is going on inside your mind.*

5 *A video camera will record a general view of the process (including hand gestures etc.)*

Try to relax as much as possible. It is very important that you consciously attempt to externalise as far as possible the images generated in the 'mind's eye'.

The subjects were given a practice problem in order to try out the process:

Problem 3

Small indicators are required to stand on the desks of a large office to display the name of the person working at that desk. Design a simple neat stand that would suit the purpose, occupy as little space as possible on the desk top but still be such that it cannot be knocked over easily. The letters forming the name are to be 20mm high.

During the warm-up exercise, the researcher interrupted the subjects to explain points and to encourage them to keep talking. The training session was recorded on the video tape produced from the session with novice designers.

Stage 4 - Actual data collection

The collection of data from the main problem followed the training session. Before starting, issues which had arisen during the training session were discussed. Subjects were also reminded of the guidelines provided for the training problem.

All three subjects were asked to solve problem 1 (see chapter 3). This was provided on a separate sheet of paper:

Problem 1

Choose an appropriate theme and design a board game which has an average play time on no more than twenty minutes. Test a series of prototypes and record the result. If possible include designs for three dimensional playing pieces made from card, together with visually presented set of rules. make suggestions for packaging and advertising.

GCSE - CDT (Kimbell et al)

During the process the researcher interrupted the subjects if the pauses were too long. The effect of interrupting is discussed later.

Then sessions lasted for approximately thirty minutes for each subject.

Stage 5 - Post-data collection meeting

Subjects were thanked for their efforts and offered the opportunity to view the the video of their individual sessions. Each subject was presented with a pack of graphic materials to thank them for participating.

Chapter 5 - Processing the data

5.0 Introduction

The purpose of this chapter is to describe the way in which the verbal protocols were processed after data collection. Three main stages can be identified in this process. That is to say, transcription, segmentation and the encoding of the segmented phrases. The mapping process, which allowed the protocols to be considered in parallel, is also described. The criteria upon which the the coding decisions were made will be found in Chapter 3.9 - 'Plan for processing the data'.

5.1 Transcription

This was an extremely labour intensive part of the process. The sound element of the video recording was transcribed by playing and replaying short extracts from the protocol. The transcript was recorded using pen and paper in continuous prose. The transcribed protocol was then transferred to a word processor. It was not practical to transcribe the protocol directly onto a word processor. Each thirty minute extract of the verbal protocols took approximately twelve hours to transcribe and word process.

As a result of the process, the text was in the form of the sample shown below:

Snakes and Ladders but three-dimensional. Make a game where everyone starts by rolling a dice and you have to get to a certain place by passing things like an adventure game, starting from 2 to 4 players. They all have an individual three-dimensional person on one big board and I'll number it from one to whatever you finish on, roll the dice until you land on a square where you have to do something or answer a question out of the box.

5.2 Segmenting

The second phase of the process involved segmenting or chunking the verbal protocols in preparation for encoding.

The protocols were therefore segmented using pauses, hesitation and syntactically complete phrases as cues for identifying instances of the general process. On occasions, it was found that single words could provide a basis for segmentation using the criteria described above:

5/49	*Snakes and Ladders but three-dimensional.*
5/50	*Make a game where everyone starts by rolling a dice*
5/51	*and you have to get to a certain place by passing things like an adventure game,*
5/52	*starting from 2 to 4 players.*
5/53	*They all have an individual three-dimensional person on one big board*
5/54	*and I'll number it from one to whatever you finish on,*
5/55	*roll the dice until you land on a square*
5/56	*where you have to do something or answer a question out of the box.*

Samples of the transcription were segmented by an independent person. A high degree of correlation was found between the the segmenting of the researcher and the independent segmenter. This seems to confirm the view of Ericsson and Simon that this process can usually be carried out to a high degree of reliability.

The novice designers produced much shorter protocols than the expert designers. This may be because of the lack of designing experience of the novices. It is also likely to relate to the age difference between expert and novice designers.

The total number of segments in each protocol were as follows:

Subject 1 (Pro 3), expert designer - 849

Subject 2 (Pro 4), expert designer - 802

Subject 3 (Pro 5), novice designer - 109

Subject 4 (Pro 6), novice designer - 83

Subject 5 (Pro 7), novice designer - 104

5.3 Encoding

The segmented transcriptions were encoded into the terminology of the theoretical model put forward in chapter 3. There were two main phases to the encoding process. The first involved the encoding of transcripts from expert designers. The second related to the encoding of transcripts from novice designers.

5.4 Phase 1 - expert designers

1 The segmented transcripts were encoded independently by the researcher and a second coder (the independent coder). The second coder had little knowledge of the research project and was not aware of the questions which underpin the project. However, the independent coder was an experienced teacher of design and technology and therefore had an understanding of design problem solving.

This coding system discussed in Chapter 3 (Figure 28) was used for this purpose:

A	Problem Restatement
B	Problem Elaboration/Refinement
C	Integration
D	Holistic Solution Development
E	Solution Elaboration/Testing
F	Inference
G	Information Search
H	Solution Validation

2 The encodings from the researcher and independent coder were compared by working through the transcript segment by segment. Differences were discussed and agreement reached about the coding category.

3 Some weeks later both the researcher and the independent coder recoded a random sample of segments in order to check bias. Differences were discussed and changes were made. However, the differences were very minor and it was felt that the overall reliability of the encoding had not been affected.

4 The evaluation of the encoding by the researcher and independent coder highlighted some practical problems in assigning codings to some of the segmented transcripts. The general framework seemed at this stage to provide a structure for analysing the behaviour of subjects as they solved design problems. However, category F - 'Inference' was felt to be too broad and not able to differentiate between 'inference' and 'assertion'. Consequently, the coding was split into two parts, F - 'Assertion' and F1 - 'Inference'.

Category G - 'Information search' also caused problems when the same piece of information was code as G throughout the protocol. It was therefore decided to redefine G - 'Information search' as "the initial application of technological or other forms of knowledge to help the development of subproblems. NB. subsequent use of this knowledge will be coded under category E".

The definition of category H - 'Solution validation' seemed to be too narrow. It was therefore defined as "Testing, justifying and revising of a solution to the problem".

The coding schedule was therefore revised as shown in Chapter 3 (Figure 29):

A	Problem Restatement
B	Problem Elaboration/Refinement
C	Integration
D	Holistic Solution Generation
E	Solution Elaboration/Testing
F	Assertions
F1	Inference
G	Information Search
H	Solution Validation

Evaluation of this coding system will be found within the case studies and also within the concluding chapter of this research.

5 The transcripts for expert designers were recoded using the system outlined above.

The process of encoding the transcripts for expert designers took many hours of work by both the researcher and independent encoder. However, it was felt that the process described above had improved reliability and validity and provided a firm basis for encoding the transcripts from novice designers.

5.5 Phase 2 - novice designers

1 The segmented transcripts were encoded independently by the researcher and the second coder (the independent coder) using the revised coding system outlined in section 5.4 above.

2 The encodings from the researcher and independent coder were compared by working through the transcript segment by segment. Differences were discussed and agreement reached about the coding category.

3 Some weeks later both the researcher and the independent coder recoded a random sample of segments in order to check bias. Differences were discussed and changes were made. However, the differences were again very minor and it was felt that the overall reliability of the encoding had not been affected.

An encoded transcript based upon the example used in this chapter is shown below:

5/49	Snakes and Ladders but three-dimensional.	D
5/50	Make a game where everyone starts by rolling a dice	E
5/51	and you have to get to a certain place by passing things like an adventure game,	E
5/52	starting from 2 to 4 players.	E
5/53	They all have an individual three-dimensional person on one big board	F
5/54	and I'll number it from one to whatever you finish on,	E
5/55	roll the dice until you land on a square	E
5/56	where you have to do something or answer a question out of the box.	E

5.6 The mapping process

A mapping process was used in order to look at the protocols in parallel. This provided a template or framework for the analysis which allowed key issues to be identified from the wealth of data embodied in the transcribed protocols. The coding schedule, which can be seen to represent a type of hypothesis for design problem solving behaviour, therefore provided a framework for analysis.

Each element of the schedule was analysed in turn and this provided a framework for discussion within the protocol. The design strategy was then discussed using the framework described in the research plan. This was followed by an analysis of the impact of drawing and modelling upon the process, which is also described in the research plan. Finally, general elements were considered to provide a summary at the end of each protocol.

Key issues raised in the protocols have been discussed in the concluding section. Differences identified between expert and novice designers have also been identified.

Chapter 6 - The Protocols

6.0 Introduction

Protocols have been developed for each of the five expert and novice designers. The purpose of the protocol is to describe behaviour of expert and novice designers as they solved design problems. At one level, this concerned providing descriptions and analysis of the process in order to inform the debate and body of knowledge related to design problem solving. Previous research existed for expert designers and the project provides an opportunity to add to that body of knowledge. However, little, if any, research of this type has been undertaken with novice designers. Therefore the first aim of the protocol is concerned with describing and analysing this process.

At a second level, the protocols provided an opportunity to compare the behaviour of expert and novice designers during the design problem solving process. This aim was to add to the body of knowledge in this area and also to provide a basis for discussing the teaching and learning strategies appropriate for novice designers. Recommendations for teaching strategies are provided in the concluding chapter.

A summary of the results for all subjects is produced on the next page (Table 1). These results provide an opportunity to compare the way expert and novice designers made use of the operators in the main problem. Detailed analysis of the results of individual subjects is provided in the protocols which follow.

The results relate to the number occasions the application of specific operators was identified in each protocol. The percentage of each operator against the total number of applications is also provided. The results are based upon the revised coding schedule provided in figure 35. Full transcripts of the segmented and coded protocols will be found in Appendices 1-5.

		Experts		Novices		
Operator		Pro 3	Pro 4	Pro 5	Pro 6	Pro 7
A	Problem restatement	30 (4.8%)	22 (3.4%)	0 (0%)	1 (2%)	0 (0%)
B	Problem elaboration/refinement	19 (2.9%)	5 (0.8%)	0 (0%)	3 (5%)	2 (3%)
C	Integration	14 (2.2%)	9 (1.4%)	7 (7%)	5 (8%)	0 (0%)
D	Holistic solution generation	4 (0.6%)	0 (0%)	5 (5%)	6 (10%)	7 (10%)
E	Solution elaboration/testing	312 (49.8%)	350 (54.8%)	43 (46%)	31 (53%)	32 (45%)
F	Assertions	81 (12.9%)	103 (16.1%)	10 (11%)	0 (0%)	1 (1%)
F1	Inference	87 (13.9%)	91 (14%)	14 (15%)	7 (12%)	9 (13%)
G	Information search	75 (12%)	48 (7.5%)	5 (5%)	4 (7%)	12 (17%)
H	Solution validation	5 (0.8%)	11 (1.7%)	10 (11%)	2 (3%)	4 (6%)

Table 1 - Summary of results (main problem)

6.1 Protocol 3

The protocol was analysed in three phases. First of all an analysis was conducted of the use of operators and heuristics to move through the search space. Secondly, the general design strategy was analysed, using the framework illustrated in chapter 3. Finally, discussion was generated around the drawings and sketches produced by the subject.General observations from the video material were used throughout the protocol to help develop and inform the analysis.

The aim was to provide a picture of problem solving behaviour from three different perspectives. At the end of the protocol, key issues have been summarised. Discussion of the implications of the findings in terms of teaching and learning strategies appropriate to the subject has also been generated. Questions which have arisen during the development of the protocol have been highlighted and used to inform the conclusions and recommendations made in the final chapter.

A similar format has been used in all of the protocols. However, the first section on initial thoughts has highlighted issues which are particular to this protocol and which therefore may not be common to all subjects.

The subject for Protocol 3 was a final year undergraduate student taking a degree in design and technology. At the time of data collection, it was anticipated that the subject would obtain a first-class honours degree. This was subsequently confirmed at the end of the course. Within the context of this research project, the subject was considered as an expert designer, although it was recognised that the subject did not fall into the category of practising professional designer. Nevertheless, it was felt that this offered interesting opportunities to compare findings with previous research into expert designers and the research with novice designers undertaken in this project. The full transcription of the protocol for subject 1 is provided in Appendix 1.

Results of transcription, segmenting and encoding

The first coding of the operators is shown below:

Operator/plan		1st Coding
A	Problem restatement	30 (4.8%)
B	Problem elaboration/refinement	19 (2.9%)
C	Integration	14 (2.2%)
D	Holistic solution generation	4 (0.6%)
E	Solution elaboration/testing	312 (49.8%)
F	Inference	168 (26.8%)
G	Information search	75 (12%)
H	Solution validation	5 (0.8%)
TOTAL		626

Table 2 - Protocol 3 results of first coding

The analysis of the protocol indicated that 75% of the time was spent in the 'E' and 'F' categories. In other words, the subject predominantly used solution elaboration and testing to move through the search space. Supporting perhaps the view that the subject worked in a very logical and linear way and decomposed the overall problem into sub-problems before systematically analysing the sub elements. The subject also used category 'G' , information search, for 12% of the time.

However, these classifications were produced under the original coding system. This coding was subsequently refined after the initial analysis of protocols 3 and 4. The new coding showed 'F' divided into 'F' - Assertion and 'F1' - Inference. Statements coded under 'G' - Information Search were recoded as 'E' on the second and subsequent use.

This recoding has changed the results in the following way:

Operator/plan		Recoding
A	Problem restatement	30 (4.8%)
B	Problem elaboration/refinement	19 (2.9%)
C	Integration	14 (2.2%)
D	Holistic solution generation	4 (0.6%)
E	Solution elaboration/testing	312 (49.8%)
F	Assertions	81 (12.9%)
F1	Inference	87 (13.9%)
G	Information search	75 (12%)
H	Solution validation	5 (0.8%)
TOTAL		626

Table 3 - Protocol 3 results from recoding

'A' Problem Restatement +'B' Problem Elaboration/Refinement

These two operators will be considered together as they are closely interrelated. Operator 'A' relates to:

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

Operator 'B' is concerned with:

A statement which extends and interprets information provided in the problem statement.

During the whole protocol, the subject referred back to the problem statement as a means of moving through the search space on a number of occasions. For example, the subject used operator 'A' Problem restatement on 30 occasions (4.8%) and operator 'B' Problem elaboration/refinement on 19 occasions (2.9%) to move through the search space. This represented 7.7% of the total protocol.

Both operators were used extensively in the first part of the protocol. Perhaps this indicated that the subject needed to spend some time understanding the problem rather than jumping straight into finding solutions. This could possibly be labelled as cautious and seemed to point towards a problem-focused rather than solution-focused approach.

Analysis of the video recording further illustrated the use of problem restatement in the early part of the protocol. The subject appeared to be highlighting essential words and phrases from the problem statement in order to understand the nature of the task. Initial thoughts were recorded in a written form.

It was therefore possible to identify the use of these operators at key points throughout the protocol. Examples will be found at segments:

3/123-3/124
3/139-3/140
3/211-3/212
3/225
3/343
3/461-3/463
3/500-3/504
3/577
3/657-3/658
3/783
3/812

The example from 3/461 is shown below:

3/461	at packaging and advertising
3/462	Pause (6 seconds)
3/463	Um
3/464	Packaging and advertising
3/465	Well what have we got we've got um
3/466	advertising

Sub-problems were identified in a number of places and these were usually explored in a small loop. The subject then tended to move back into the main problem by using category 'A' - Problem Restatement:

3/35 - 3/46	*exploration of sub problems*
3/47	Choose an appropriate theme
3/48	and design a board game so

In other words, operators 'A' and 'B' were not only used to provide a reference point during the process, but also as a means of changing direction when a sub-element became exhausted.

This discussion of the problem statement at regular intervals during the process seemed to provide some sort of reference point which was used to keep the process focused. This referal-back model can be seen as a continuous loop which provided a means of moving through the search space at key intervals:

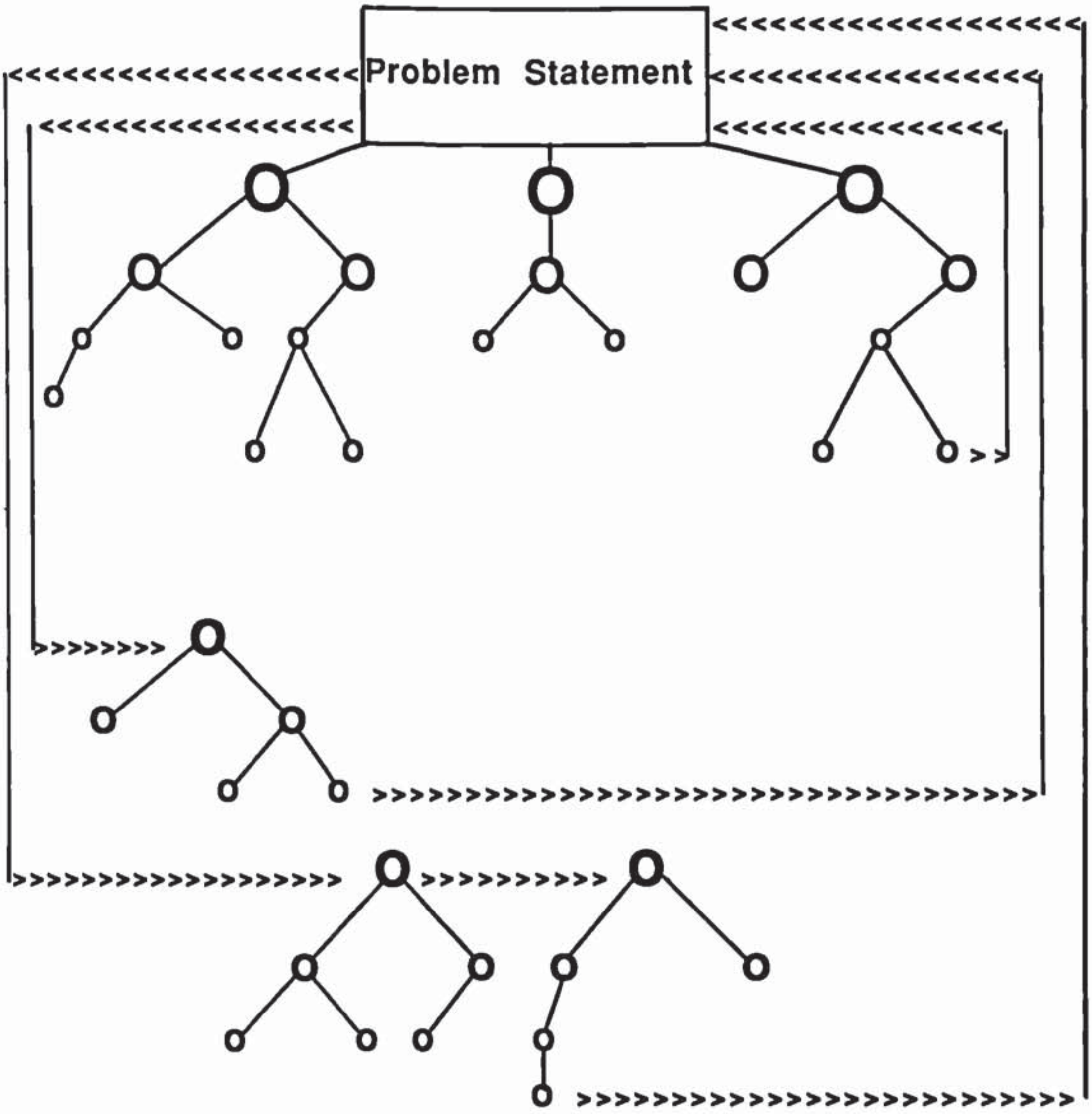

Figure 36 - Referral-back model

This referral to the problem statement also seemed to act as a prop during periods of inactivity. It seemed to provide a means of keeping movement through the search space. Is this a valid strategy for others? Does it illustrate the importance of generating a clear specification at the outset?

At 3/657 there was a sudden move to a separate sub-problem which seemed to be unrelated to the previous analysis:

3/657 Packaging
3/658 Could be packaged separately

This was followed by a rapid move back to the analysis started in the previous sections. Was the subject again using the problem statement as a reference point in order to cross check progress through the search space?

Holistic solution (intuitive leap) >>>>>>>>> fluent Analysis >>>>>>>> detour >>>>>>>>>> fluent analysis

At 3/740 the subject moved back to the summary related to packaging. This indicated that the problem statement was still very much in mind. However, this seemed to be implicit now rather than explicit as earlier. This fluent section continued until 3/766.

'C' - Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems.

The use of this operator was identified on 14 occasions (2.2%). It seemed to be used at key stages within the protocol:

3/56, 3/119, 3/162, 3/190, 3/335, 3/485, 3/510, 3/540, 3/613, 3/666, 3/736, 3/766.

The sequence from 3/107 to 3/119 illustrated an exploration of sub problems which was integrated into a new partial solution at 3/119:

3/107	We could have some sort of
3/109	reward built into the game
3/110	You know like um flashing lights
3/111	Oh no perhaps that's a bit inane
3/112	We'll stick to um
3/114	No we'll leave out
3/115	that type of thing
3/117	No the reward could simply be
3/118	the complete satisfaction of completion
3/119	of actually doing it

Similar sequences to this were observed at the points in the protocol highlighted above. However, it was not always easy to identify a single element to code as 'C'. The process of integration seemed, in this protocol, to be more identifiable in groups of operators. This may suggest that the subject did not always follow a logical-linear process which resulted in systematic analysis followed by various elements being integrated together.This issue is also discussed in the final evaluation of methodology.

'D' - Holistic Solution Generation

The generation of solutions to the problem from an undetermined or apparent intuitive source.

The generation of holistic solutions to the problem, 'D', was observed on four occasions (0.6%) within the protocol. This perhaps illustrated that the subject worked in a systematic and linear way in breaking down the problem into sub-parts before arriving at a possible solution. However, these four uses of holistic solution generation may indicate that the generation of solutions from an undetermined and apparent intuitive source may have been significant in providing a context for systematic search at key stages within the process. They seemed to play a key role in the problem solving process by providing a renewed energy and creative insight into the problem. Nevertheless, the protocol suggested that the subject primarily used systematic search strategies to move through the problem space.

A number of questions were raised during the analysis of this aspect. Where do these holistic solutions come from? Are they really intuitive, or are they based upon past experience? Or are they gradually generated as the subject analyses sub-elements in detail. In other words, was the subject simultaneously working in a systematic linear way and also in an holistic way? Did the subject appear to be working in a parallel fashion in places? For example was he simultaneously working on two different solutions to the problem?

A pattern which seemed to emerge from the protocol is that of a detailed analysis of sub problems, sometimes jumping from one to another, and then returning to the overall problem statement. However, at key stages through the process, the subject appeared to generate holistic solutions from apparent intuitive or undetermined sources.

At 3/577 the subject seemed to make a big effort to move the process forward. This was achieved by drawing together a number of issues previously discussed and generating from this a single entity. Perhaps this could be described as the systematic generation of an holistic solution:

3/577	3D playing pieces
3/578	So if we had um
3/579	Going back to this er
3/580	this thing of tactile
3/581	If we go back to this board here
3/582	and we had them in order of

3/583 squidginess say

Collectively, these segments could have been categorised as 'C' - Integration, which as stated previously, is difficult to assign to individual segments. At 3/609 another holistic solution is generated:

3/609 Instead of being a board
3/610 it could actually be a sphere

Was this an example of an intuitive jump from an unknown source, or did it result from the previous systematic analysis? In other words, was there evidence that the subject had gradually worked towards this new solution?

'E' - Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions

The use of this operator was identified on 312 occasions (49.8%) within the protocol. This was the major operator identified and seemed to suggest that the subject was demonstrating an ability to systematically explore a problem. An example of this systematic search was seen between 3/35-3/46, where a systematic analysis appeared to take place around a range of sub-problems:

3/35 I've got colour shapes
3/36 textures, tones
3/37 Pause (4 seconds)
3/38 How about black to grey
3/39 with um
3/40 from it and it and shades
3/41 black to grey to white
3/42 Pause (4 seconds)

3/43 Textures
3/44 We've got rough, smooth, glossy, matt
3/45 etc.
3/46 Colours

The diagram below illustrates a sub problem gradually being explored in a systematic way through a series of sub issues:

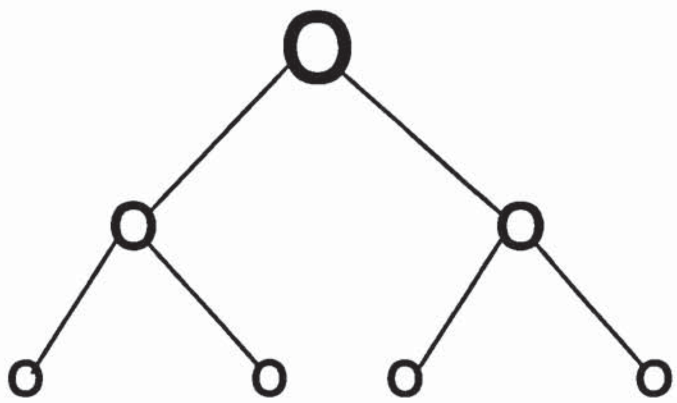

Figure 37 - A systematic exploration

This pattern links well with conventional models of design problem solving which are implicit in many teaching programmes. For example, the pattern illustrated above seems to fit into the analysis > synthesis > evaluation model of designing discussed by Akin (1979). This issue is considered at a later stage within the protocol.

The analysis was mainly in a written form at this stage. It was interesting to note that the subject used two sheets of paper at this early stage, one to write and the other to draw. It will be interesting to compare this approach with the pre-sketching and sketching strategies discussed be Akin (1979). The use of drawing within the process is discussed in the third section of this protocol.

The general analysis of sub problems related to the overall problem could also be seen between 3/58 and 3/81. This seemed to show the subject using the overall context to identify smaller parts for analysis. Operator 'E' was used extensively throughout this phase. It was interesting to note that the sequence was started through the application of operator 'A' - Problem restatement. The interaction of operators 'E', 'F' and 'F1' could also be observed in this sequence:

3/64	the target group for the game
3/67	because that will determine the um
3/68	that will determine the intellectual
3/69	scope for the game

A further example of the interaction of operators 'E', 'F' and 'F1' could be seen between 3/466 and 3/474:

3/466	advertising
3/467	well for a start there's no
3/469	This sort of toy could be for um
3/470	To go out to this target group
3/471	Could be blind
3/472	Could be blind but
3/473	it could also be just sighted

This sequence continued to 3/488 and the overall content is shown below. This longer sequence contained a number of the cycles identified above, in which 'F' tended to precede 'E', with operator 'F1' concluding the cycle:

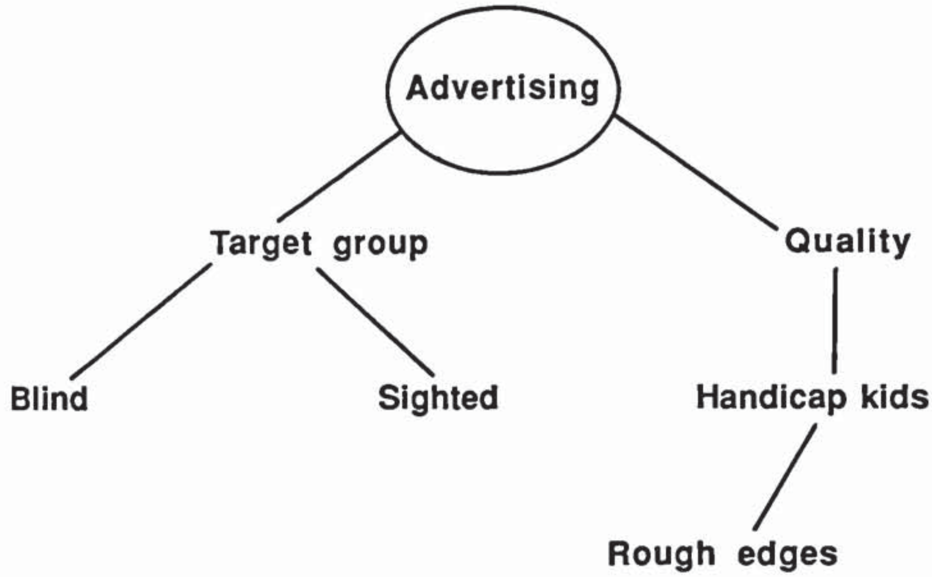

Figure 38 - A cycle based upon assertion, exploration and inference

'F' - Assertions

Assertions from the generation of new information from internal sources.

The use of operator 'F' could be identified on 81 occasions (12.9%) within the protocol. As illustrated above, it seemed to be an important element in starting a cycle of exploration within the protocol:

3/38	How about black to grey
3/137	Things that are useful to know
3/205	Tones can be made up like this
3/265	The child's got to know when it's right
3/379	May be it could just be one item

On occasions, dual coding became a problem. This particularly occurred when either operator 'G' - Information search or operator 'F' - Assertion could have been used to code the transcribed segment. However, the overall nature of the exploratory cycles were still clearly identifiable in spite of these encoding problems.

'F1' - Inference

Higher order conclusions, propositions or justifications not given in the problem statement but generated by the problem solver.

Operator 'F1' was observed on 87 occasions (13.9%) within the protocol. As discussed above, the operator seemed to be an important element in developing exploratory cycles within the protocol.

The section 3/297-3/316 demonstrated an interesting cycle of exploration. A need seemed to be established at 3/297:

3/297 they've got to feel things

This is followed by inference at 3/313:

3/311-3/313 Ah but they'd be able to feel the pegs anyway wouldn't they

The operators applied to the segments between these sections were mainly 'E' and 'G'.

This identification of a sub-need followed by the inference drawn from it, seemed to provide the means for further analysing this part of the problem. This analysis started at 3/301 and continued through to 3/336:

3/301 if they're feeling
3/302 There's cubes
3/303 cubes round
3/304 cubes sharp edges
3/305 spheres......................

In other words, to move through the search space the subject had identified that there was a need to feel the pieces. From this it was inferred that there was a need to look at the shape of the pieces. A detailed analysis of this element then took place. The subject seemed to be generating a series of ideas and then manipulating them to develop a new idea and hence satisfy the need.

This process can be described in the following way:

Problem >>>>>> Sub problem (3/297) >>>>>>> Inference (3/298) >>>>>>>> Analysis (3/301-3/336) >>>>>>>> Restatement (3/343)

'G' - Information Search

The initial application of technological or other forms of knowledge to help the development of sub-solutions. N.B. subsequent use of this knowledge will be coded under category 'E'.

The use of this operator was identified on 75 occasions (12%) within the protocol. This illustrated that the subject had a broad technological base which could be utilised within the problem solving process.

An example of the use of Design and Technology knowledge to move through the search space could be seen in the vocabulary used at 3/86-3/87:

3/86	colour, primary colour
3/87	secondary colours, tertiary colours

Further examples could be seen at key stages within the protocol. This seemed to provide some evidence that this operator helped the subject through the search space.

The subject used a complex interaction of strategies, rules, types and operators to move through the search space. Whilst it was clear that the overall strategy suggested a continuous, systematic, linear problem solver who uses the specification for the problem as a means of continually reflecting upon progress, it was also clear that a range of forms of knowledge were used within this complex process. Schon (1988) describes these as 'types' which serve as holding environments for design knowledge. He suggests that rules are derived from these underlying types.

Within this protocol, it was possible to identify a number of knowledge types which are used by the subject to move through the search space. One key form of knowledge seems to derive from the vocabulary of mental images which come from past experience. These seemed to be snapshots of the man-made world which the designer used to inform and develop design decisions. For example, in protocol 3 this can be seen at:

3/18	I've got portable
3/19	cars

The subject also showed that knowledge of language can sometimes help the journey through the search space:

3/50	if it's portable
3/51	it's got to be
3/52	fairly small
3/53	compact better word

The knowledge related to the subjects perception and interpretation of the problem also seemed to be an important aspect of the process. Schon (1988) refers to this as spatial gestalt which provides the figures upon which the designer reasons. It is clear within this study that this perception of the problem statement varies from subject to subject.

Technological knowledge is an important dimension of the problem solving process. The subject within Protocol 3 showed evidence of a sound technological knowledge and vocabulary which helped in the development of solutions to the problem. This could be seen in many places within the protocol, for example:

3/35	I've got colours, shapes
3/36	textures, tone

Knowledge and understanding of the psychological aspects of designing required to satisfy human needs could be identified in a number of places within Protocol 3. This was really suggesting that knowledge of human behaviour was being used in the process. Examples of this can be seen at:

3/92	We need some reward
3/103	What's satisfaction
3/118	the complete satisfaction of completion

It is clear from protocol 3 that the subject had developed knowledge of design aspects or requirements which are regarded as being central to the process of designing. For example, these may relate to identifying sub-problems/issues such as function, aesthetics, materials and so on, which many designers use as a framework, either implicitly or explicitly, at some some stages of the problem solving process.

The use of conceptual knowledge could also be identified within protocol 3:

3/158	looking at three dimensional
3/159	three dimensional series

From 3/671 the subject seemed to be using technological knowledge to help in the analysis. Knowledge of the properties of various materials was implicit in this section:

3/671	well impossible to model in card
3/672	Need to be modelled in er
3/673	Would need to be modelled in foam

3/674	or or may be in
3/675	in timber

'H' - Solution Validation

Testing, justifying and revising of a solution to the problem.

The use of this operator was identified on 5 occasions (0.8%) of the protocol.

It was clear from part of the protocol that 'H'- Solution Validation was difficult to pick out through a single operator. It was more apparent through a larger section of the protocol. For example, in the sequence 3/440- 3/446, although operators 'E' and 'F' have been assigned, it seemed that the whole sequence suggested solution validation against the problem statement:

3/440	It's hardly a board game though is it
3/444	Almost inclined to just
3/445	disregard this
3/446	board game business

Does this suggest that the categories are inadequate in this situation? Should the focus be on the sequence rather than individual operators? Is the sequence a form of heuristic? This issue of dual coding is considered in the final section.

This issue was highlighted when the subject developed an analysis of sub problems between 3/379 and 3/378.This analysis was followed by a brief use of category 'H' - Solution validation which was coded as 'F' and 'E' on the first coding and was recoded as 'H'.

3/389	That's not quite
3/390	a board game is it

The sequence from 3/677 provided a summary of the thought processes where the subject was drawing together ideas, or elements of ideas, from previous analyses. In other words, solution validation was taking place. However, it was not coded under 'H' and further illustrated the need to look at groups of operators in order to understand the thought processes more fully. Perhaps this phase could also be described as a move towards solution validation.

General Issues

A number of general issues which did not fit directly under any of the operator descriptions could be identified within the protocol.

The subject appeared to use analogical thinking as a means of moving through the search space in places:

3/162 A bit like a rubic cube thing

Gick and Holyoak (1985) suggest a strategy based upon analogical thinking for solving ill-structured problems. It may be possible to devise similar approaches within school design programmes. Examples of this approach can be seen in some literature on design methodology. For example, Cross and Roy (1975) suggest that analogies can be used as a means of enlarging the search space. This issue is considered in more detail in the concluding section

Sometimes the subject kept talking, but nothing seemed to be happening. For example, the stage between 3/337 and 3/342 had a number of long pauses:

3/337 Pause (13 seconds)

3/338	Pause
3/339	Pause (5 seconds)
3/340	I'm stuck
3/341	Stuck
3/342	Pause (12 seconds)
3/343	Design a board
3/344	Pause (16 seconds)

What was happening at this stage? Was the subject genuinely stuck? Was his mind empty of thoughts? Was he discounting ideas he had already discussed? What strategies could be used to help him create new ideas?

In section 3/400-3/403 the subject repeated the same phrase which seemed to eventually allow the extension of thought patterns:

3/400	A series of
3/401	Pause (4 seconds)
3/402	A series of
3/403	A series of balls

Fluency was apparent in this section and there were few pauses. It was almost as if the mental block had been removed and issues suddenly slotted into place. However, this was again followed by a long pause:

3/421	Pause (15 seconds)

Does the subject need a recovery time? What is happening during this phase?

At 3/448 the subject seemed to be forcing himself to keep thinking. What was happening here? Was he clutching at straws? Would he operate in this way if he was not in a research situation?

The subject appeared to undertake another period of general reflection between 3/493 and 3/499. This 'holding' period seemed to provide the space needed to regenerate thoughts. Indeed it continued, with some long pauses and short periods analysis through to 3/577.

In this phase the subject seemed to be forcing himself to move out of a mental block by making himself focus upon another sub-problem. Was the pressure of the task getting to him at this stage? Did he need a consolidation or thinking phase at this time? Do we sometimes force school pupils to solve problems in a timed situation? Could this, for some pupils, be against their natural thinking style?

It was interesting to note that at 3/769 the process of designing under such conditions was challenged:

3/770	Whooshed through this thing
3/771	There's no um
3/772	time for reflection

Heuristics

A number of rules of thumb or general plans of action could be identified within the protocol. The subject appeared, at first glance, to be a very systematic problem solver who took a linear route through the problem space. He also appeared to be very cautious and not able to take creative leaps during the design problem solving process. These initial thoughts suggested that the subject would mainly use means-ends-analysis and hypothesize-and-test, with perhaps little use of hill climbing.

In the early stages the subject used the problem statement as a means of applying an hypothesize-and-test strategy. For example, between 3/7 and 3/11 the subject used an element from the problem statement to develop an hypothesis:

3/7 if possible include designs
3/8 from 3D playing pieces
3/9 Include designs from 3D playing pieces
3/10 So we're going to be picking it up
3/11 in hands maybe

Means-ends-analysis could be identified at an early stage within the protocol. Again the problem statement was used as a starting point for the heuristic:

3/16 Design a board game so
3/17 look up board games
3/18 I've got portable
3/19 cars
3/21 It's got to be in a case
3/22 put it in an envelope

This process could be seen as the generation of a series of sub solutions to be 'popped' at a later stage or to be rejected.

The section of the protocol between 3/273 and 3/284 also provided an interesting example of means-ends-analysis:

3/273 We could have a series of slots
3/274 or pegs
3/275 So we could have for instance
3/276 we could have four little pegs
3/277 on this one
3/278 on that one there
3/279 and then we could have
3/280 four little pegs here
3/281 three there

3/282 and so on and so forth

3/283 three there

3/284 on that one

The sections starting at 3/403 and 3/848 also provided examples of the use of means-ens-analysis to move the subject through the search space. Perhaps indicating that this was the major heuristic used by the subject

A number of questions arise from this aspect of the protocol. In design problem solving does the subject need to decompose into sub-problems or focus upon selected constraints because of the complexity of the problem space (or does this just occur with 'expert' designers?) Are sub-problems solved and then 'held' for integration at a later stage? How can this be described? Systematic means-ends-analysis?

The diagram below shows the strategy of means-ends-analysis with the outcome of the process being either accepted or rejected by the designer:

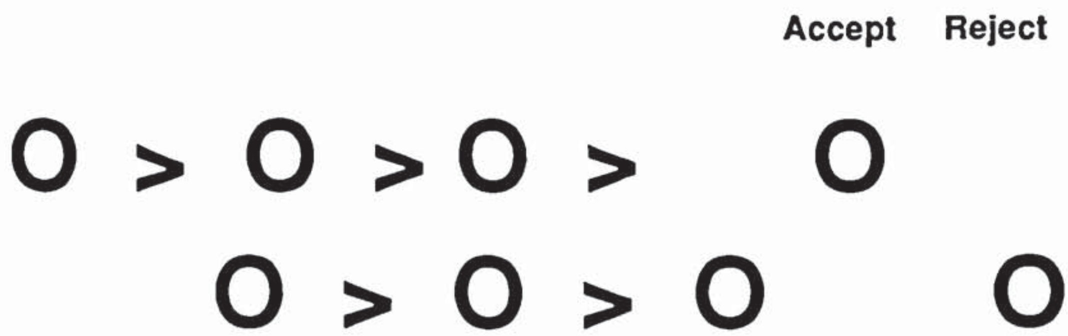

Figure 39- Acceptance and rejection within means-ends-analysis

Is this the pattern used by a systematic thinker? Does an 'expert' designer impose this structure? Does the final solution combine all/most of the elements of the sub solutions? In other words, does the solution integrate the accepted elements?

Does the problem solving process with this subject comprise a series of means-ends-analyses which result in acceptance or rejection of the sub problem? The accepted elements gradually become integrated into the overall solution. On some occasions the acceptance (pop!) is used as a basis for continuing the solution of sub-problems. That is to say, the subsequent analysis is directly related to the previous sub-solution. On other occasions, the acceptance is held in store and a new sub-solution is generated which is not directly related to the previous one. Rejections may result in the analysis continuing within the same theme. However, rejection may result in a move to an unrelated sub-problem.

An example of this sequence is shown below in which the subject used means-ends-analysis to explore sub-problems, some of which are rejected with others being accepted:

3/85 - 3/86 - 3/87 - 3/88 - 3/89

3/90 (Accept)

New unrelated sub problem:

3/92 - 3/94 - 3/95 >>

>> 3/107 - 3/109 - 3/110 -

3/111(Reject)

Figure 40 - The use of means-ends-analysis in Protocol 3

Means-ends-analysis could also be identified at 3/403-3/420.

A sub problem was identified at 3/403 > 3/404(push) > 3/405(push) > 3/406(push) >>> 3/420 (pop!)

A sub-problem/subsolution was identified and the subject went through a series of operations in which the present state was compared with a new state that could result in moving closer to the goal state.

Pattern matching, which was perhaps triggered by analogical thinking, could be identified at 3/162:

3/158	looking at three dimensional
3/159	three dimensional series
3/160	of three dimensional boards
3/162	A bit like a rubic cube thing

Information seemed to be organised into patterns which once formed no longer have to be analysed. The information was enough to trigger a new pattern. For example, "a bit like a rubic cube thing." The pattern matching strategy eventually triggers analogical thinking.

The only example of hill-climbing appeared to be at the very end of the protocol when the subject had run out of ideas and was desperately trying to keep talking:

3/848	I wonder if these things would float as well
3/849	Play in the bath

Overall it can be seen that means-ends-analysis was the principal heuristic used by the subject.

Research method 2 - Design Strategy

The subject seemed to be very much a convergent, serialist thinker. Systematic search patterns were apparent in many parts of the protocol. Information was processed in phases of the protocol before moving towards a single solution. It seemed clear that the subject was preceding by small steps and was trying to get clarification of each point before moving on to the next. The path was fairly straight although there are times when the subject deviated from this linear approach. The information in the problem statement seemed to provide a reference point during the process. It suggested that the subject needed a very clear specification before proceeding. If this was not given in the problem statement, then the subject developed his own framework and constraints for solving the problem.

In describing behaviour in terms of the key words put forward by Kimbell et al (1991), the following appear to be applicable to this subject:

Safe - the subject seemed to work within a tight system with few examples of hill climbing. That is to say, the subject did not often deviate from a linear approach to the problem.

Fluent - sub-sections of the protocol illustrated fluent and coherent design strategies. However, they also seemed to be mechanical in places with the application of procedures which had perhaps been learned by rote.

Predictable - the process tended to be predictable in places in terms of the subject following a conventional analysis of the problem using the constraints embodied in the problem statement as a framework.

Determined - even though the subject experienced mental blocks in places, a determined effort was made to keep the process moving. At times this required referral to the problem statement.

Methodical - there was evidence within the protocol of a methodical movement through the search space as the subject carefully moved from constraint to constraint.

Thoughtful - it was clear that the subject had given a great deal of thought to the design problem solving activity. The subject appeared keen to resolve the problem in a satisfactory manner.

A balance between reflective and active ability could be identified throughout the protocol. The subject moved consistently between thinking around the task and acting to develop proposals based upon this thinking. Active ability manifested itself in terms of drawings rather than models. The quality of appraisal was apparent at many stages within the protocol.

In terms of the model of expert designers put forward by Krampen (1983), the subject appeared to work in a similar way. However, the analysis and exploration was very detailed as the subject moved between general holistic solution concepts:

Definition of problem
Analysis of sub-elements
Generation of sub-solutions >> solution concepts
Reference to problem statement
Analysis of sub-elements
Generation of sub-solutions >> solution concepts
Reference to problem statement
Analysis of sub-elements
Generation of sub-solutions >> solution concepts

Reference to problem statement
Solution validation

From the description above it can be seen that the subject was working very much in the way suggested by the traditional analysis-synthesis-evaluation model. Synthesis did not usually occur until after a thorough analysis of the problem. At times, this analysis may have continued for too long with the subject unable to direct this activity to the generation of holistic solution ideas.

In terms of the problem-focused and solution-focused strategies identified by Lawson (1979), the subject worked very much in the way of the former. The problem statement was an essential element of within the design task, with the subject making frequent reference to the constraints embodied within this statement. At times the subject appeared to be bogged down in problem detail and unable to move towards a solution-focused strategy.

The subject did not appear to impose a primary generator at an early stage within the problem and consequently the level of satisficing was not always sufficient to to help the subject move towards the generation of solution concepts.

Research approach 3 - Drawing and modelling

1 The use of drawing to support thinking

The subject demonstrated good drawing ability which seemed to enhance design thinking. It was clear from the video recording that in places the subject was talking whilst drawing. In other places, the drawing seemed to be retrospective, or summarising thinking which had already taken place. The use of drawing to try out ideas was also evident in some places.

It was clear therefore that a number of models of the role of drawing within the design process could be identified. The subject used drawing as a means of aiding thinking and also to retrospectively record design thoughts:

Images >>>>>>>>>> Drawings >>>>>>>>>>>> Generation of new Images >>>>>>>>>>>>>> Drawings

At the beginning of the protocol the subject was both writing and drawing, with a greater emphasis on drawing in the initial stages. A very systematic approach was demonstrated which illustrated the sequence of thoughts and decisions. All sheets comprised approximately 50% drawing and 50% writing.

The subject made genuine use of drawing to aid thinking. This begs the question of how this skill can be taught. Laseau (1980) puts forward a number of suggestions for developing graphic thinking. This early drawing was used productively to develop first thoughts and allowed for the rapid exploration of a number of ideas. The drawing could be described as free-ranging but controlled at this stage.

In places, particularly towards the end, there was evidence of drawing for synthesis. However, the drawings were detailed throughout the process.

2 The style and nature of the drawing

The drawing was detailed and complex in places with full discussion of how the design would work. Discussion was also related to the way the design would be used and made.

A clear drawing style was apparent in which the issues and proposals could be clearly identified. The drawings helped to clarify the designers intentions.

The subject demonstrated confidence in communication with a bold and strong drawing style used. Freehand drawing was used throughout the process. The interaction between words and pictures also continued throughout the process. The subject was continually switching between 2D and 3D drawing techniques and words.

3 The use of modelling to support thinking

The subject did not use modelling for either analysing first ideas or for synthesis. This may have been because of the complexity of the design task which ensured that the subject did not move beyond initial exploration. However, modelling materials had been provided for subjects to use during this phase if required.

Conclusions

A number of issues arose from the protocol which perhaps need to be highlighted for discussion in the final section.

Issue 1

The subject made significant use of operators 'A' - Problem restatement and operator 'B' - Problem elaboration/refinement throughout the process. The subject seemed to need to understand the constraints embodied in the problem statement before starting to work towards a solution. The problem statement provided a reference point focusing or keeping momentum at key points within the protocol. The application of this operator was also used as a means of changing direction. Comparison has been made with the way expert and novice designers undertake this aspect of design problem solving. The teaching strategies required to develop this aspect of problem solving have also been considered in the concluding section.

Issue 2

The subject made little use of operator 'D' - Holistic solution generation. This seemed to be because the subject was preoccupied with systematically exploring elements of the problem and consequently appeared to find it difficult to generate holistic solutions. Teaching strategies to widen the search space and generate a larger number of holistic solution concepts have been considered in the concluding section.

Issue 3

Operators 'E', 'F' and 'F1' could be identified for approximately 75% of the protocol. This seemed to provide further evidence of the systematic analysis undertaken by the subject. At times, these operators were used in a cycle of F >> E >> F1. This suggested that operator 'F' - Assertion was used to start the cycle, with operator 'E' - Solution elaboration/testing being used to explore sub-elements. Operator 'F1' - Inference was used to conclude the cycle. The differences between novice and expert designers have been considered in terms of these cycles. Teaching strategies to promote the development of this aspect of design problem solving have also been considered.

Issue 4

The application of operator 'G' - Information search suggested that the subject had a broad technological knowledge base upon which to draw during the design problem solving process. Comparison has been made with other expert and novice designers. Consideration has also been given to the teaching strategies necessary to promote the development of the knowledge necessary to support design thinking.

Issue 5

Operator 'H' - Solution validation was difficult to identify within the protocol. This may have been because of methodological problems. It may also be related to the more explicit use of operators 'A' and 'B' which perhaps could have been coded as 'H' towards the end of the protocol. The way in which this operator was used has been compared with other expert and novice designers. Teaching strategies to promote its use have also been considered.

Issue 6

Long pauses were apparent in parts of the protocol. It is not clear whether the subject was genuinely stuck at these points or was imposing them in order to provide a period of consolidation. Comparisons have been made with other expert and novice designers. Methods for encouraging verbalisation during this period have also been considered.

Issue 7

The subject worked in a very systematic and linear way and conducted a very thorough analysis of sub-elements of the problem. This aspect has been used to compare expert and novice designers. Strategies to promote deviation from this linear approach have also been considered.

Issue 8

It appeared from the video and drawings produced during the collection of data that the subject used drawing to aid thinking. The subject appeared to use drawings and words in order to conduct a conversation with himself. This aspect has been compared with other expert and novice designers and teaching strategies have been suggested to promote the skill of 'thinking through drawing'.

Issue 9

The subject used mainly systematic heuristics such as means-ends-analysis and hypothesise and test. Pattern matching was observed on an odd occasion and hill climbing was used at the very end of the protocol when the subject had run out of ideas. Teaching strategies to develop this aspect of design problem solving are considered in the final section.

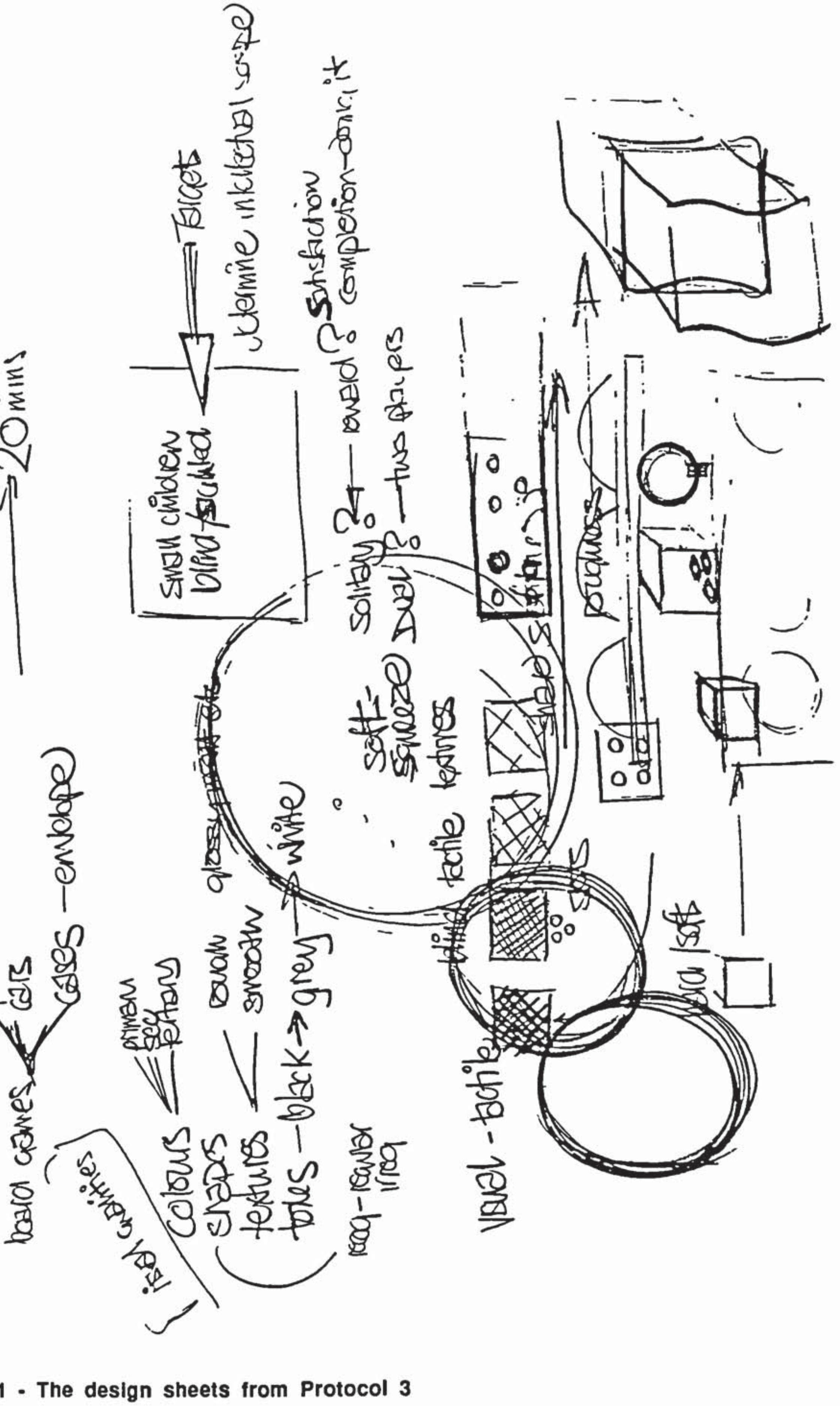

Figure 41 - The design sheets from Protocol 3

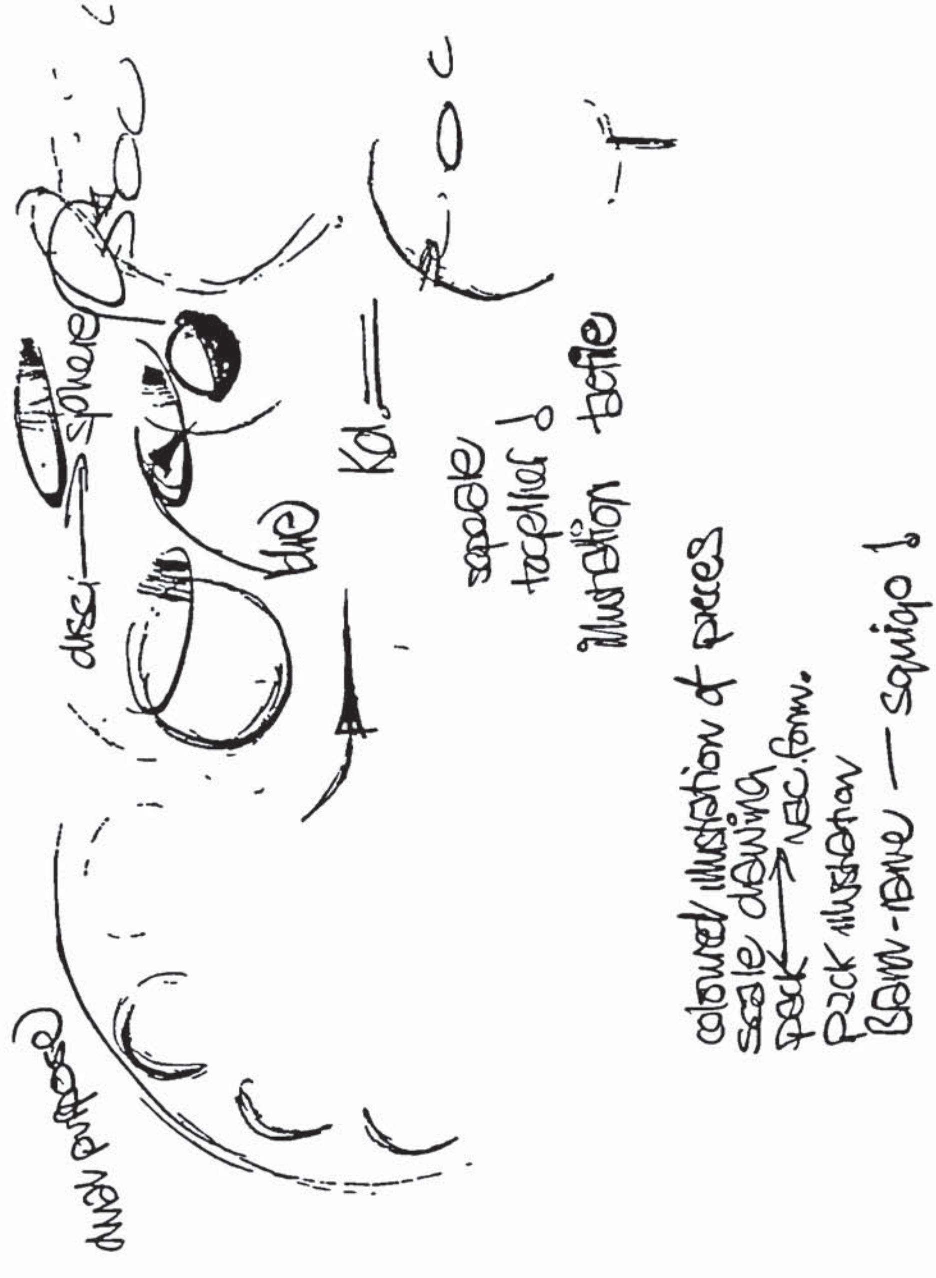

Figure 42 - The design sheets from Protocol 3

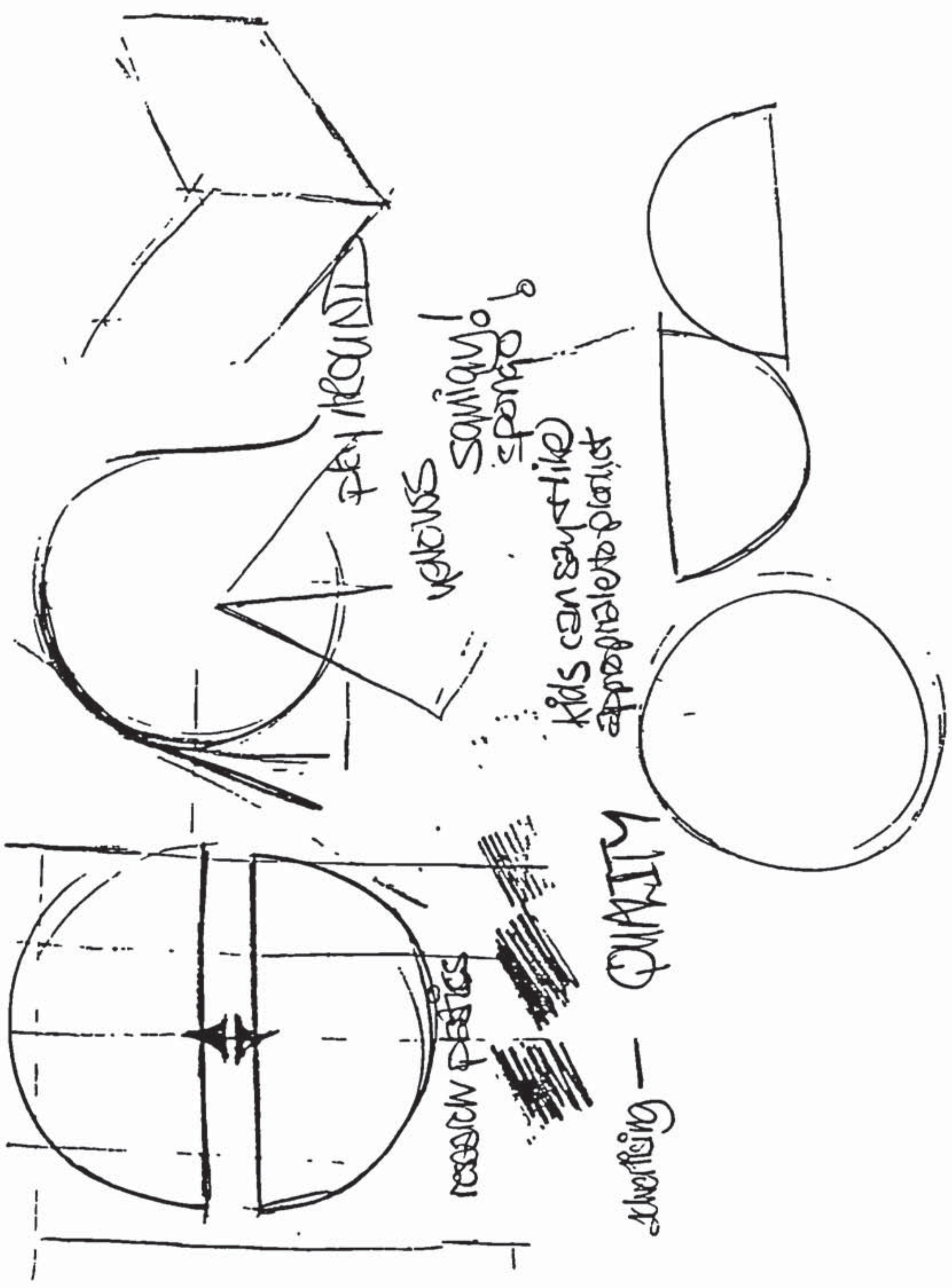

Figure 43 - The design sheets from Protocol 3

6.2 Protocol 4

The protocol was developed in three phases. First of all an analysis was conducted of the use of operators and heuristics to move through the search space. Secondly, discussion was generated around the drawings and sketches produced by the subject. Finally, the general design strategy was analysed, using the framework illustrated in chapter 3. General observations from the video material were used throughout the protocol to help develop and inform the analysis.

The aim was to provide a picture of problem solving behaviour from three different perspectives. At the end of the protocol key issues have been summarised. Discussion of the implications of the findings in terms of teaching and learning strategies appropriate to the subject have also been generated. Questions which have arisen during the development of the protocol have been highlighted and used to inform the conclusions and recommendations made in the final chapter.

A similar format has been used in all of the protocols. However, the first section on initial thoughts has highlighted issues which are particular to this protocol and which therefore may not be common to all subjects.

The subject for protocol 4 was a second year undergraduate student taking a degree in design and technology. At the time of data collection, it was anticipated that he would obtain a first-class honours degree. However, the subject left before the end of the degree programme to pursue commercially a design project identified during the degree course. The project was successful in the commercial market and the subject has developed a flourishing business related to product design and development. Within this research project, it was therefore felt appropriate to consider the subject as an expert designer. It was considered that this offered interesting opportunities to compare findings with previous research into expert designers and the research with novice designers undertaken within this project.

The subject was required to solve a different design task from that given to the other expert designer. The background to this decision is provided in chapter 4. The practice problem was the same for both novice and expert designers. The main problem for protocol 4 provided an opportunity for thinking through modelling:

Using a sheet of A4 card, design and make a book support which could be used for revision/study and then be stored in an A4 folder.

The full transcript of the protocol for this subject is provided in Appendix 2.

Results of transcription, segmenting and encoding

Operator/plan		1st Coding
A	Problem restatement	22 (3.5%)
B	Problem elaboration/refinement	5 (0.8%)
C	Integration	10 (1.6%)
D	Holistic solution generation	0 (0%)
E	Solution elaboration/testing	353 (55.6%)
F	Inference	194 (30%)
G	Information search	48 (7.5%)
H	Solution validation	3 (0.5%)
TOTAL		625

Table 4 - Protocol 4 results of first coding

Results of transcription, segmenting and encoding

Operator/plan		Recoding
A	Problem restatement	22 (3.5%)
B	Problem elaboration/refinement	5 (0.8%)
C	Integration	9 (1.4%)
D	Holistic solution generation	0 (0%)
E	Solution elaboration/testing	350 (54.8%)
F	Assertions	103 (16.1%)
F1	Inference	91 (14%)
G	Information search	48 (7.5%)
H	Solution validation	11 (1.7%)
TOTAL		639

Table 5 - Protocol 4 results of recoding

Initial thoughts

It was clear after initially viewing the video recording that the subject worked in a very different way to the subject discussed in Protocol 3. The design task encouraged the subject to think and design through modelling. This modelling activity was preceded by a short initial drawing activity. At times it was not clear whether the subject was verbalising a description of the process of modelling rather than internalised thought processes. It begs the question of whether these are the same thing.

It appeared from the initial review of video material that the subject started the process by analysing the problem statement and the constraints embodied within it. Drawing was then used to help the generation of an holistic solution concept which was then explored through modelling. The subject appeared to use a modelling process to analyse sub-elements of the problem. In other words, he appeared to be testing through practical activity. At key stages, the subject appeared to be checking progress against the constraints embodied in the problem statement.

'A' Problem Restatement +'B' Problem Elaboration/Refinement

These two operators were considered together as they are closely interrelated. Operator 'A' relates to:

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

Operator 'B' is concerned with:

A statement which extends and interprets information provided in the problem statement.

Operator 'A' was used on 22 occasions or 3.5% of the protocol. Operator 'B' occurred on 8 occasions (0.8%). This compares with 4.8% and 2.9% for Protocol 3, the other expert designer.

Protocol 4 was based upon a different design task to the other four protocols. This task provided an opportunity to solve the problem through modelling in card and had a number of constraints embodied in the problem statement:

A4 card
Book support
Revision/study
Stored in A4 folder

These constraints appear to have provided a reference point at key stages throughout the process which seems to support the referral-back model identified in Protocol 3. The diagram below illustrates the points at which operators 'A' and 'B' were used within the protocol:

Problem statement

* 4/3 - 4/8
* 4/26 - 4/27
* 4/87 - 4/91
* 4/268
* 4/478 - 4/480
* 4/484 - 4/485
* 4/6064/753 - 4/756

Solution

At the start of the protocol the subject made explicit use of operator 'A' in order to identify the constraints embodied in the problem statement:

4/4	Using a sheet of A4 paper
4/5	design and make a book support
4/6	which could be used
4/7	for revision/study
4/8	and then stored in an A4 folder

The subject then attempted to interpret this by applying operator 'B':

4/11	Well it's got to be the sort of book you'd be
4/12	you'd be studying with

Towards the end of the protocol operator 'A' was used as a form of solution validation. This perhaps indicates that the phrase could be dually coded as 'A' and 'H' Solution validation:

4/753	Right we're using one A4 sheet
4/754	of card
4/756	book support

Operator 'B' was also identified at key stages of the protocol, but was not used to the same extent as in protocol 3. It could be identified in the following segments:

* 4/11
* 4/287
* 4/610
* 4/617

This may have been due to the nature of the task used for this protocol which was fairly straight forward with key elements clearly identified. However, the main problem used within the other protocols was much more complex and provided scope for further interpretation. Nevertheless, this contrasts with evidence from novice designers and perhaps illustrated the need to develop teaching strategies connected with this aspect of design problem solving.

The impact of the differing design tasks also needs to be considered. In particular, it is worth considering whether the actions of manipulating the card replaced verbalisation.

'C' - Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems.

The use of this operator was identified on 9 occasions (1.4%), perhaps illustrating that the subject worked in a systematic way and logically moved to the generation of partial and whole solutions after the analysis of sub-problems. For example:

4/306 You can still get it out of one sheet with a fold at the bottom

and,

4/560 actually stands up quite

4/561 quite nicely like that

In both cases the subject was integrating the preceding exploration of sub-problems into partial solutions to the problem.

A further example could be identified at 4/83-4/84:

4/83 Er and a permanent attachment
4/84 on this face here

In this case operator 'C' was used to integrate a sub-solution to the problem. This operator was preceded by a cycle of exploration using operators 'E', 'F' and 'F1'.

An interesting example of the application of operator 'C' was identified at 4/151:

4/151 Right now we'll achieve what we've got in the sketch

In this case the subject was applying operator 'C' to integrate a period of thinking and exploration through drawing into an actual card model. In other words, the subject seemed to require the process of modelling in order to integrate the preceding exploration. This seemed to relate to the reflective/active ability discussed by SEAC/EMU (1990). This issue is discussed in the final section of this protocol.

'D' - Holistic Solution Generation

The generation of solutions to the problem from an undetermined or apparent intuitive source.

The use of operator 'D' was not identified at any stage during the protocol. This may be be due to the subject working in the systematic way described above with all partial or holistic solutions resulting from previous analysis of sub-problems, or it may be related to limitations in the research methodology.

The nature of the task may also influence the operators used within the design process. This activity provided an opportunity to think through modelling. It may be that this forced the problem solver to think in a more systematic way and consequently follow an analysis > synthesis > evaluation strategy. Alternatively, the protocol may include a record of what the subject was doing, rather than what he was thinking.

Nevertheless, it was clear that the subject did solve the problem and consequently developed an holistic solution. However, this seemed to gradually evolve from cycles of exploration of sub-elements of the problem and therefore no direct evidence was available of the application of operator 'D'. It could be seen that holistic solution generation occurred towards the end of the protocol and was embodied in a range of segments of the transcript, with no single one being able to be coded as 'D'. However, the initial drawings indicate that a solution concept was developed after the analysis of the problem statement. It appeared that this must have been embodied in a group of segments of the transcript as it was not identified in a single segment.

'E' - Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions

Category 'E' can be identified as the major operator used within this protocol. It was identified on 350 occasions (54.8%).

A number of short cycles of exploration could be identified throughout the protocol. These usually started with 'F' - Assertion and concluded with 'F1' - Inference, with the application of knowledge 'G' also within the cycle:

4/15 about the same sort of size as this sheet

4/16 so it's got to be quite tall
4/17 and also angled up
4/18 I think so that you can
4/19 possibly stand the book up
4/20 and then view the the book while you're
4/21 while you're writing down
4/22 or drawing sketching whatever

A similar cycle, which integrated assertion, knowledge and inference and which appeared to be driven by category 'E', could be seen at:

4/44 Roughly A4 size
4/45 slightly smaller than A4 size
4/48 flaps at each side like this
4/49 going down here
4/52 That'll give it an angle
4/53 so that the book can be supported

Throughout the protocol similar cycles could be identified and the use of operator 'E' as a means of solving the problem appeared to be an essential part of the strategy used by the subject. This approach suggested that the subject had decomposed the problem into a series of sub-problems which were explored right through to solution validation. It further suggested that the type of problem used with this subject encouraged this sort of exploration with the final solution emerging at the end of the process.

The extent to which the nature of the design task influences the strategies employed will need to be considered. The way in which a wider search can be generated will also need to be discussed.

'F' - Assertions

Assertions from the generation of new information from internal sources.

This operator was identified on 103 occasions (16.1%) within the protocol.

This operator was used throughout the protocol and, as discussed above, was usually found in combination with 'E' - Solution elaboration and testing and 'F1' - Inference. It appeared that the subject used assertion to set up a sub-problem/solution which was then explored through the application of operator 'E', with the cycle concluded by inference (F1):

4/411	**Assertion**	
4/412		}
4/413		}
4/417	**Exploration**	}
4/419		}
4/421		}
4/425		}
4/426	**Inference**	

This was immediately followed by a similar cycle, which was in turn followed by a mid-protocol validation of the solution.

Examples of the application of operator 'F' could be observed throughout the protocol:

4/297-4/298 we don't want to be studying an extremely small book

4/379 Two and a half inches straight across the bottom

4/411 we can also modify that again

In each case, the application of the operator seemed to provide the means of starting an exploratory cycle which was continued through the application of 'E' and concluded through the application of 'F1'.

'F1' - Inference

Higher order conclusions, propositions or justifications not given in the problem statement but generated by the problem solver.

Inference was identified on 93 occasions (14%) within the protocol. It was obviously a key element in the cycle described above and was used to conclude short cycles throughout the protocol. These were observed from the very beginning of the process right through to the final section:

4/33	so that is its maximum
4/40	so that it can be stored flat
4/53	so that the book can be supported
4/659	that might actually work
4/707	obviously for a pocket size book
4/757	Right it will support something vaguely book-shaped

The language used within the protocol provided interesting pointers to the application of this operator. For example, the segment was often started by the word 'so', 'that', 'it', or 'right'

Towards the end, it was more difficult to make the distinction between inference and 'H' - Solution validation:

4/707	obviously for a pocket size book
4/725	prevents the whole thing from sliding apart
4/757	Right it will support something vaguely book-shaped

This further highlights the problem of dual coding which is discussed in the evaluation of the methodology.

'G' - Information Search

The initial application of technological or other forms of knowledge to help the development of sub-solutions. N.B. subsequent use of this knowledge will be coded under category 'E'.

'G' was used on 48 occasions (7.5%), although the nature of the task did not really call upon a detailed technological language or vocabulary. This technological knowledge could be classified under the following headings:

(i) knowledge of materials and processes;
(ii) ergonomic/anthropometric knowledge.

Examples of (i) could be seen at:

4/103 by scoring or bending
4/131 probably 45 degrees

Examples of (ii) were observed at:

4/203 too much and too great a length there so
4/255 that would provide a support and an angle suitable for reading

The operator was used throughout the protocol and, as discussed above, was often part of a cycle involving assertion, exploration and inference:

4/251 OK that's a bit more like it
4/252 Right
4/253 Now that's
4/255 that would provide a support at an angle suitable for reading
4/256 or studying

In the example above, within the exploratory cycle the subject was drawing upon ergonomic knowledge in order to move through the search space. This again provided an example of where the segment could have been dually coded.

Did the nature of the task have an influence upon the type of knowledge or vocabulary used? Was this a fairly neutral task which did not depend upon a great technological knowledge?

'H' - Solution Validation

Testing, justifying and revising of a solution to the problem.

Solution validation 'H' could be identified on 11 occasions (1.7%). This may have been because the subject was able to 'complete' the design task rather just than start the exploration phase. In other words, the nature of the design task allowed the subject to move through a complete design cycle. This contrasts with the tasks used with other subjects in which only initial exploration was possible within the time constraints of the research project.

A gradual move towards solution validation could be seen at key stages in the latter part of the protocol. This was often preceded by exploration of the problem.

Solution validation could also be seen at a mid-point of the protocol. The subject seemed to be combining this validation with the use of the problem statement as a reference point during the process. This again highlighted the problem of dual coding:

4/455 It's on a one A4 sheet
4/457 and it does fold flat

The final section of the protocol illustrated that the subject was accepting the solution in terms of the problem statement:

4/751	It supports a book
4/753	Right we're using one A4 sheet
4/758	and it can fold down
4/773	So there we have it
4/794	And it seems to fulfil that

Segment 4/753 was again coded as the application of operator 'A' - problem restatement. This further illustrated the problem of dual coding.

The use of heuristics within the protocols

Means-end-analysis seemed to be used throughout the protocol. An operator (assertion) was applied in order to determine whether the new state was closer to the goal state - if it was, the move was made (inference), if not (after a dead-end) the problem solver searched for another move that produced a state closer to the goal state:

4/14	Probably about
4/15	about the same sort of size as this sheet
4/16	So it's got to be quite tall
4/17	and also angled up
4/18	I think so that you can
4/19	possibly stand the book up

In this example the subject appeared to use a heuristic similar to means-end-analysis:

4/14 (push) > 4/15 (push) > 4/16 (push) > 4/17 (push) > 4/18 (push) > 4/19 (pop!)

Another example could be seen at:

4/311 That would be really easy to do
4/312 and give
4/313 a moderate amount of support
4/314 to a book

However, it may also be possible to describe the cycles above as hypothesise-and-test - Does the assertion > exploration > inference model suggest the generation of an hypothesis which is explored and concluded through inference?

Pattern matching could not be identified within the protocol. There was also little evidence of hill-climbing being used by the subject. This again may have been due to the nature of the design task which seemed to encourage the use of means-end-analysis and hypothesise-and-test.

Research approach 2 - Design Strategy

The subject appeared to quickly converge onto a solution concept for the problem and then to diverge within the exploration phase. In other words, the subject appeared to generate a general solution outline at the outset which was then systematically explored before the result was validated. However, the initial solution concept was rather more hazy than those observed in some of the other protocols:

Problem	**>>>>**	**Solution concept**	**>>>>>**	**Exploration of sub-problems**	**>>>>>**	**Solution validation**

Figure 44 - Protocol 4 general design strategy

The subject appeared to adopt the serial-analytic-holistic strategy described by Tovey (1986). The involved the use of holistic thinking as an initiating strategy for the design process which provided an undetailed overall concept as a framework for the subsequent more detailed thinking. However, elements of a serial analytic strategy could also be identified in parts of the protocol. The nature of the design task may have influenced the use of this strategy.

In describing behaviour in terms of the key words put forward by Kimbell et al (1991), the following appear to be applicable to this subject:

Resourceful - the subject seemed to be able to draw upon his own resources to solve the problem and did not find it difficult to continue after an initial misinterpretation of the problem statement.

Focused - throughout the protocol the subject was focused on the task in hand. There were few long periods of inactivity and pauses in the protocol related to periods of modelling rather than the subject being unable to generate thoughts.

Methodical - the detailed exploration identified through the use of operators 'E', 'F' and 'F1' indicated that the subject worked through the protocol in a methodical and logical way.

Determined - the subject appeared throughout the protocol to be determined to solve the problem and was not deterred when things did not go as planned.

The nature of the task allowed the subject to demonstrate both reflective and active ability. The subject was continuously moving from thinking around the task to actions in response of the task which resulted in the development of new proposals. However, the nature of the task resulted in the subject focusing upon demonstrating active ability at key points within the protocol. For example, at segment 4/151 the subject moved directly to working in an active way:

```
                    >>>>>>>
              <<<<<<<<<<<<
               >>>>>>>>>>>>>>>>>>
Initial                                Modelling
concept             >>>>>>>>>>>>>      + drawing
                         >>>>>>>>>>>>
                         >>>>>>>>>>>>>>>
                         >>>>>>>>>>>>>>>>>>>
```

Figure 45 - Protocol 4 - reflective and active ability (see Kimbell et al, Figure 4, page 31)

The subject appeared to adopt an approach which was different to either the expert or novice model put forward by Krampen (1983). The subject first of all became familiar in the problem and then generated an overall solution concept which was explored and validated in blocks of activity before the final validation of the solution:

Familiarisation with problem
Clarification by sketching
Solution concept generation
Clarification/exploration of sub-elements
Solution validation
Clarification/exploration of sub-elements
Solution validation

This compared with expert model put forward by Krampen which suggests the development of two possible solution attempts followed by presentation of the solution and verification. However, the differences may have been due to the nature of the design task used in this research project:

Familiarisation with problem
Clarification by sketching
First solution attempt
Verification and rejection
Second attempt
Presentation of solution and correction of minor mistakes
Verification

With this type of design task, the subject tended to work in the reverse of the analysis-synthesis-evaluation model:

Synthesis >> Analysis >> Realisation >> Analysis >> Realisation >> Evaluation >> Validation

The subject appeared to develop an holistic solution concept at the outset which was explored through drawing and then further developed through modelling before finally being evaluated and validated.

The subject appeared at first glance to follow a solution-focused strategy. However, with closer analysis it could be seen that the subject was using a combination of solution and problem-focused strategies. The initial urge to move towards a solution was tempered by the use of the problem statement throughout the process.

It was clear that the subject imposed a 'primary generator' very early in the process. This helped the subject to identify the constraints embodied in the problem and make a creative jump between the problem statement and solution concept. The process of 'satisficing' could also be identified as the subject used the constraints embodied in the problem statement as a framework for analysing the solution concept.

Research approach 3 - Drawing and modelling

1 The use of drawing to support thinking

The subject only used drawing in the first part of the protocol. This drawing comprised three or four outline solution concepts based around a similar overall concept. The subject therefore did not explore a range of ideas through free ranging drawing. Detail was not applied to the concept drawings.

2 The style and nature of the drawing

The drawings did not contain a great deal of detail and consequently gave little information of how the product would work or be made. Details of construction and form were decided through modelling.

The subject seemed to have developed an easy drawing style which was based upon basic over-lapping outline drawings. Colour was not used and the no words were used to explain or expand thinking. All drawings were freehand and in a 3D form.

3 The use of modelling to support thinking

Modelling was used in order to explore the problem for a large part of the protocol. At one level the modelling took the form of synthesising ideas developed from the drawing stage. At another level the subject used modelling to explore elements of the problem and to try out potential sub-solutions and overall solutions.

The subject was confident in the use of modelling materials and demonstrated high level basic craft skills. This allowed the production of a high quality product which made evaluation and validation easier.

It was not clear in places whether the subject was using modelling to aid thinking or to show the product of thinking.

Conclusions

A number of issues arose from the protocol which perhaps need to be highlighted for discussion in the concluding section.

Issue 1

It was clear that the subject made significant use of operators 'A' - Problem restatement and 'B' - Problem elaboration/refinement throughout the process. This suggested that the subject was using the problem statement as a reference point in a similar way to Protocol 3. This occurred in spite of these two expert designers undertaking very different tasks. This behaviour is compared with other expert designers in the final section. Consideration has also been given to teaching strategies to promote this method of working with novice designers.

Issue 2

Operator 'C' - Integration appeared to be applied at key stages within the protocol. There was evidence of systematic analysis within the protocol which may have been closely related to the cycles of exploration identified between operators 'E' - Solution elaboration/testing, 'F' - Assertion and 'F1' - Inference. As indicated earlier, these operators appeared to form a cycle: F >> E >> F1. There was some evidence within the protocol that after a series of these cycles operator 'C' - Integration was applied. The general use of these cycles by subjects within this research project is considered in the concluding section. Teaching strategies to promote the development of these cycles have also been considered.

Issue 3

It was noticeable that operator 'D' - Holistic solution generation was not identified at any stage in the process. However, it was clear that the subject did develop an overall solution concept near the beginning of the protocol, although this could not be identified through the application of individual operators. The nature of the task may also be related to the lack of use of this operator. The scope for the use of problem solving activities such as brainstorming with this type of design task have been considered in the concluding section.

Issue 4

The subject demonstrated evidence of having access to a wide range of design and technological knowledge. However, the nature of the task did not really provide great opportunity for the demonstration of technological knowledge. It was interesting to note how frequently operator 'G' - Information search occurred within the exploratory cycles described above.

Issue 5

There was evidence of the use of 'H' - Solution validation at key stages within the protocol. Towards the end, the application of this operator provided confirmation that the solution was being accepted. The fact that the subject was able to move through a complete cycle of design was obviously related to the nature of the task. The role of teaching strategies to develop this aspect of designing is considered in the concluding section. The relationship of operator 'H' with operators 'A' and 'B', in terms of dual coding, has also been considered.

Issue 6

Means-end analysis and hypothesise-and-test were the main heuristics used during the design problem solving process. Methods for utilising other heuristics need to be considered and these are discussed in the concluding section. Ways of building these heuristics into teaching strategies are also discussed.

Issue 7

An interesting model of designing was observed during the protocol. This seemed to relate to the nature of the task, which encouraged thinking through modelling. The subject appeared to operate from synthesis >> analysis >> realisation >> analysis >> realisation >> evaluation >> validation. The way this relates to the analysis - synthesis - evaluation model is discussed in the concluding section. Comparison is also made with the work of the other subjects. The way in which these models can inform teaching strategies is also considered.

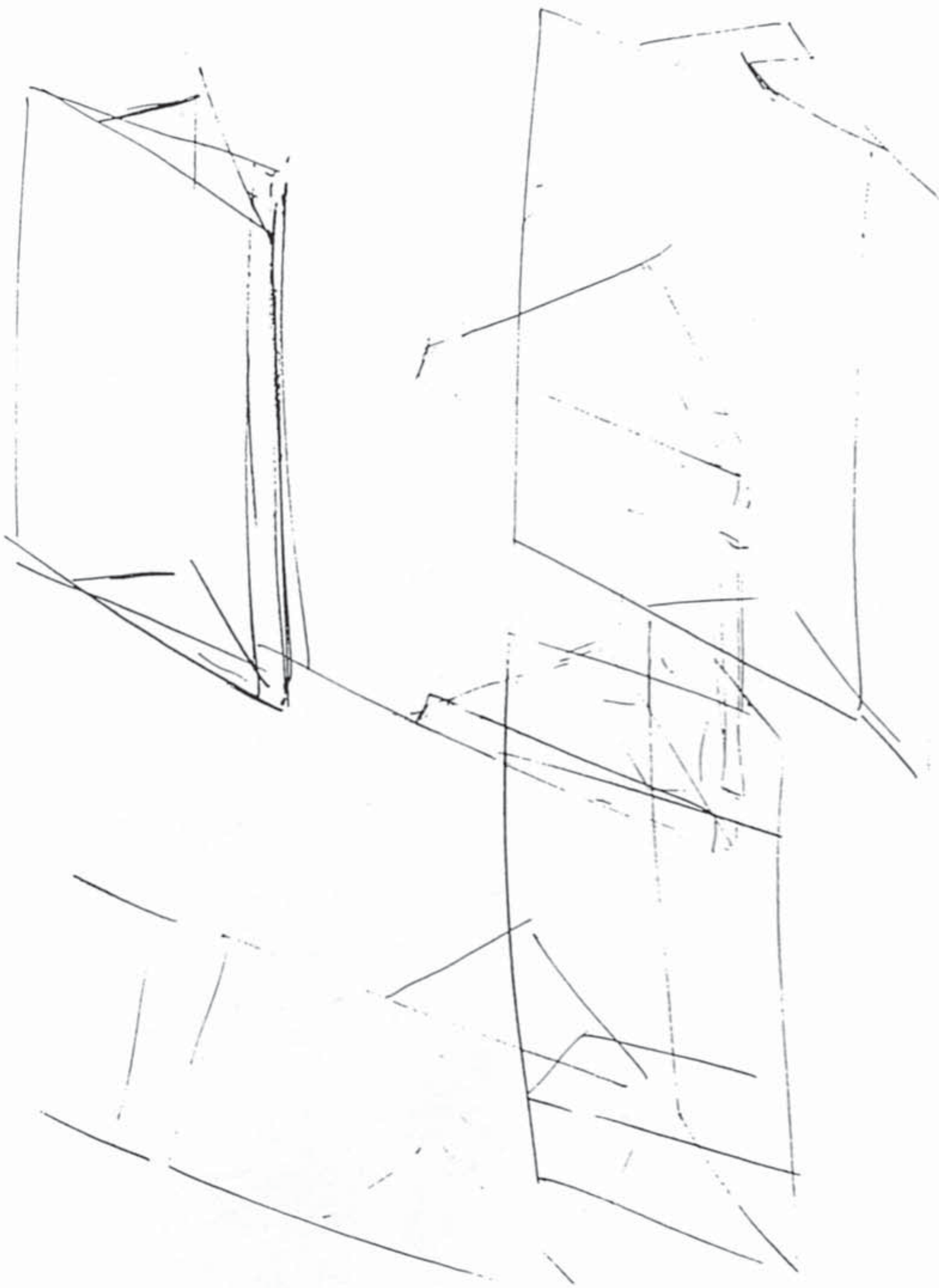

Figure 46 - The design sheet from Protocol 4

6.3 Protocol 5

The protocol was developed in three phases. First of all an analysis was conducted of the use of operators and heuristics to move through the search space. Secondly, discussion was generated around the drawings and sketches produced by the subject. Finally, the general design strategy was analysed, using the framework illustrated in chapter 3. General observations from the video material were used throughout the protocol to help develop and inform the analysis.

The aim was to provide a picture of problem solving behaviour from three different perspectives. At the end of the protocol key issues have been summarised. Discussion of the implications of the findings in terms of teaching and learning strategies appropriate to the subject have also been generated. Questions which have arisen during the development of the protocol have been highlighted and used to inform the conclusions and recommendations made in the final chapter.

A similar format has been used in all of the protocols. However, the first section on initial thoughts has highlighted issues which are particular to this protocol and which therefore may not be common to all subjects.

The subject for protocol 5 was a year 9 pupil at a large comprehensive school in the City of Birmingham. The pupil was assessed as being of below average ability in terms of design problem solving. At the time of data collection the subject had just selected Design and Realisation to study at GCSE level in years 10 and 11. The subject was estimated to obtain a grade E in the GCSE.

The full transcript of the protocol for this subject is provided in Appendix 3.

Results of transcription, segmenting and encoding

Operator/plan		1st Coding
A	Problem restatement	0 (0%)
B	Problem elaboration/refinement	0 (0%)
C	Integration	0 (0%)
D	Holistic solution generation	2 (4%)
E	Solution elaboration/testing	18 (35%)
F	Assertions	9 (17%)
F1	Inference	9 (17%)
G	Information search	7 (13%)
H	Solution validation	7 (13%)
TOTAL		52

Table 6 - Protocol 5 results from the practice problem

Results of transcription, segmenting and encoding

Operator/plan		1st Coding
A	Problem restatement	0 (0%)
B	Problem elaboration/refinement	0 (0%)
C	Integration	7 (7%)
D	Holistic solution generation	5 (5%)
E	Solution elaboration/testing	43 (46%)
F	Assertions	10 (11%)
F1	Inference	14 (15%)
G	Information search	5 (5%)
H	Solution validation	10 (11%)
TOTAL		94

Table 7 - Protocol 5 results from the main problem

Initial thoughts

Initially, this subject seemed to be quite a fluent problem solver during the generation of the protocol. However, some prompting was needed to encourage the subject to talk aloud. This may have had some effect upon the data collected. Nevertheless, at times, a clear strategy for design problem solving could be observed. Overall, however, there was evidence that the subject had difficulty generating design ideas.

It was apparent that the subject immediately developed a single solution to the problem and then analysed sub-problems in some depth. In other words, a combination of holistic and convergent thinking was being used.

During both problems, modelling techniques were used to aid thinking. It would be interesting to see how this subject would operate with a problem which actively encouraged a modelling approach. Perhaps this illustrates that this subject was able to balance the reflective and active abilities described by the Kimbell et al (1991).

It was also clear that the subject seemed to spend a great deal of time thinking around the main concept rather than the detail of construction, and materials.The subject seemed to keep returning to the issues raised in the problem statement. However, it may be difficult to code responses under either 'A' or 'B'.

It was also clear that the subject found difficulty in considering other possible solutions to the problem. This was true even when the researcher prompted the subject to try to do this.

It is clear from observation of the video recording that the subject immediately generated an holistic solution to the problem. This holistic solution was clarified through sketching at an early stage. The subject then analysed a range of sub problems associated with the overall solution. He appeared to be going through a process of ratification of the solution, whilst analysing elements in detail.

Card modelling was used quite early in the process. It was not clear if this has been undertaken to aid thinking, or to demonstrate the product of his thinking. The modelling stage illustrated the student knowledge of basic modelling techniques. For example, scoring the card to aid folding.

The student verbalised quite fluently for parts of the protocol. However, the graphic images recorded did not seem to reflect this level of thinking. In fact, they appeared to be quite crude and unsophisticated and may not have done justice to the thinking which had been developed.

Will the subject suffer during assessment? Does this really indicate that Design and Technology capability is not very well developed. If so, which teaching strategies could aid this student?

Prompting by the researcher took place at intervals through the generation of the protocol. There were times when the subject seemed to be less fluent. Did this prompting change the process?

'A' Problem Restatement +'B' Problem Elaboration/Refinement

These two operators will be considered together as they are closely interrelated. Operator 'A' relates to:

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

Operator 'B' is concerned with:

A statement which extends and interprets information provided in the problem statement.

The use of operator 'A' and 'B' could not be identified within either the practice or main problem. This suggested that the subject was working in a solution focused mode identified in the other protocols from novice designers. A single solution to the problem appeared to be generated at the outset. This solution was gradually validated during the process, However, reference to operators 'A' and 'B' may have been implicit within this process, but in such a way that it made it difficult to code under 'A' or 'B'. For example:

5/6	and wouldn't fall over
5/7	and would show the letters easily
5/8	and wouldn't take up much space

These segments have been coded as operator 'H' - Solution Validation, but it can be seen that they are based upon key constraints embodied in the problem statement. Nevertheless, the theory upon which the coding was based was synthesised from previous research with expert designers. It may require modification in light of the solution focused strategy identified in novice designers.

Holistic solutions were developed at the outset in both the practice and main problems. These appeared to have been achieved without any analysis of the problem statement. In fact, in both protocols, the subject does not, at any stage, make an exact copy (A) of the whole or part of the problem outlined in the brief. Problem elaboration and refinement, which includes statements which extend and interpret information given in the problem statement, do not seem to be used to move the subject through the problem space.

'C' - Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems.

Operator 'C' - Integration could not be identified in the practice problem, but was observed on 7 occasions (7%) in the main problem. These differences may be due to the nature of the design tasks. The practice problem was a relatively straight forward task which perhaps encouraged a solution > synthesis > evaluation approach. The main problem was more complex and consequently required a more systematic analysis.

An example of the generation of a partial solution to the problem preceded by exploration of sub problems could be seen at:

5/71 Try drawing actual game bigger now
5/72 and deciding what goes where on it
5/73 1, 2, 3, 4, 5 (drawing lines on card to make board)
5/74 We could have it on the theme of 'Indiana Jones'

Between 5/71 and 5/73 the subject was looking at sub elements of the problem before arriving at a new solution concept at 5/74.

'D' - Holistic Solution Generation

The generation of solutions to the problem from an undetermined or apparent intuitive source.

In both the practice and main problems, the subject developed an holistic solution to the problem at the outset. This occurred without reference to the problem statement

For example, in the practice problem :

5/1 I'm going to design a triangular shape
5/2 with a flat bottom
5/3 and pyramid edges

This development of an holistic solution was also seen at an early stage of the main problem :

5/46 I could try a family game
5/47 for about 4 people,
5/48 something on the lines of chess.
5/49 Snakes and ladders but three-dimensional

The basic strategy seems to be based around the generation of holistic solutions (D) or solution concepts (5/48 and 5/49) which were then elaborated and tested (E) through the generation of a range of sub-solutions. This suggests a strategy which is the reverse of the conventional models of design problem solving:

Solution > Analysis > Validation

The subject was clearly adopting a solution focused approach from the outset.

'E' - Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions

This operator was be identified on 18 occasions (35%) in the practice problem and on 43 occasions (46%) in the main problem. In both cases it was the major operator identified in the protocol. Category 'E' was often followed by 'F1' - Inference and on occasions it was preceded by 'F' - Assertion. However, this was not always the case:

5/83 Could even make the actual things on the board three dimensional
5/84 like the tree
5/85 The rules have got to be simple really
5/86 because if they are too complicated people won't want to read through them before they play

In the practice problem similar cycles were used to test various sub-elements:

5/27 You could use a flatter piece of paper with a stand at the back
5/28 to hold that up
5/29 but that could fall over easily

This cycle was followed by a series of similar patterns:

5/33 Cardboard would do it
5/34 or even a metal - a soft metal with the name engraved on it
5/35 Tin
5/36 something that would bend quite easily

5/42 You could glue it to the desk
5/43 or even put a weight inside and hold it down on the desk
5/44 and it would not move from there

The subject appeared to have generated an holistic solution concept at the outset in both the practice and main problems and then used a series of exploratory cycles to analyse the sub-elements.

'F' - Assertions

Assertions from the generation of new information from internal sources.

At key stages in this process, the subject used 'F' - Assertions on 9 occasions (17%) in the practice problem and on 10 occasions (11%) in the main problem:

5/57 So I'll design something we can use

5/68 This is a picture of how I want it to look like say

5/76 'Q' equals a question

5/112 Packaging does not need to be too big for the actual game

On occasions, this use of operator 'F' helped to start the cycles described in 'E'. The cycle was continued through 'E' - Solution elaboration and testing and concluded by the use of operator 'F1' - Inference:

5/57 So I'll design something we can use
5/58 (I'll draw) normal people, men or women
5/59 this is a rough idea of what it will look like with a sword or gun in hand
5/60 make these three dimensional
5/61 but also with one person with something to hold it up on the bottom

'F1' - Inference

Higher order conclusions, propositions or justifications not given in the problem statement but generated by the problem solver.

Inferential thought (F1) was periodically generated for the purpose of decision making in the development of these sub- problems and hence also to aid the movement through the search space. It was identified on 9 occasions (17%) in the practice problem and on 14 occasions (15%) in the main problem:

5/78 So you move on, if you don't land on that square you move on

5/80 So a box could be for advertising on television or magazines

5/86 really because if they are too complicated people won't want to read through them before they play

'F1' appeared to be a key element in bringing cycles of exploration and analysis to conclusion. The segments coded as 'F1' often included the words 'so' and 'because'.

'G' - Information Search

The initial application of technological or other forms of knowledge to help the development of sub-solutions. N.B. subsequent use of this knowledge will be coded under category 'E'.

In the practice problem the use of operator 'G' was noted on 7 occasions (13%) and on 5 occasions (5%) in the main problem. The subject used little technological or other bodies of knowledge (G) from outside the problem statement to aid the development of solutions. Often the knowledge used seemed to be of a non-technical nature:

5/100 I would make the board out of some kind of wood and varnish it

5/101 I would make these people out of moulded plastic and paint them

For much of the time, the subject seemed to be using conceptual knowledge rather than the technological knowledge usually associated with design and technology.

However, in the practice problem, technological and other forms of knowledge were used to help movement through the search space for 13% of the time. The examples below show how this knowledge was used within the protocol. The nature of the task may be an important factor in this aspect of the research. It was also possible that, in the main project, the subject would have had to increasingly use a knowledge base as the solutions developed. In other words, the subject was still operating in an exploratory stage and detailed examination may not have begun:

5/3 and pyramid edges

5/10 all side are equal

5/15 to give a triangle

5/35 Tin - something that would bend easily

This short extract from the protocol demonstrated a reasonable technological knowledge and perhaps illustrated that the subject's knowledge base may have been broader than the main problem suggested.

'H' - Solution Validation

Testing, justifying and revising of a solution to the problem.

The use of this operator was identified on 7 occasions (13%) in the practice problem and on 10 occasions (11%) in the main problem.

In the practice problem, solution validation occurred very early in the protocol. This may be because it was being used as a means of defining and interpreting the problem statement. This further illustrates the problem of dual coding:

5/6 and wouldn't fall over
5/7 and would show the letters easily
5/8 and wouldn't take up much space

Solution validation was also identified near the mid-point of the protocol:

5/30 and this (triangular shape) would stay still

Towards the end of the protocol 'H' was used to finally validate the solution and as a means of concluding the protocol:

5/38 I was thinking would it stand out on the desk
5/39 or would it fall over or anything like that
5/45 I think it would solve the problem of putting the name on the desk

In the main project, it was interesting to note that even after prompting about alternative solutions the subject immediately returned to an exploration of the sub problems and sub-solutions of the original solution :

5/110 I suppose you would have to use questions and dice
5/111 or smaller games

5/112 Packaging does not seem to be too big for the actual game
5/113 and so just make the box out of strong card
5/114 which slips over another box

The role of heuristics within the protocol

Hill climbing was a major strategy used by the subject. It could be identified at the outset of both the practice and main problems where it was used to generate holistic solution concepts which were subsequently explored and justified:

Practice problem

5/1 I'm going the design a triangular shape

Main problem

5/46 I could try a family game
5/47 for about 4 people
5/48 something on the lines of chess
5/49 Snakes and ladders but three-dimensional

In both cases hill climbing was used in the first segments of the protocol in order to move towards a solution. The subject made no attempt to analyse the problem statement before adopting this search strategy.

Means-ends-analysis was the other major heuristic identified in the protocol. The holistic solution concept developed at the outset seemed to provide a basis for this search strategy to 'pop' elements of the solution For example the use of this strategy could be seen at:

5/53 They all have an individual 3D person on one big board
5/54 and I'll number it from one to whatever you finish on,
5/55 roll the dice until you land on a square

5/56 where you have to do something or answer a question
out of the box

The subject seemed to implicitly breaking the problem into small parts, based upon the constraints embodied in the problem statement, which were then processed using means-ends-analysis. This was often undertaken in very short sequences, perhaps suggesting more of a justification and providing detail to the solution rather than a thorough analysis:

5/85 The rules have got to be really simple
5/86 because if they are too complicated people won't
want to read through them before they play

5/99 The board out of some kind of wood
5/100 and varnish it

5/101 I would make the people out of moulded plastic
5/102 and paint them

A strategy based upon analogical thinking could be identified in places:

5/48 something on the lines of chess

5/49 Snakes and ladders but three-dimensional

5/74 We could have it a theme of 'Indiana Jones'

Research approach 2 - Design strategy

In both problems, the subject started with an holistic concept of the solution to the problem. This was explored in a linear and serialistic way before converging to solution validation.

Problem >> Solution >>> Exploration >>>>>>> Solution
statement concept
validation

Figure 47 - Protocol 5 design strategy

This model appeared to replicate the serial-analytical-holistic strategy (Tovey, 1986) as the overall concept developed at the outset provided a framework for detailed exploration of the sub-problem.

In describing behaviour in terms of the key words put forward by Kimbell et al (1991), the following appear to be applicable to this subject:

Safe - the subject did not move outside the holistic solution concepts developed at the start of each problem. There was little evidence of hill climbing after this initial development.

Focused - once the initial ideas had been generated the subject focused attention on providing detail to the solution.

Methodical - the subject worked through the sub elements of the problem in a methodical way. More and more detail was gradually developed.

Determined - the subject seemed determined to develop a solution from the initial holistic concept. However, this did not include developing a wide search space.

The subject appeared to move between reflective and active abilities. Sub-elements were explored and then confirmed the outcome in terms of sub-solutions developed from the initial solution concept.

The subject did not seem to follow Krampen's model of the design problem solving behaviour of novice designers. Instead the following pattern was identified:

Concept solution
Exploration cycles
Solution validation

This was also true when comparison was made with the analysis-synthesis-evaluation model. The subject seemed to adopt:

synthesis > analysis > validation

A single idea, rather than a group of concepts, was developed. The 'primary generator' was identified very early in the process.

Research approach 3 - Drawing and modelling

1 The use of drawing to support thinking

The subject quickly developed a drawing of a concept solution. This was used as a basis for exploring the problem through words, drawings and modelling. This tended to be a fairly limited process with few ideas being developed. The drawing was rather restricted.

There was some evidence of drawing for synthesis in that detail was applied to the original concept.

2 The style and nature of the drawing

The drawings were somewhat crude and presented a rather shallow range of proposals and issues for consideration. Much of the detail was provided in written form. It was very difficult to follow the pattern of thinking from the drawing.

The drawings lacked confidence, although the images were quite bold. Freehand drawing was of limited quality and was presented in 2D form. Interaction between words and pictures was observed in places.

It was interesting to note that the verbalised transcript was more fluent than the drawings.

3 The use of modelling to support thinking

The subject used card modelling very early in the process to support thinking and seemed to find this easier than thinking through drawing. This may suggest that the subject preferred to think through doing. It would be interesting to see how the subject would cope with the problem undertaken by subject 2 (Pro 4).

Conclusions

A number of issues can be identified from the protocol:

Issue 1

The first issue which became apparent from the results related to the use of operators 'A', 'B' and 'C'. Operator 'A' - Problem restatement and operator 'B' - Problem elaboration/refinement were not identified at any stage in the protocol. The subject did not seem to explicitly use and develop the constraints embodied in the problem statements. In other words, the subject was working in a solution-focussed way, rather than in the problem-focussed way identified in some expert designers. The ability of expert designers to decompose problem statements and to develop further constraints has been highlighted by Chan (1991). This seems to provide a means of changing from a solution-focussed to a problem-focussed way of working.

The issue highlighted above is compounded when operator 'C' - Integration is considered. It seems that, due to an inability to develop the constraints of the problem statement, the subject found it difficult to set a framework which would help the generation of whole or partial solutions to the problem.

Teaching strategies would involve the decomposition of the problem statement in order to identify the constraints embodied within it. The subject would also be encouraged to identify additional constraints and then to use this as a framework for exploration of the problem.

Issue 2

Operator 'D' - Holistic solution development illustrated that in both problems the subject developed holistic solution concepts at the outset. These solution concepts then dominated the protocol and the subject did not consider any other general solutions to the problem. This problem was also identified by Kimbell et al (1991). This seems to be a common problem with novice designers who obviously lack the experience of expert designers.

It would therefore seem to be important to consider teaching strategies which would help the development of a range of holistic solution concepts at the outset. These may include strategies such as brainstorming and synectics.

Issue 3

The protocols analysed within this research project illustrated the way in which operators 'E' - Solution elaboration and testing, 'F' - Assertion and 'F1' - Inference were used as part of the exploration process. Expert designers tend to follow the cycle of: Assertion > exploration > inference, whilst with this subject the cycle was less identifiable and seemed to be shorter: exploration > inference.

Issue 4

Operator 'H' - Solution validation was used by the subject throughout the initial problem. However, in the main problem its use was less explicit. This may have been because of the more complex nature of the second problem. There seems to be a need to develop explicit teaching methods to encourage solution evaluation and validation.

Issue 5

The use of operator 'G' - Information search demonstrated that the subject had a reasonable knowledge base upon which to draw during the problem solving process. However, the nature of the tasks and the phase of designing focused upon in the project did not really provide opportunities for the subject to demonstrate broad technological and other forms of knowledge.

Teaching strategies related to the development of a design and technology vocabulary and knowledge may need to be considered.

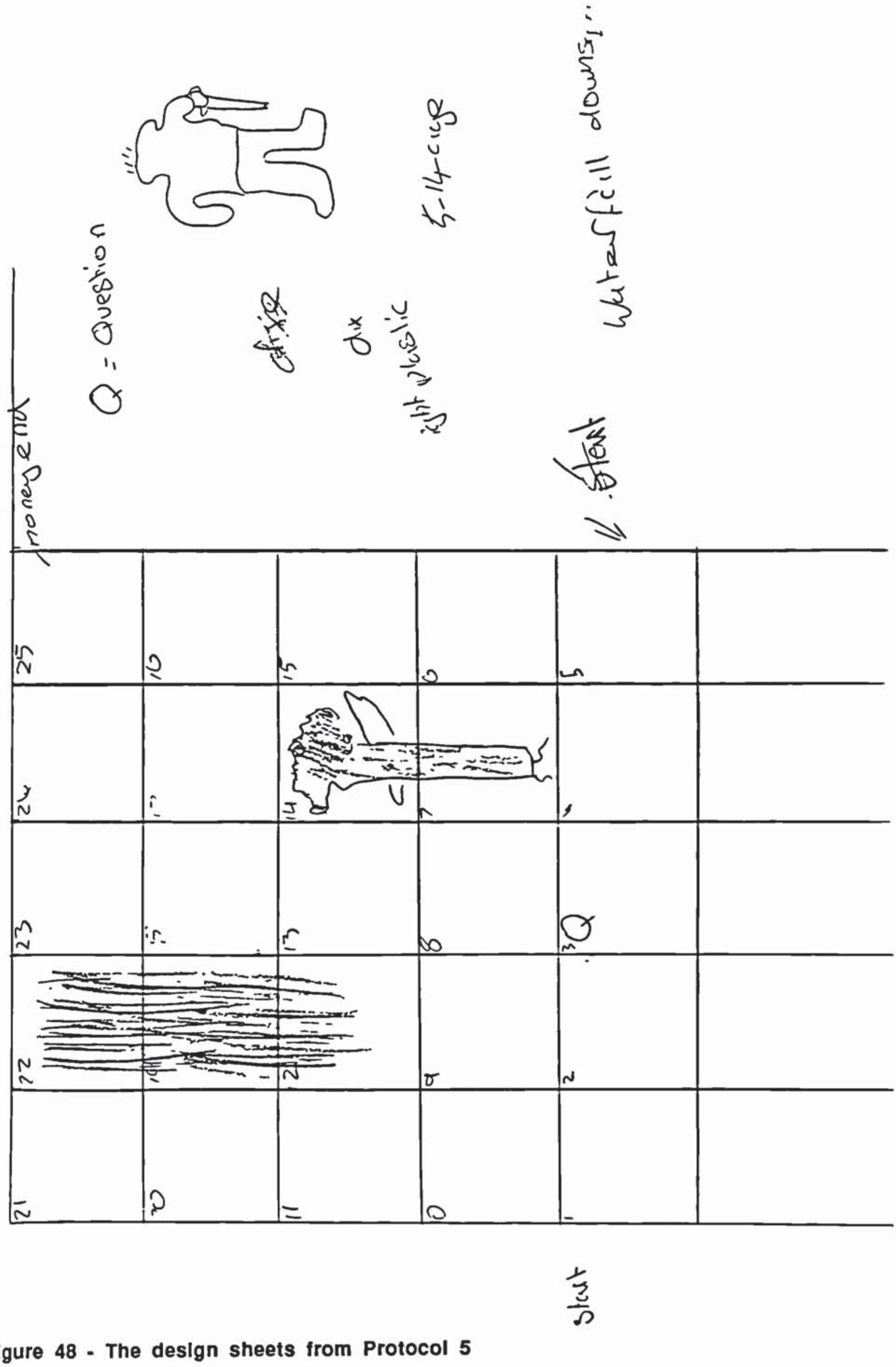

Figure 48 - The design sheets from Protocol 5

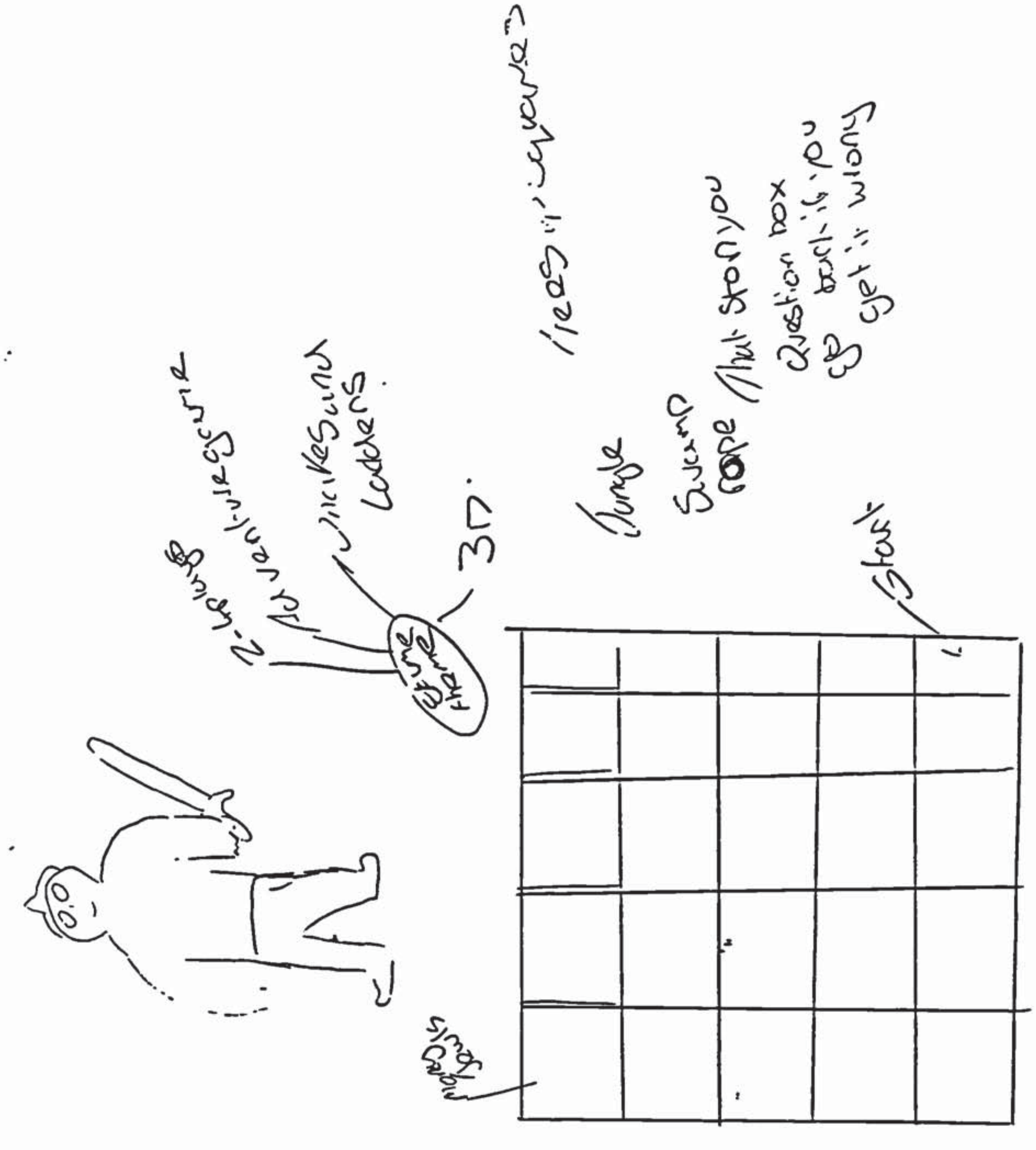

Figure 49 - The design sheets from Protocol 5

6.4 Protocol 6

The protocol was developed in three phases. First of all an analysis was conducted of the use of operators and heuristics to move through the search space. Secondly, discussion was generated around the drawings and sketches produced by the subject. Finally, the general design strategy was analysed, using the framework illustrated in chapter 3. General observations from the video material were used throughout the protocol to help develop and inform the analysis.

The aim was to provide a picture of problem solving behaviour from three different perspectives. At the end of the protocol key issues have been summarised. Discussion of the implications of the findings in terms of teaching and learning strategies appropriate to the subject have also been generated. Questions which have arisen during the development of the protocol have been highlighted and used to inform the conclusions and recommendations made in the final chapter.

A similar format has been used in all of the protocols. However, the first section on initial thoughts has highlighted issues which are particular to this protocol and which therefore may not be common to all subjects.

The subject for protocol 6 was a year 9 pupil at a large comprehensive school in the City of Birmingham. The pupil was assessed as being of above average ability in terms of design problem solving. At the time of data collection the subject had just selected Art to study at GCSE level in years 10 and 11. The subject was estimated to obtain an A/B grade in the GCSE.

The full transcript of the protocol for this subject will be found in Appendix 4.

Operator/plan		1st Coding
A	Problem restatement	0 (0%)
B	Problem elaboration/refinement	1 (6%)
C	Integration	0 (0%)
D	Holistic solution generation	2 (11%)
E	Solution elaboration/testing	10 (56%)
F	Assertions	1 (6%)
F1	Inference	2 (11%)
G	Information search	2 (11%)
H	Solution validation	0 (0%)
TOTAL		18

Table 8 - Protocol 6 results from the practice problem

Operator/plan		1st Coding
A	Problem restatement	1 (2%)
B	Problem elaboration/refinement	3 (5%)
C	Integration	5 (8%)
D	Holistic solution generation	6 (10%)
E	Solution elaboration/testing	31 (53%)
F	Assertions	0 (0%)
F1	Inference	7 (12%)
G	Information search	4 (7%)
H	Solution validation	2 (3%)
TOTAL		59

Table 9 - Protocol 6 results from the main problem

Initial thoughts

The protocol was short in terms of length and the time taken to generate the transcript. This was similar to protocols produced by other novice designers, but much shorter than those produced by expert designers. A similar pattern of thinking was observed in both the practice and main problems

In was clear that the subject had difficulty in verbalising during the task and prompting from the researcher was therefore required. It is not clear whether the problems in verbalising related to an inability to think of design ideas, or just to difficulties in externalising them. Alternatively, it is possible that the subject was nervous about 'performing' in front of a camera. The effect of this prompting is difficult to determine. Does it change the flow of ideas, or merely encourage the subject to externalise them?

It was also clear that the language level within the problem statements also caused some problems for the subject:

6/1 What are indicators?

6/20 What is a prototype?

This was an issue which was explored within the analysis of the protocol.

It was interesting to note at the outset that category 'F' - Assertion was only used on one occasion. It was also observed at this stage that often operator 'F' - Inference was preceded by operator 'E' - Solution elaboration/testing.

'A' Problem Restatement +'B' Problem Elaboration/Refinement

These two operators will be considered together as they are closely interrelated. Operator 'A' relates to:

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

Operator 'B' is concerned with:

A statement which extends and interprets information provided in the problem statement.

Operator 'A' was only used once within the practice and main problems. Operator 'B' was identified on 4 occasions. This contrasts with the evidence from the expert designers, who continuously used the two operators as reference points throughout the protocols. It may be that the novice designers are using a more solution focused approach. This notion is supported by Lawson (1979) and Kimbell et al (1991) who suggest that school pupils often have a hazy notion "in their mind's eye" of what the solution is like:

"It is not uncommon for pupils to believe that, almost from the start of an activity, they have a complete solution sorted out in their mind".

Kimbell et al (1991)

On two occasions operator 'B' was used in question form to ask the researcher the meaning of key words in the problem statements:

6/1 What are indicators?
6/20 What is a prototype?

This suggested that the subject was using the problem statement in order to interpret and understand the nature of the task, but lacked the vocabulary to full understand the meaning. However, examples of the direct use of categories 'A' and 'B' can be seen at:

6/23 It can only take 20 minutes
6/24 That it has to have a set of rules
6/25 Packaging

These were used at the beginning of the main problem and were not observed in the remainder of the transcript. However, the design sheets developed during the protocol indicate that the subject developed a 'scattergraph' at the beginning of the process. This diagram (see Figure 53) included an analysis of the problem statement.

'C' - Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems.

Category 'C' - was not observed within the practice problem but was identified on 5 occasions (8%) in the main problem. Was this because of the different types of problems used within the practice and main sessions?

An example of systematic exploration of sub-problems followed by the generation of sub-solutions can be seen in the following passage:

6/26 It is going to be a football
6/27 which needs a ball
6/28 players
6/29 questions
6/30 The ball is a dice
6/31 Questions for a goal

In this section the subject appeared to be simultaneously discussing two elements of the problem. This resulted in decisions related to sub-solutions being made at 6/30 and 6/31.

The example at 6/68 further illustrated the subject's ability to analyse sub-elements and then to generate sub-solutions based upon this analysis. This suggested that the subject demonstrated, in places, similar problem solving strategies to those identified in expert designers:

6/68 like a photograph type of a football pitch and a goal being scored.

'D' - Holistic Solution Generation

The generation of solutions from an undetermined or apparent intuitive source

This use of this operator was identified on 2 occasions (11%) in the short practice problem and on 6 occasions (10%) in the main problem. In the practice problem two examples can be identified which do not appear to be related to previous segments within the transcript:

6/16 A circle name plate
6/19 I am thinking of a tea or coffee cup

In the main problem, the protocol started with the generation of an holistic solution, or overall solution concept, to the problem from apparent intuitive source. This was followed by the use of operator 'A' and 'B' to provide a framework for the subsequent analysis:

6/22 Football
6/23 It can only take 20 minutes
6/24 That is to have a set of rules
6/25 Packaging

Although the use of operator 'D' was identified on 6 occasions in the main problem, all were related to the overall solution concept identified at the outset. The subject appeared to have found it difficult to move beyond the original concept. Does this suggest that novice designers confirm the pattern to the solution very early in the process? Do novice designers find it difficult to move away from an original idea?

'E' - Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions

This was the major operator used within both design tasks. In the practice problem, category 'E' was identified on 10 occasions (56%) and on 31 occasions (53%) in the main problem. In the first task, the subject appeared to follow an analysis > synthesis > evaluation model. The problem was broken down into a number of sub-problems which were generated from the problem statement (and which perhaps could have been coded as 'B'):

6/4	A scattergraph naming the points
6/5	the height of it
6/6	that it has to be small
6/7	that it can't get knocked over

From this brief analysis a solution was generated and the subject then worked on sub-solutions to the overall problem:

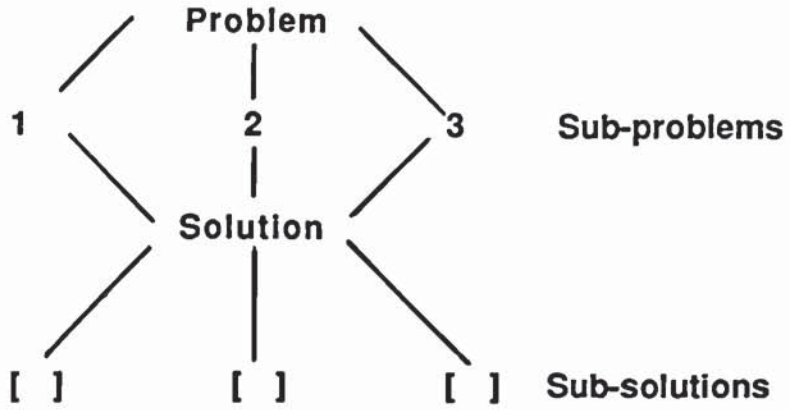

Figure 50 - Development of sub-solutions within Protocol 6

In the main problem, the subject identified a concept of the solution very early in the process and then gradually refined this whole concept into sub-solutions. A great deal of detail was generated for these sub-solutions and the subject did not move away from the initial concept which was put forward at the start of the protocol:

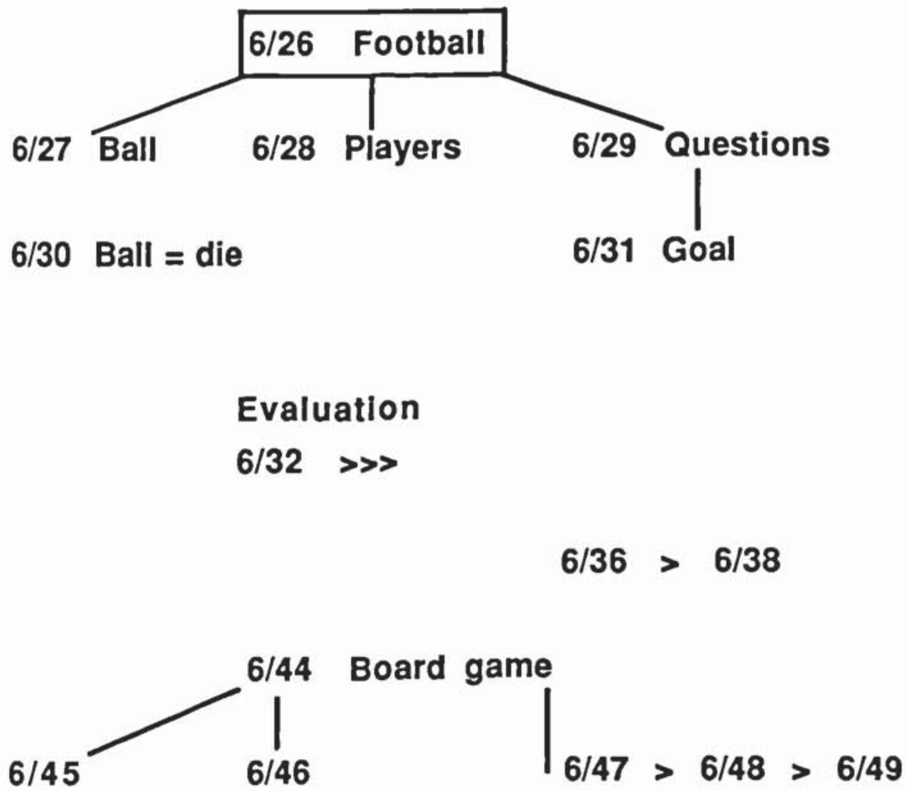

Figure 51 - Developing the initial solution concept

The strategy used here seemed to be the reverse of the analysis-synthesis-evaluation model illustrated above:

Synthesis >> Analysis >> Evaluation >> Analysis >> Synthesis

This could also be described in the following way:

Problem >> Solution concept >> exploration >>
Sub-solutions >> Solution validation

It was interesting to note that category 'E' was often followed by 'F1' - Inference. This perhaps suggests that inference was used bring the sub-elements to conclusion:

6/32	whether it is supposed to be like questions
6/33	or like tiddlywinks or something like that
6/34	Something for an active game
6/35	That it can't be boring

'F' - Assertions

Assertions from the generation of new information from internal sources.

The use of this operator was identified on 1 occasion (6%) in the practice problem. In the main problem it was not identified on any occasion (0%). This contrasted with the examples found in the protocols of expert designers in which assertion was used to set-up the sub-element, followed by the use of category 'E' to explore the sub-element and operator 'F1' inference to conclude the sequence. An example of this cycle can be seen in the practice problem:

6/15 I have to make an original design
6/16 A circle name plate
6/17 I am thinking of something that will stand up
6/18 By structuring it

Is the use of 'F' - Assertion an important part of the process? If so, how can this skill be developed in novice designers? What type of teaching strategies could be used? Is the use of this operator linked to operators 'E' and 'F1'.

'F1' - Inference

Higher order conclusions, propositions or justifications not given in the problem statement but generated by the problem solver.

The operator was used on 2 occasions (11%) in the practice problem and on 7 occasions (12%) in the main problem. This was usually preceded by 'E' - Solution elaboration and testing in the cycle described above:

6/51 How to make the board look better
6/52 The rules
6/53 one of them is that when you land on a free kick
6/54 you have to have another roll of the dice

The importance of this cycle within the design problem solving process needs to be considered. Should this cycle be taught? If so, how can this be done?

'G' - Information Search

The initial application of technological or other forms of knowledge to help the development of sub-solutions. N.B. subsequent use of this knowledge will be coded under category 'E'.

The use of this operator was identified on 2 occasions (11%) in the practice problem and on 4 occasions (7%) in the main problem:

6/12 Something that can be stuck on
6/13 or nailed in maybe
6/66 in blue marker pen
6/71 cardboard
6/72 and maybe a plastic ball as a dice
6/76 pieces as plastic

The subject demonstrated a poor design and technological vocabulary and poor technological knowledge with little reflection on the processes and materials which underpin the process. To what extent can this knowledge and understanding be developed?

However, the nature of the design task may not have encouraged the use of a wide vocabulary or technological knowledge. It may be that in the initial exploration the subject was dealing with broad concepts rather than detailed information.

'H' - Solution Validation

Testing, justifying and revising of a solution to the problem.

This operator was not used in the practice problem (0%) and was identified on 2 occasions (3%) in the main problem. These came at the very end of the protocol and only emerged because of prompting by the researcher:

What do you think of what you have designed?
6/82 Could do better
How would you improve it?
6/83 Take longer over it

The comments at 6/82 and 6/83 seem to be too general to be of much help in the process and may have only emerged because of the prompting. It is possible that the subject was still nervous at this stage and was keen to end the activity. However, this element was clearly identifiable in the practice of expert designers. How can it be developed with novice designers? Which strategies would be most appropriate?

Heuristics

This was a short protocol and the subject was plainly nervous about designing under research conditions. However, interesting insights into the general design strategies and rules of thumb were identified during the process.

In the practice problem, the subject appeared to use a systematic form of hill climbing at the start of the process. This was aided by the use of a scattergraph to analyse the problem statement (6/4). Hill climbing was also identified at the outset of the main problem. At this stage (6/21), the subject indicated that a general solution concept had been formulated related to a hobby:

6/22 Football

6/26 It is going to be a football

Whether this was a true example of hill climbing is open to debate. It may be that the subject was merely drawing upon a major aspect of her past experience in order to generate design concepts.

Means-ends-analysis was used in a number of places in the main problem. The sequence below shows this strategy being used to 'pop' off a sub element of the solution:

6/26 It is going to be a football
6/27 which needs a ball
6/28 players
6/29 questions
6/30 The ball is a dice
6/31 Questions for a goal

However, in places the subject seems to be justifying and providing detail to the solution. An example of this can be seen between 6/40 and 6/50.

Another example of means-ends-analysis could be identified between 6/52-6/63. The subject seemed to be gradually 'popping' off a sub-solution. The word 'when' was prominent in this sequence:

6/52 The rules
6/53 one of them is when you land on a free kick
6/54 you have another roll of the dice
6/55 When you land on a penalty
6/56 you take a penalty question
6/57 and you can score a goal
6/58 When you land on an injury square
6/59 you miss a go
6/60 When you land on a plain square
6/61 then do nothing
6/62 When you land on half-time
6/63 you miss a go

A form of pattern matching was identified at 6/32:

6/32 Whether it is supposed to be like questions
6/33 or like tiddlywinks or something like that

Research approach 2 - Design Strategy

The subject appeared to develop an holistic solution at the outset of the problem and then explored this problem in a serialistic and convergent way. That is to say, the subject was tending to work in small logical steps and attempting to clarify each point before moving on to the next. The result was a narrow and straight path through the problem space with little digression from the original concept which was determined at the beginning of the process.

This strategy would seem to be similar to the serial-analytic-holistic strategy put forward by Tovey (1986) which is based upon the use of holistic thinking as an initial strategy in order to develop a detailed overall concept of a solution which provides the framework for more detailed analysis.

In describing behaviour in terms of the key words put forward by Kimbell et al (1991), the following appear to be applicable to this subject:

Safe - the subject took a fairly safe route through the problem space. The solution to the main problem was based upon a hobby of the subject and little attempt was made to move away from this initial solution concept.

Focused - the subject focused upon solution concepts at an early stage in the process. In the practice problem, this was aided by the use of a 'scattergraph' to provide a framework for the this solution concept.

Preoccupied - the subject was clearly preoccupied with single solution concepts in both the practice and main problems. This preoccupation ensured that the subject did not move outside these initial concepts. Consequently, there was no evidence of the use of hill climbing after the initial stages.

Predictable - the subject followed a very predictable route through the problem space with few surprises or changes in direction being identified.

The reflective/active model was difficult to apply in this context. However, there was evidence that the subject moved between the two abilities. The process started with the generation of a concept solution, which could perhaps be described as active ability, and then moved backwards and forwards between the two. Reflective ability could be identified when the subject was thinking around the task and considering issues which were directly related to it. Active ability could be identified at the outset and as sub-solutions were concluded during the exploration process. However, the model generated from this process may contrast with the one put forward by the SEAC/EMU (1990).

Comparison of the strategies adopted by the novice designer within this research project with those for novice and expert designers put forward by Krampen (1983) raises some interesting issues. This subject produced a much shorter design cycle which seems to illustrate that novice designers are often unable to move from the single solution concept developed at the outset.

In comparing the behaviour of the subject with the analysis > synthesis > evaluation model, the subject would appear to work to the reverse of this model:

synthesis > analysis > evaluation

However, this may be too simplistic to explain the process and the concept solution > problem definition > exploration > validation model described above may a more accurate way of describing the subject's behaviour.

From the discussion above, it can be clearly seen that the subject adopted a solution focused approach when solving the problem. Reference to the problem statement was only made at the outset and the subject did not use the referral-back model which was identified with one of the expert designers. However, use of the problem statement may have been implicit within the protocol and would therefore not have shown up in the encoding.

'Satisficing' appeared to occur very early within the process. This suggested that the development of the initial solution concept provided the 'primary generator' at this very early stage of the process

Research approach 3 - Drawing and modelling

1 The use of drawing to support thinking

The subject used drawings and notes to explore first ideas. This started with an analysis of the problem statement in which the subject was identifying and interpreting the constraints embodied in the statement. The detail of this was not apparent through the analysis of operators.

The subject did not undertake a rapid exploration of a large number of ideas through free ranging drawing, but tended to use words and drawings to refine the original concept solution. A 'scattergraph' was used in the initial stages of the practice problem in order to analyse the constraints embodied in the problem statement. The drawing for synthesis provided detail related to sub-elements as the subject progressed from concept to format.

2 The style and nature of the drawing

The range of drawings and depth of issues explored was quite narrow, but the drawings of elements of the single solution explored were quite detailed and helped to clarify the overall concept. The subject did not go beyond this stage within the time available.

The drawings were quite clear and supported by written notes which were either based around 'spider' diagrams or were in point form. These drawings were mainly in a 2D format. The communication was generally confident and suggested that the subject could develop a bold style which would help the exploration of ideas. This issue has been considered under teaching strategies.

3 The use of modelling to support thinking

Modelling was not used within the process. This could have been due to the nature of the task and the phase of design activity considered within this research project.

Conclusions

General comments

This was the shortest protocol of the three novice designers. This may be due to the stress of data collection. Perhaps future research could be undertaken in a less-threatening way. The effects of prompting also need to be considered.

Issue 1

Little use was made of operators 'A' or 'B' during the practice problem. The subject appeared to be working very much in a solution-focused manner and made little use of the problem statements either as a means of providing a reference point during the process, or in order to develop new constraints to inform the problem solving framework. This seems to be a common problem with novice designers. In the main problem there was evidence that the subject used a 'spider' diagram to consider the constraints embodied in the problem statement. This could form the basis of a teaching strategy to encourage the use of these operators.

Issue 2

In both the practice and main problems the subject found it difficult to move beyond the holistic solution concept developed at the outset. It seemed that the desire to seek a solution proved to be an overwhelming constraint within the problem solving process. This may have been because the novice designers lacked the expertise, experience and confidence found in expert designers. It may also be because novice designers are often solving problems with tight time constraints. Whatever the reason, it would seem to be essential for novice designers to be encouraged to widen the search space at the outset. Jones (1970,1981) describes these methods of searching for ideas as divergence and transformation.

Issue 3

The cycles surrounding operators 'E', 'F' and 'F1' provided interesting information about the strategies employed by the subject within sub-elements of the problem. The subject appeared to have demonstrated an ability to analyse these sub-elements through the use of operator 'E' - Solution elaboration and testing followed by operator 'F1' - Inference. This cycle was similar to that found with expert designers, but in the case of expert designers the cycles were often started through the use of operator 'F' - Assertion. In other words, the expert designers appeared to be generating a type of hypothesis through the use of 'F' and then exploring it using 'E' and then concluding the cycle by testing through the use of 'F1'. This cycle, or heuristic, seems similar to the hypothesize-and-test model discussed in Chapter 3. It may also be similar to means-end analysis.

In the development of teaching strategies, there is a need to use appropriate heuristics to develop cycles of exploration:

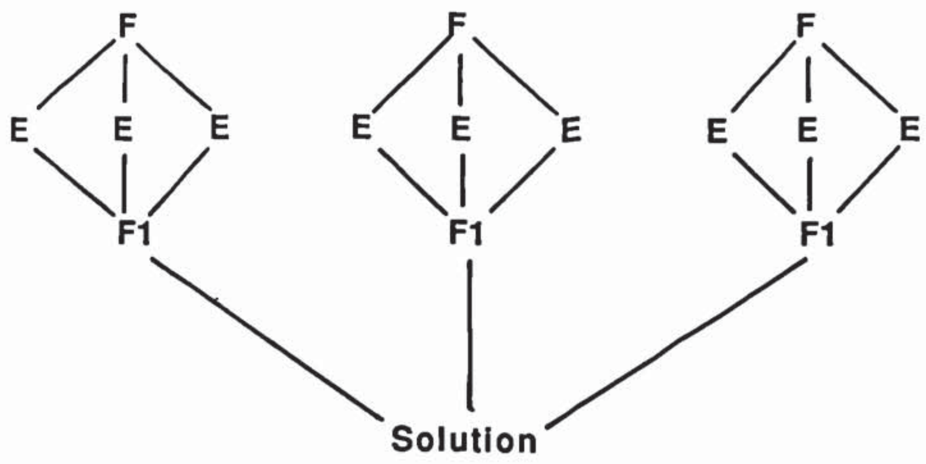

Figure 52 - Developing cycles of exploration

Issue 3

The subject generally demonstrated a poor design and technology vocabulary and knowledge. This made it difficult for the full meaning of the problem statement to be understood. The subject only gave details of materials used within the solution in a very general way. This illustrates a dilemma for design and technology teachers who are often trying to balance approaches which encourage problem solving with the development of craft skills and subject knowledge. It indicates that teaching strategies will need to balance these issues, particularly within the foundation programmes for design and technology. There therefore seems to be a need to develop a design and technology vocabulary around each problem undertaken by pupils. The pilot SATs materials provide examples of the aspect (MEGNAP D&T, 1990).

Issue 5

The subject seemed to have few strategies for validating and evaluating solutions during the process. This may be because of the nature of the research and the consequent phase of design activity undertaken within the protocol. However, even when prompted by the researcher the subject only made very general comments in this area and seemed to find it very difficult to undertake more detailed evaluation and validation of the solution. This perhaps suggests the need for teaching strategies to focus explicitly upon this aspect of design problem solving.

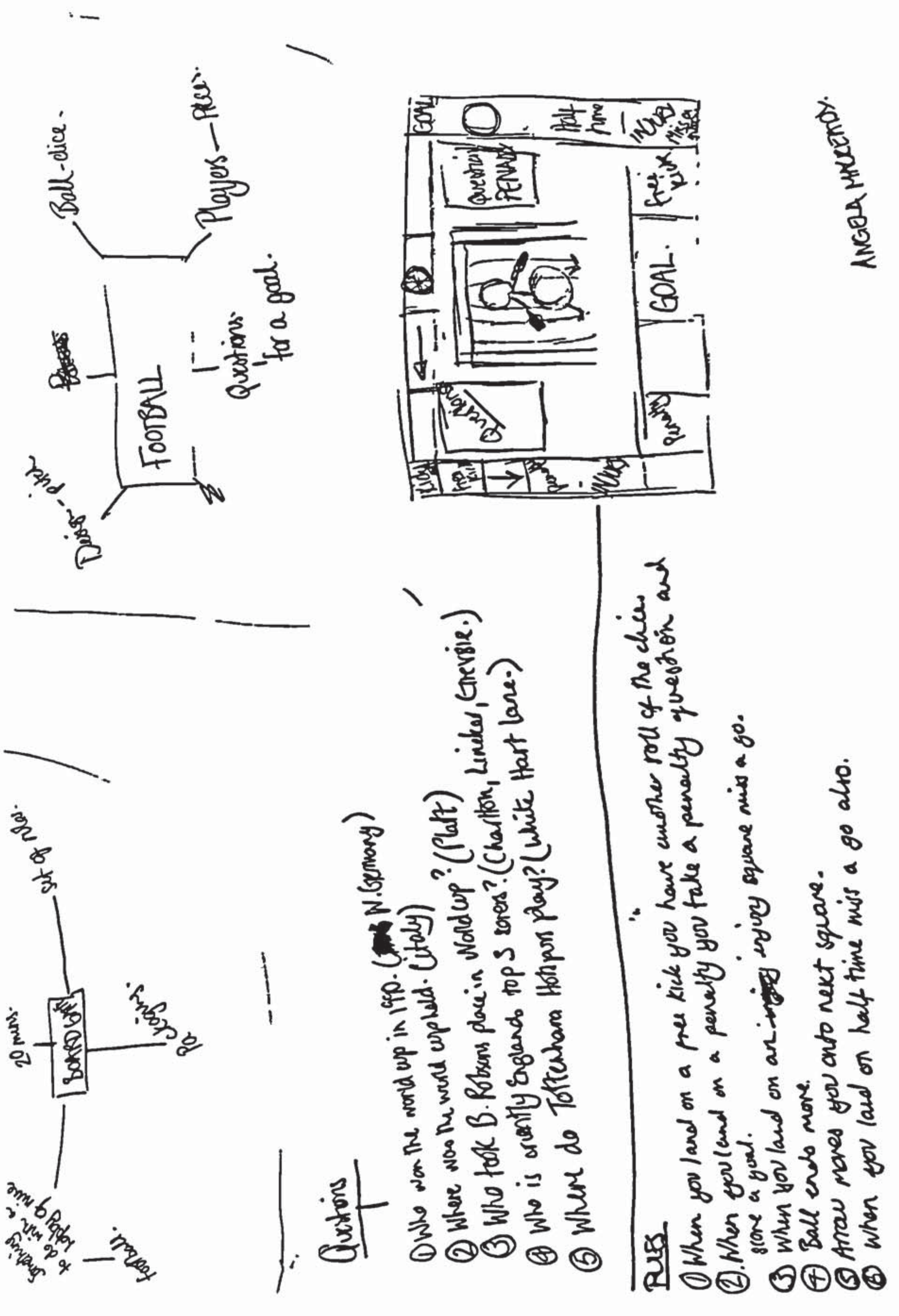

Figure 53 - The design sheets from Protocol 6

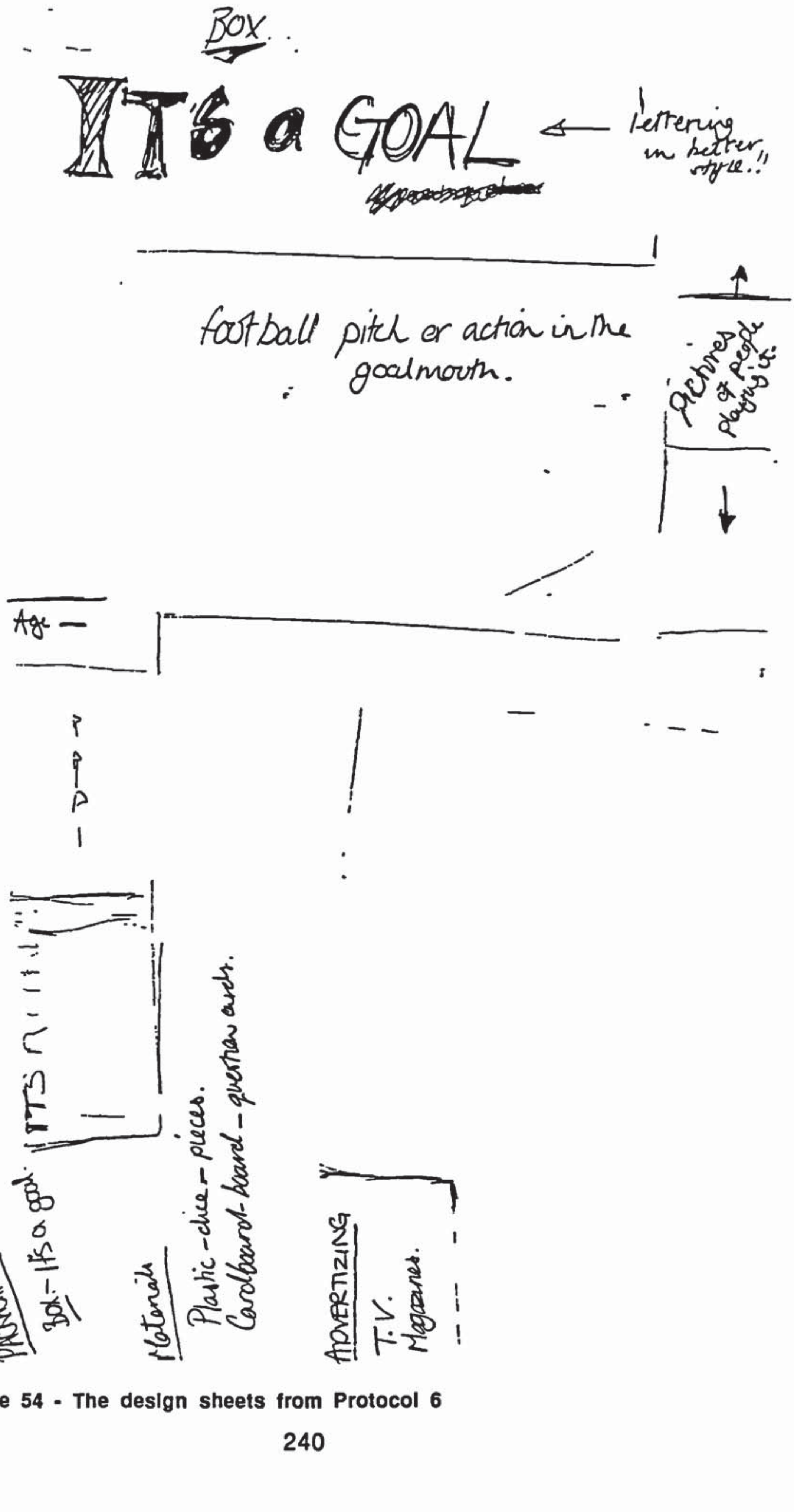

Figure 54 - The design sheets from Protocol 6

6.5 Protocol 7

The protocol was developed in three phases. First of all an analysis was conducted of the use of operators and heuristics to move through the search space. Secondly, discussion was generated around the drawings and sketches produced by the subject. Finally, the general design strategy was analysed, using the framework illustrated in chapter 3. General observations from the video material were used throughout the protocol to help develop and inform the analysis.

The aim was to provide a picture of problem solving behaviour from three different perspectives. At the end of the protocol key issues have been summarised. Discussion of the implications of the findings in terms of teaching and learning strategies appropriate to the subject have also been generated. Questions which have arisen during the development of the protocol have been highlighted and used to inform the conclusions and recommendations made in the final chapter.

A similar format has been used in all of the protocols. However, the first section on initial thoughts has highlighted issues which are particular to this protocol and which therefore may not be common to all subjects.

The subject for protocol 6 was a year 9 pupil at a large comprehensive school in the City of Birmingham. The pupil was assessed as being of average ability in terms of design problem solving. At the time of data collection the subject had just selected Design and Communication to study at GCSE level in years 10 and 11. At the time of writing this report, the subject was estimated to obtain a grade B in the 1993 GCSE.

The full transcription of the protocol for this subject will be found in Appendix 5.

Operator/plan		1st Coding
A	Problem restatement	0 (0%)
B	Problem elaboration/refinement	2 (6%)
C	Integration	0 (0%)
D	Holistic solution generation	5 (14%)
E	Solution elaboration/testing	11 (31%)
F	Assertions	0 (0%)
F1	Inference	7 (20%)
G	Information search	8 (23%)
H	Solution validation	2 (6%)
TOTAL		35

Table 10 - Protocol 7 results from the practice problem

Operator/plan		1st Coding
A	Problem restatement	0 (0%)
B	Problem elaboration/refinement	2 (3%)
C	Integration	0 (0%)
D	Holistic solution generation	7 (10%)
E	Solution elaboration/testing	32 (45%)
F	Assertions	1 (1%)
F1	Inference	9 (13%)
G	Information search	12 (17%)
H	Solution validation	4 (6%)
TOTAL		71

Table 11 - Protocol 7 results from the main problem

Initial thoughts

It was immediately noticeable that the protocols of the 'novice' designers were much shorter than those of the 'expert' designers. The main problem for Protocol 7 has been codified into 104 segments. This compares with 845 for Protocol 3 and 802 for Protocol 4. The other novice designers produced 117 (Pro 5) and 83 (Pro 6). Does this mean that the 'novice' designers are processing less information when designing?

'A' Problem Restatement +'B' Problem Elaboration/Refinement

These two operators will be considered together as they are closely interrelated. Operator 'A' relates to:

An exact copy or restatement of the whole or part of the problem statement, or a verbalisation which captures the basic content of the problem statement.

Operator 'B' is concerned with:

A statement which extends and interprets information provided in the problem statement.

Operator 'A' was not identified in either the practice or main problem. Operator 'B' was observed on 2 occasions (6%) in the practice problem and also on 2 occasions (3%) in the main problem.

The practice problem illustrated the immediate generation of an holistic solution - coded as 'D' - to the problem, preceded by a rapid analysis of the problem statement using the codification 'B - Problem restatement/refinement' :

7/1 So it's an actual stand
7/2 for a name to go on
7/3 I will do a metal frame
7/4 with a board
7/5 with a name on it

The first two phrases (7/1, 7/2) illustrated that the subject had understood some of the essential design constraints embodied in the problem statement. However, these were the only referrals to the problem statement and operator 'A' - Direct problem restatement was not used at any stage during the practice problem. This perhaps illustrates that either the problem was very straight forward with the 'novice' designer finding it easy to pick out the main constraints, or the subject was keen to move rapidly to a solution-focused approach (Lawson, 1979).

A close examination of the problem statement reveals that a number of design constraints can be identified :

> **Practice problem**
> **Small indicators are required to stand in the desks of a large office to display the name of the person working at the desk. Design a simple neat stand that would suit the purpose, occupy as little space as possible on the desk but still be such that it cannot be knocked over easily. The letters forming the name are to be 20 mm high.**

From the problem statement the following design constraints can be identified:

Indicators
Small
Stand on desks
Large office
Display name of person
Simple
Neat
Suit purpose
Occupy little space
Not easily knocked over
Letters 20 mm high

Chan (1990) suggests that an 'expert' designer would use these constraints as a framework for designing and may add to them their own constraints during the process. For example, a general framework for designing could include such issues as materials, function and size.

In the main problem, the subject again did not use category 'A' - Problem restatement and only used category 'B' - Problem elaboration/refinement on two occasions, both in the latter stages of the protocol. These seem to have been as a result of prompting by the researcher:

Have another read of the sheet and see if there is anything else you need to think about.

7/79 For the packaging

7/80 you would need a cardboard box

7/81 What is a prototype?

7/81 suggested that the subject attempted the problem without fully understanding the constraints embodied within it. This seemed to further illustrate that the subject appeared to move very quickly into a solution-focused approach. It may be that strategies to aid a problem-focused approach would help this novice designer.

However, the subject at this stage may have been developing conceptual ideas for the solution and would be more concerned with detail at a later stage. Or was the subject decomposing and narrowing the constraints in order to achieve a solution to the problem? (Carroll et al, 1979)

'C' - Integration

The generation of new partial or whole solutions to the problem based upon previous exploration of the sub-problems.

Operator 'C' could not be identified in either the practice or main problem. The subject appeared to generate a number of holistic solutions to tasks which were then followed by exploration of the sub-problems. In other words, the subject was adapting a strategy which was the reverse of the analysis > synthesis > evaluation model implied in the coding schedule.

It would therefore appear that the subject was working in the following way:

Solution
*
Analysis
*
Evaluation

The subject seemed to develop whole solutions to the problem and analyse them, rather than set up a framework of sub-problems (possibly from design constraints) to aid the process. This further illustrated the need for structured teaching approaches linked to the constraints embodied in the problem statement. These are discussed in the final section.

'D' - Holistic Solution Generation

The generation of solution to the problem from an undetermined or apparent intuitive source.

The use of this operator was observed on 5 occasions (14%) in the practice problem and on 7 occasions (10%) in the main problem. This suggested that the subject was able to develop a range of solutions within both the practice and main problems.

Within the practice problem, the first solution to the problem was quickly followed by two more:

7/7 I could have a wooden triangle

7/12 Or I could have a rectangular piece of wood

The early part of the protocol seemed to suggest the widening of the search space through a multi-solution approach:

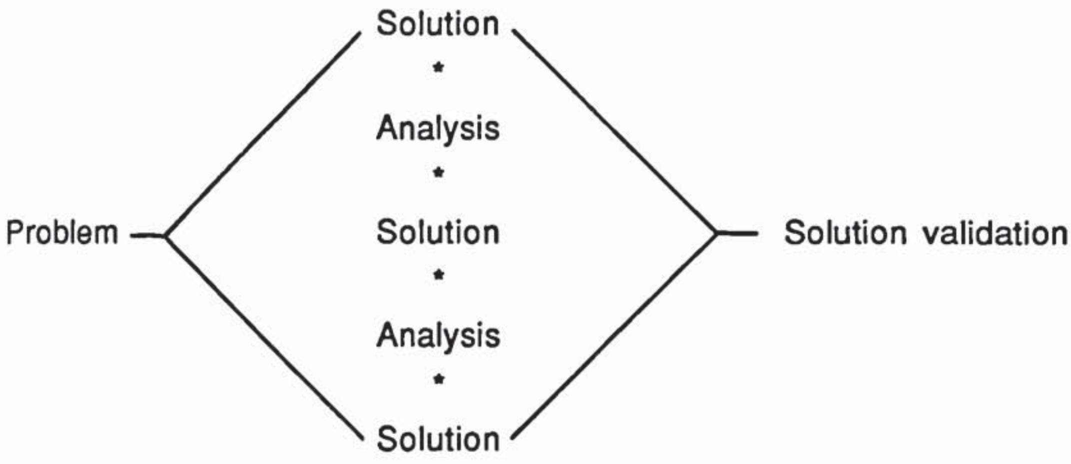

Figure 55 - Developing a wide search space

It can be seen that the subject developed a range of solutions during this first part of the protocol, and indeed created a large search space in a very short period of time. These were mainly holistic solutions which seem to come from an apparently intuitive source and were not preceded by an analysis of sub-problems. They could be described as solution concepts rather than detailed solutions.

In the main problem, category 'D' was seen at the very beginning of the protocol (7/37-7/39) when the the solution which dominates the protocol was identified:

7/37 I think I will do a game where the characters have to get to a certain place

7/38 and the first one that gets there wins

The only other use of this operator occurred at:

7/74 I could have a different set of rules

The rest of the protocol involved a complex analysis of this single solution. Towards the end, when prompted by the researcher, the subject developed a second holistic solution to the problem. However, this quickly fizzled out:

Any other ideas for a board game apart from this one/

7/99 I could do an adventure game

7/100 where you have to kill a monster

7/101 like Hero Quest or something like that.

The subject then quickly returned to a sub-element of the problem statement:

7/102 in order to fit in all the things

The diagram below illustrates the framework of solution(s) and sub-solutions developed during the design problem solving process:

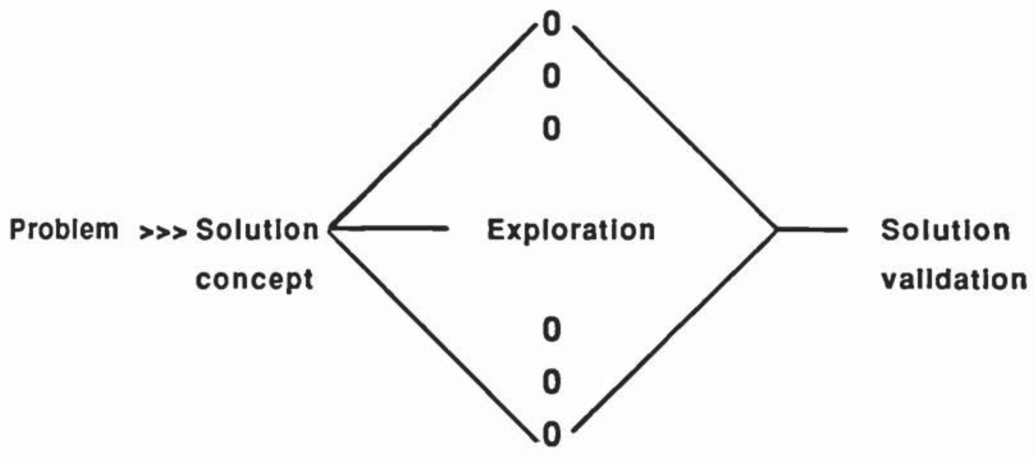

Figure 56 - A framework of solutions and sub-solutions

It is possible that the development of the single solution concept within the main problem was because the problem was more complex and therefore required the subject's full attention.

'E' - Solution Elaboration/Testing

The exploration of potential solutions perhaps through the generation of a range of sub-solutions.

Operator 'E' - Solution elaboration/testing was used extensively at this stage to move through the search space. It was identified on 11 occasions (31%) in the practice problem and on 32 occasions (45%) in the main problem.

On first examination, the problem space of the main problem looked structured but in reality it consisted mainly of an elaboration of the first solution with limited analysis. Perhaps a framework based upon the design constraints would help the designer decompose the overall problem into a range of sub-problems. Carroll et al (1979) discuss this notion of decomposition. Nevertheless, it is possible to show graphically the range of this early thinking. It should be noted , however, that charts of this type can imply a clear structure which does not exist in reality:

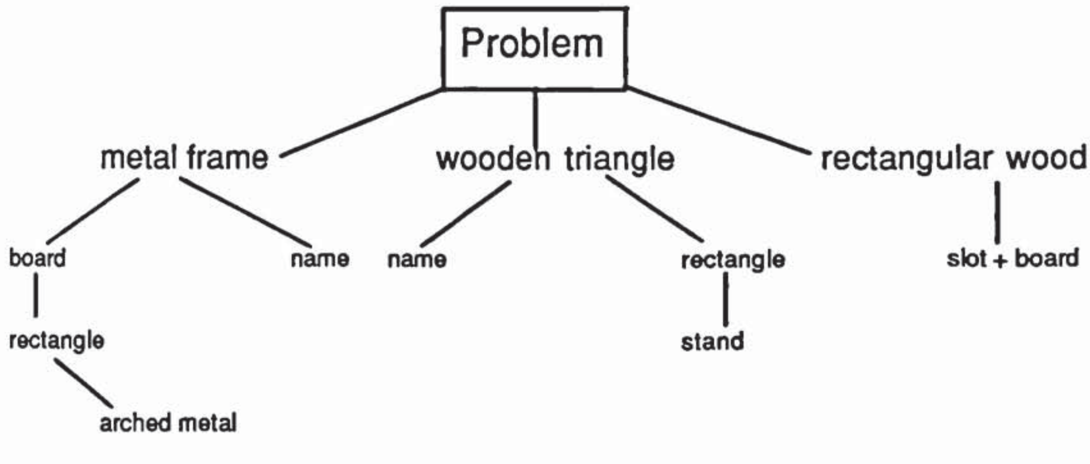

Figure 57- The decomposition of the problem into sub-problems

As with the other novice designers, the use of operator 'E' was followed by operator 'F1' - Inference. This suggested that the subject was setting up exploratory cycles which were concluded by the use of 'F1'.

'F' - Assertions

Assertions from the generation of new information from internal sources.

Operator 'F' - Assertion was not identified in the practice problem and was only identified on 1 occasion (1%) in the main problem. It was clear that the subject was not following the pattern identified in expert designers in which the subject uses operator 'F' to set up an exploratory cycle:

'F' >> 'E' >> 'F1'

This is an issue which will be considered in the discussion of teaching strategies.

'F1' - Inference

Higher order conclusions, propositions or justifications not given in the problem statement but generated by the problem solver.

This operator was identified on 7 occasions (21%) in the practice problem and on 9 occasions (13%) in the main problem.

'F1' - Inference had a key role in concluding exploratory cycles and was usually preceded by category 'E' - Solution elaboration/testing:

7/46 You could collect things along the way
7/47 to help you get through the black hole

7/52 with various problems
7/53 like being attacked by other spaceships

'G' - Information Search

The initial application of technological or other forms of knowledge to help the development of sub-solutions. N.B. subsequent use of this knowledge will be coded under category 'E'.

Operator 'G' - Information search was identified on 8 occasions (23%) in the practice problem and on 12 occasions (17%) in the main problem. It could therefore be seen that in both problems the subject had a large percentage of the protocol coded as 'G'. However, on closer examination it appeared that this knowledge was of quite a general nature. Nevertheless, the subject was clearly using this basic knowledge of design and technology processes more explicitly than the other novice designers:

7/7	and arched metal frame
7/14	Plastic for the actual name
7/15	and wood or metal
7/16	or I could do a triangle
7/21	Paint them on
7/22	or little letters glued onto the box
7/30	With some thin white plastic
7/32	Stick some black letters

The problem of dual coding was apparent when assigning this operator to segments of the transcript.

'H' - Solution Validation

Testing, justifying and revising of a solution to the problem.

This operator was observed on 2 occasions (6%) of the practice problem and on 4 occasions (6%) in the main problem.

Category 'H' - Solution validation was only used when the subject was prompted by the researcher:

Which of those ideas do you like best?

7/29 The one with the bulb in that lights up the letters

Solution validation was also observed at:

7/35 My second choice would be the one with slots

On this occasion, the solution validation was unprompted, but perhaps influenced by the first prompting by the researcher. This may illustrate the need for guidance or structure in this area. This issue is discussed in the section relating to the teaching strategies appropriate for this subject.

Heuristics

The practice problem illustrated an interesting process with a simple search strategy seemingly used by the subject. This could be described as a straight-in - multi-solution approach in which conceptual solutions were developed, possibly based upon the past experience of the subject rather than through a thorough analysis of the problem.This seems to relate to researcher's experience in schools which suggests that the very first ideas developed seem to dominate pupil thinking processes. Kimbell et al (1991) also support this view of design behaviour demonstrated by novice designers. In the practice problem, detail is not discussed until 7/21, and this only occurs after prompting by the researcher.

The behaviour of the novice designer within this problem suggested a hill climbing search strategy in which the search started from any point in the search space. However, each cycle of the four holistic solutions suggested that perhaps the subject was using a means-end-analysis heuristic. For example, between 7/3 and 7/7 the subject was exploring a possible solution to the problem which was temporarily accepted at 7/7. This happened several times within the cycle before 7/25 was accepted at 7/25-7/29 and verified at 7/30-7/34:

Temp. Accept Reject

7/3 - 7/4 - 7/5 - 7/6 >>>>>>>>> 7/7

7/8 - 7/9 - 7/10 >>>>>>>>>>>> 7/11

7/12 - 7/13 - 7/14 >>>>>>>>>>> 7/15

7/16 - 7/17 >>>>>>>>>>>>>>>>>>>>>

7/18 - 7/19 >>>>>>>>>>>>>>>>>>>>>

7/23 - 7/24 - 7/25 >>>>>>>>>>>>>>>>>>>>>>>>>>

7/26 7/27 >>>>>>>>>>>>>>>>>>> 7/28

7/29 -----7/25 <<<<<<

7/30-7/34
Verification

Figure 58 - The use of means-ends-analysis within Protocol 7

In the main problem, means-end-analysis was also evident. The cycle in this case was much longer, starting at 7/37 and concluding at 7/57. This sequence included several shorter cycles, each of which seemed to use a form of means-end analysis, with sub-solutions being temporarily accepted before acceptance of the overall concept at 7/57.

Research approach 2 - General design strategy

The practice problem suggested that the subject was a divergent thinker as a large number of solutions were developed within a very short period of time. Within the protocol, six principal solutions were generated during a five minute period. However, analysis of the protocol developed for the main problem suggested a more holistic/convergent approach with only one overall solution being considered. These conflicting findings could suggest that the nature of the problem may be related to the approach adopted. The first problem was quite simple and straight forward and would allow subjects to draw upon their past experience in a direct way. The second problem was rather more complex and perhaps resulted in a rapid move towards a single solution, followed by verification of that solution.

In terms of Tovey's description, the main problem suggested an holistic synthetic strategy. Tovey suggests that this approach involves a concept-led solution in which there is little need to evaluate alternative proposals as the initial concepts have already been through an evaluative filter.

In describing behaviour in terms of the key words put forward by Kimbell et al, the following appear to be applicable to this subject:

Focused - in terms of always looking for a solution to the problem.

Systematic - relating to the systematic detailing of the single solution put forward at the outset. This really relates to the process of synthesis rather than analysis.

Intuitive - solutions appear to come from intuitive sources. Little use is made of the problem statement to develop a constraints framework.

In comparing behaviour with the APU model, which discusses the interaction of mind and hand, it can be seen quite clearly that the subject did not demonstrate the processes embodied in the model. A process of discussion which gradually leads towards more concrete solutions was not really evident in the behaviour of the subject. What is more evident when also looking at the evidence from the video and drawings/models, is the interaction of mind and hand to verify the holistic solution developed at the outset:

Imaging | **Confronting**

Holistic solution development >>>>>>> Verbally externalised +

<<<<<<<<< Drawing

>>>>>>>>>>>>>>>>>>

<<<<<<<<<<<<<<<<<<

Details verified >>>>>>>>>>>>>>>>>Verbally externalised +

<<<<<<<<<<<<<<<<< recording

>>>>>>>>>>>>>>>>>>>>>>>>>>>

<<<<<<<<<<<<<<<<<<<<<<<<<<<

Continuation of verification >>>>>>>>> Verbally externalised +

<<<<<<<<< drawing

>>>>>>>>>>>>>>>>>>>>>>>>>>>

<<<<<<<<<<<<<<<<<<<<<<<<<<<

Validation >>>>>>>>>>>>>>>>>>>>> Modelled

Figure 59 - The interaction of mind and hand in Protocol 7

The models of Krampen describing the behaviour of 'expert' and 'novice' designers provided an interesting basis for discussion. Krampen suggests that 'expert' designers solve problems in the following way;

Familiarisation with problem
Clarification by sketching
First solution attempt
Verification and rejection
Second attempt
Presentation of solution and correction of minor mistakes
Verification

Krampen indicates that 'novice' designers follow a route which includes more attempts at a solution with little clarification through sketching, and verification left until the latter stage:

Definition of the problem
Possible choice for solution
Simplification
First attempt solution
Reiteration and second attempt
Third attempt
Verification and presentation
Summing up difficulties of problem

The structure apparent within the main problem of protocol 7 was much shorter and differed considerably from the models put forward for novice and expert designers. The basic process involved the generation of a single solution which is clarifies analysed and verified:

First solution attempt
Clarification
Analysis
Verification

It can therefore be seen that the analysis-synthesis-evaluation model was not evident within the activities of the subject. Perhaps the process can be seen as the development of a conceptual idea which is redefined into sub- problems and which is then verified in terms of material, construction and so on:

Conceptual Idea

*

Refinement into sub problems

*

Detailing

*

Verification

Perhaps the approach could also be considered as conjecture-analysis rather than analysis-synthesis-evaluation.

The practice problem showed a different pattern which perhaps related more closely to Krampen's examples:

First solution attempt
Clarification
Second solution attempt
Clarification
Third solution attempt
Clarification
Fourth solution attempt
Clarification
Analysis
Verification

The subject seemed to be very much solution-focused rather than problem-focused. The problem statement was barely used within the process as a means of identifying and developing constraints to provide a framework for problem solving. The approach highlighted in this protocol contrasted greatly with the referral-back approach identified in Protocol 3.

In terms of the theories of Darke, it is clear that within this protocol 'satisficing' occurred at a very early stage. The subject was prepared to generate a quick solution without conducting a prolonged and detailed analysis of the problem. The subject, from the outset, clearly imposed a 'primary generator' to help focus upon a solution to the problem. Perhaps one of the aims should be to develop teaching strategies which encourage 'satisficing' after a more detailed analysis of the problem.

This subject seemed, at first glance, to be a very systematic problem solver who took a very linear route through the problem. He also appeared to be very cautious and not able to take creative leaps during the design problem solving process.

Research approach 3 - Drawing and modelling

1 The use of drawing to support thinking

At the beginning of the protocol the subject used drawings to record first ideas in terms of the metal frame. This was followed by a drawing of the second main idea, the wooden triangle. At this stage, drawing seemed to help externalise thoughts and the subject was continuously drawing whilst talking. However, it was not clear whether the subject was recording ideas or using drawing to help analyse or explore ideas.

In places, there were a series of more detailed drawings which seemed to be recording thoughts rather than aiding thinking through drawing. These detailed drawings were used to differentiate between ideas. They seemed to relate to Schenk's (1991) category of drawing for synthesis where the detail are used as an aid to decision making and perhaps indicating a move from concept to format.

In the main problem, the subject quickly started to draw a single solution which dominated the project. This contrasted with the practice problem in which the subject considered a number of ideas. Drawing seemed to be undertaken to record and differentiate between ideas.

This suggested drawing for synthesis rather than drawing for analysis and first ideas. However, it may be that the subject used the initial holistic solution, which results in an outline drawing, as a basis for for considering and analysing sub issues. Is the externalised drawing an important element/basis for providing new images and ideas?

2 The style and nature of the drawing

The unsophisticated drawing style seemed to mask the level of thinking embodied within the process. The protocol indicated a process which went beyond the basic drawings into the deeper thoughts of the subject. It was clear that many ideas were not externalised into a concrete form. This suggested that the subject would suffer in assessment situations.

This raises the question of the appropriateness of teaching methods and materials to develop 'thinking through drawing' skills. Students, or 'novice' designers, are taught a range of drawing skills on design and technology courses within schools. However, these are mainly related to presentation and sketching skills, rather than the active use of drawing to aid exploration and analysis of the problem. This issue will be discussed in the concluding section and chapter. This illustrated the need to discuss the process of designing with student and perhaps the need for some parts of assessment to be based upon verbal discussion and verbal presentations.

Prompting promoted some drawing activity, but mainly to record thoughts retrospectively or to add detail to original drawings rather than as first ideas. Prompting also resulted in the adding of sub-issues in the form of written statements rather than through drawing. This seemed to further illustrate the need to teach 'novice' designers the skills of drawing to aid thinking.

Generally the subject demonstrated a rapid, unsophisticated drawing style which combined 2D and 3D drawing. Some of the drawings were quite complex in places. Words were used to illustrate key elements of the solution.

3 The use of modelling to support thinking

Modelling occurred in the later stages. It seemed to be used as an aid to synthesis by adding detail and aiding the move from concept to format. The time spent modelling and colouring resulted in little verbal dialogue. Is the subject developing ideas or working in a physical representation stage? In other words, were the models used to aid the process of thinking or to show the product of thought?

Conclusions

Issue 1

As with the other novice designers, the subject demonstrated an inability to use the problem statement as a framework during the design problem solving process. It seems that the subject needs to be taught to identify and develop constraints within the problem statement and to refer to these statements at key points within the process. A generic framework to suit any type of problem may help with this aspect.

Issue 2

The subject shows little evidence of being able to develop solutions and sub-solutions **after** previous analysis of sub-elements. The procedure followed seems to be the reverse of this approach. There is a need to develop teaching strategies to develop this aspect. This may include encouraging the subject to stand back from the problem and to 'satisfice' at a later stage. This may require strategies which encourage analysis prior to solution development, which may result in the following cycle:

Concept (from brainstorming) >> analysis >> solution cycles

Issue 3

The subject demonstrated in the practice problem an ability to generate a wide search space and consequently he produced a number of possible solutions to the problem. However, in the more complex main problem only a single solution was identified. It may be that the subject found it difficult to draw together all the sub-elements of this problem in order to generate alternative solutions. This type of problem may encourage decomposition and 'satisficing' at a very early stage in the process as the subject may not be able to handle the multi-dimensions of such a complex task. However, many of the design tasks found within key stage 3 of the National Curriculum are rather more complex than the practice tasks. It may therefore be necessary to consider appropriate teaching strategies in this area which could involve design methods such as brainstorming and synectics.

Issue 4

As with the other novice designers, the subject used operator 'E' - solution elaboration and testing for a large part of the protocol. This was often followed by 'F1' - Inference, but was not preceded by 'F' - Assertion. It seems that expert designers use the full cycle F >> E >> F1 in order to explore elements of the problem space. This cycle is a type of heuristic based upon means-end-analysis or hypothesise-and-test. It would therefore seem to be important that subjects are provided with teaching methods which aid the development of these exploratory cycles. A range of heuristics could be considered within this process.

Issue 5

The subject only used operator 'H' - Solution validation after prompting by the researcher. Evaluation and validation are important dimensions of the design problem solving process which perhaps need to be made more explicit for novice designers. Expert designers tend to use the problem statement as a reference point and therefore appear to be considering the value of solutions and sub-solutions throughout the process. They also tend to use the problem statement as a means of validating the final solution.

Issue 6

The subject demonstrated a limited range of drawing skills within the research activity. There was evidence of an ability to use 3D drawing and to produce detailed drawings of elements of the design. Words were also used to provide detail to the designs. However, the subject seemed to lack the skill of drawing rapidly to develop first ideas which is often found in expert designers. Teaching strategies therefore need to consider this this issue and may include the use of rapid drawing activities. There is a clearly a need to develop teaching strategies which encourage the use of drawing to aid thinking (Laseau, 1980).

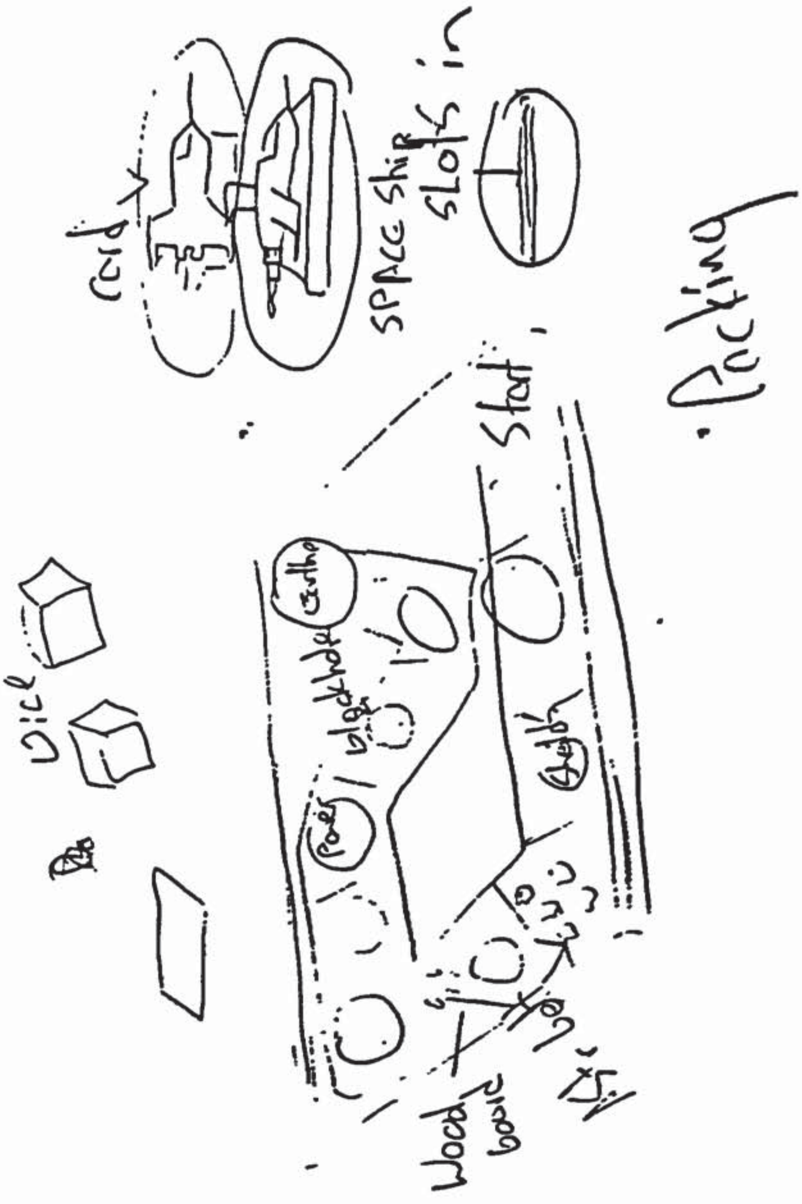

Figure 60 - The design sheet from Protocol 7

Chapter 7 - Discussion and Conclusions

7.0 Introduction

The aim of this chapter is to draw together elements from the individual protocols of expert and novice designers in order to compare behaviour. The key questions raised in chapter one forms the basis for this analysis.

Seven main aspects have been considered:

1. Key issues have been identified and a comparison has been made using the coding schedule as a framework. The heuristics used by both the expert and novice designers have also been explored.

2. Consideration has also been given to teaching strategies and design methods which could be utilised to develop design expertise in novice designers.

3. The findings of the research in terms of the design strategies demonstrated by the expert and novice designers have been compared with previous research.

4. Discussion of the first three issues has allowed the hypothesis embodied in the coding schedule to be considered.

5. The general educational implications have been discussed. Illustrations of possible teaching strategies for novice designers have been based upon the principal target problem used in the research.

6 The research design has been evaluated.

7 Finally, the potential for future research has been considered and a coding schedule based upon a reflective analysis of this research has been put forward.

7.1 Conclusions

Issue 1 - The use of the problem statement

The way in which the problem statement was used during the protocols provides an interesting basis for comparing the design methods of the expert and novice designers. Both of the expert designers made significant use of the problem statement throughout the process. Both also used problem restatement and problem elaboration and refinement to understand the problem in the first stages. This seems to concur with the work of Akin (1979) who, when looking at a similar aspect, stated that the first 26 segments of the protocol related to the use of problem documents. Eckersley (1988) also noted that one of his expert designers used a literal copy of the problem statements in 32 of the the first 60 segments of the protocol. The second designer in Eckersley's study was observed to refer to the functional requirements embodied in the problem statement on 17 occasions out of the first 40 segments.

The expert designers who provided one focus of this research project appeared to be using the problem statement as a basis for exploring possible solutions. That is to say, the breaking down or decomposition of the problem into smaller elements helped to provide a manageable framework for the expert designers. At times it also appeared that they generated further constraints which were not directly embodied in the problem statement. Carroll, Thomas and Malhotra (1979) indicated that the expert designers observed in their study tended to, "decompose a complex design problem into several simpler design cycles, each concerned specifically with part of the overall design problem". The expert designers referred to the problem statement at key points throughout the process. This 'referral-back' strategy aided the movement through the problem space.

The behaviour of expert designers contrasted with that found in the novice designers observed in this research project. The three novice designers hardly used either operator 'A' - Problem restatement or operator 'B' - Problem elaboration and refinement. Any application tended to be through the latter operator (B), indicating that the explicit detail of the problem statement was not being used, with the novice designers relying on implicit use of problem elaboration and refinement. The subjects appeared to focus almost immediately upon a solution to the task without attempting a detailed analysis and understanding of the nature of the problem. Tovey (1986) quoting Darke (1979) and Lawson (1979) indicated that a variation of the patterns found in the novice designers could be observed with some expert and semi-expert designers:

> "They have perceived a solution-led procedure in which the emphasis is on the identification within the design problems of whatever will allow the generation of solution conjecture at the earliest possible moment, in other words before the problem has been fully analysed and understood........." (Tovey,1986)

In this project, the expert designers appeared to reduce the number of constraints to manageable proportions, whilst the novice designers did not seem to go through this process. The novice designers appeared to develop solution concepts at an early stage within the process without reference to the problem statement. The behaviour of the novice designers contrasts with the findings of Cross (1989), reported in Roozenburg and Cross (1991), who suggested that in the case of expert designers there is a symmetrical relationship between problem and solution, and between sub-problems and sub-solutions. The relationship is not one-way and the problem definition is dependent upon solution concepts. This therefore suggests that the 'conjecture' stage put forward by Darke (1979) provides a means of interacting with and clarifying the problem, a process which is much less explicit with novice designers.

Conclusion 1 - The use of the problem statement

Expert designers use the problem statement as a means of moving through the problem space. Understanding the nature of the task is gained through problem restatement and problem elaboration in the early stages. Referral to the problem statement occurs at key stages throughout the process and seems to provide a framework for continuous evaluation, and at times, a 'prop' when the designer is having difficulty generating ideas. The continuous use of the problem statement provides a means of reducing the problem into cognitively manageable units. The diagram below illustrates the way reference to the problem statement is made at key points of the process. That is to say, during the initial phase, the exploration cycles, and also when solution validation is taking place:

```
        I <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
        I <<<<<<<<<<<<<<<<<<<<<<<<<<<
        I <<<<<<<<<<<<<<<<
        I <<<<<<<<<
Problem   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>   Solution
        I >>>>>>>>>
        I >>>>>>>>>>>>>>>>
        I >>>>>>>>>>>>>>>>>>>>>>>>>>>
        I >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
```

Figure 61 - Expert designers - explicit use of problem statement, evaluation and validation throughout the process

In contrast, novice designers make little explicit use of the problem statement at any stage in the process. Consequently, the novice designers tend to work in design cycles which do not contain the same evaluatory loops as expert designers. Rather an occasional reference to the problem statement can be observed. However, in Protocol 6 the subject who was considered to of the highest ability of the novice designers used a 'spider' diagram to consider the problem statement. Nevertheless, the general result is a reduction of the opportunities for the novice designers to focus upon cognitively manageable elements of the problem. The diagram below illustrates this intermittent use of the problem statement:

```
        I                                        <<
        I                    <
        I       <
Problem     >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>     Solution
        I       >
        I                    >
        I                                        >>
```

Figure 62 - Novice designers - little use of problem statement, evaluation and validation during the designing process.

Issue 1 - Implications for teaching

How then can these novice designers be encouraged to use the problem statement in a similar way to expert designers? Which teaching strategies will be most helpful to novice designers? Very little has been written about design methods appropriate for novice designers. However, Jones (1970 and 1981) and Cross and Roy (1975) provide collections of design methods which could be used at different stages of a design project. Cross and Roy describe these design methods as tools or techniques for conducting design projects. They suggest that a skilled designer will select and combine these methods into a design process. The methods provide a means of formalising what designers often do inside their heads.

Two of the methods put forward by Jones (1970 and 1981) and Cross and Roy (1975) seem to be appropriate in this context - systematic search and stating objectives.

Systematic search is a process in which the constituents of the problem are identified and analysed in order to "solve design problems with logical certainty."

Stating objectives refers to the identification of the external conditions with which the design must be compatible.

Cross and Roy put forward a number of other methods which could be used to encourage novice designers to make greater use of the problem statement - objectives tree, interaction matrix and performance specification.

Objectives tree is a method of listing the design objectives and sub-objectives in a project, and constructing a diagram of the hierarchical relationships between them.

The interaction matrix provides a method of exploring and setting out in chart form the interaction between a number of elements within a problem.

Performance specification involves writing an accurate description of the performance required in a design solution, so as to allow an appropriate degree of freedom to the designer, and to allow an objective evaluation of any proposed solution.

From the field of secondary education, and therefore directly related to the needs of the novice designers who are the focus of this project, McMillan et al (1987) put forward a range of design strategies for consideration within the school context. Whilst none are directly related to the problem statement, the strategy called checklists could be adapted for this purpose. For example, they describe a search checklist which could be applied to the problem statement:

What has to be done?
Why has it to be done?

When has it to be done?
Where has it to be done?
Who has to do it?
How has it to be done?

Issue 2 - Holistic solution generation

Both of the expert designers tended to develop holistic solution concepts near the beginning of the design cycle. Darke (1979), in research with professional architects, also found that a narrowing down of the range of solutions occurred early in the process with a 'conjecture or conceptualisation of a possible solution'. However, as stated above, within this project this occurred after an initial analysis of the problem statement. This initial analysis seemed to help the subjects draw together the key objectives of the problem in order to provide a starting point for further exploration. In other words, the conceptualised solution provided a basis for analysing the problem in more detail. This is supported by Darke who suggested that the objectives identified through the first phase provided the 'primary generator' for developing holistic solution concepts.

One of the expert designers also seemed to generate holistic solution concepts at key points within the process. This seemed to represent a summary of thinking, generated as a result of previous analysis of sub-elements of the problem. The subject also appeared to force himself to develop new solution concepts at stages in the problem when progress was becoming difficult. These new solution concepts then seemed to provide the subject with renewed energy to pursue the problem. In other places the subject seemed to be working in parallel fashion. That is to say, working on the detailed analysis of one solution concept whilst simultaneously developing another overall solution format.

The novice designers also generated holistic solution concepts at the outset of the problem. However, this was not preceded by an analysis of the problem statement and therefore occurred very early in the process. In other words, the novice designers started the process with the immediate generation of an holistic solution concept. The solution concept generated at this stage provided the framework for the finally accepted solution.

This contrasts with the expert designers in which the use of the 'primary generator' to develop holistic solution concepts can be seen as 'a conjecture which has been tested against the case material' (Darke,1979). These findings are also supported by Akin (1979) who showed that the experienced designer restructures the problem numerous times by modifying the initial constraint set, thus defining the the right problem as the right solution is determined almost simultaneously. He suggests that this skill is lacking in the inexperienced designer. It was clear in this project that the novice designers, on the other hand, developed unsubstantiated solution concepts which could only be intuitively generated from past experience.

One of the novice designers worked in a very different way. A range of holistic solutions were developed within a short period of time, perhaps illustrating the ability to develop a wide search space. It could be argued that the development of a range of holistic solution concepts should be encouraged at the outset in order to provide a framework for analysis. Indeed, many models of the design process imply that a wide search space should be generated from the outset.

It is worth noting, however, that this development of a wide search space occurred with the practice problem rather than the more complex main problem. This perhaps indicates that novice designers can only undertake what is cognitively manageable. In other words, the detailed structure embodied in a complex problem may reduce the creative thought which the subject can bring to bear on the task.

Conclusion 2 - Holistic solution generation

Expert designers tend to generate holistic solution concepts after an initial analysis of the problem statement. The objectives identified during this phase provide the 'primary generator' for holistic solution concepts. These solution concepts fulfil the function of providing a starting point for the exploration phase. They are developed using the past experience of the designer and the procedural knowledge which can be brought to bear on the problem. The expert designers therefore seem to start the process in the way described in the diagram below. This shows the analysis of the problem statement providing a framework for the development for the generation of holistic solution concepts:

		Consideration		**Holistic**
Problem	**>>>>**	**of problem**	**>>>>>>**	**solution**
statement		**statement**		**generation**

Figure 63 - Expert designers - holistic solution generation

Novice designers also generate holistic solutions at the outset. However, these are not preceded by the identification of objectives embodied in the problem statement. The solution concept developed at this stage provides the basis for the final solution and appears to be generated from the limited past experience of the novice designer. This suggests that the novice designers start the process by the immediate generation of an holistic solution as illustrated below

		Holistic
Problem	**>>>>>>>**	**solution**
statement		**generation**

Figure 64 - Novice designers - holistic solution generation

Issue 2 - Implications for teaching

Teaching strategies related to interaction with the problem statement have been discussed under issue 1. The purpose of this phase is to consider teaching strategies which can be used to develop holistic solution concepts through the exploration of a wide search space. Whether this phase immediately follows analysis is open to doubt as the stages within the process may depend upon the nature of the problem and the natural cognitive style of the designer. Cross and Roy (1975) illustrate this point:

> "There is nothing very critical about choosing methods, but you will find that some are more appropriate than others to particular types of projects, to particular stages in a project, and to particular people".

Nevertheless, it could be argued that 'beginning' or novice designers require a framework for design problem solving to be taught in an explicit manner. The ability to select appropriate design methods will come as experience is developed.

Cross and Roy (1975) highlight methods which can be used during the exploration phase - brainstorming and enlarging the search space.

'Brainstorming' is a group participation technique for quickly generating a wide range of ideas for tackling a stated problem.

'Enlarging the search space' is not a complete 'method' as such, but a collection of techniques aimed at triggering creativity.

Jones (1970 and 1981) highlights a number of methods of searching for ideas which include brainstorming, synectics, removing mental blocks and morphological charts. He suggests that brainstorming and synectics, which involves the use of analogies, may be useful in this phase of the design project.

Issue 3 - The exploration cycles

Hertz (1992) describes exploration as:

> "a search for ideas which should not fit into any strictly defined place in the structure. This means that the existence of the ideas is not presumed a priori. Therefore an exploration introduces new ideas and usually also new concepts in the part of the existing structure dealt with, and hence extends the structure."
>
> Hertz (1992)

Cycles of exploration are key elements within the design problem solving process and are used extensively by both expert and novice designers. These cycles seem to provide smaller, more cognitively manageable units for exploration. This is supported by Thomas and Carroll (1979) who found in their research that the "overall attack on a design problem was often organised into relatively and smaller cycles."

The expert designers tended to specify some of these sub-elements during the problem analysis phase and develop others during the further stages of the design process. Novice designers, on the other hand, seemed to identify them at any stage of the design process, apart from through the initial analysis of the problem statement. Thomas and Carroll found that with expert designers the sub-problems were dynamically produced during design and were not completely specified at the beginning. This seems to concur with the findings for expert designers from this research.

The notion of designers decomposing the problem into cognitively manageable units was first highlighted by Simon (1969) and subsequently confirmed in other research projects (Jeffries et al,1981; Anderson et al,1984).

Within this research, the identification of operators used in the process provided an interesting insight into the nature of the cycles. The expert designers seemed to use operator 'F' - assertion to start the cycle which was then explored by applying operator 'E' - solution elaboration and testing and concluded by applying operator 'F1' - inference. In other words, within these small exploratory cycles the expert designers seemed to generate a type of hypothesis which is subsequently tested.

In contrast, the novice designers used a shorter cycle which comprised the application of operators 'E' -solution elaboration and testing and 'F1' - inference. In other words, operator 'F' - assertion was not used in an explicit way to start the cycle. However, its use may have been implicit within the process.

It also seemed from the protocols of both the expert and novice designers that the development of the exploratory cycles did not happen in a logical, linear way, but occurred in a much more haphazard fashion. A logical design process would suggest that after the analysis of the problem a wide search space would be developed which would provide a framework of solution concepts requiring detailed exploration of sub-elements. The findings in this research indicate that the cycles are interspersed with holistic solution concepts throughout the process, with these holistic solutions sometimes being generated as a result of the exploratory cycles and at other times from apparently different sources.

Conclusion 3 - The exploration cycles

Expert designers decompose elements of the problem into smaller, more cognitively manageable cycles which are explored using an hypothesise-and-test type approach. The cycle is based upon the use of assertion to start the process (F), which is then explored (E) and concluded using inference (F1):

F >>>> E >>>> F1

Novice designers also decompose the problem into smaller elements for exploration, but use a different type of cycle in which the focus of the exploration seems to be developed implicitly. The issue is then explored (E) and concluded through inference (F1):

E >>>> F1

The cycles of exploration do not appear to operate in the systematic and linear way shown below. This diagram suggests that the analysis of the problem statement provides a means of generating a solution concept which then provides a starting point for widening the search space through a process of exploration:

		Consideration		**Holistic**		
Problem	>>>>>	**of problem**	>>>>>>	**solution**	>>>>	**Exploration**
statement		**statement**		**generation**		**cycles**

Figure 65 - a systematic model of exploration

Rather the cycles for exploration occur in a more haphazard manner with exploration and the generation of solution concepts occurring in any order:

Exploration cycles >>>	Holistic solution generation >>>>	Exploration cycles >>>>	Holistic solution generation

Figure 66 - Cycles of exploration - novice designers

Issue 3 - Implications for teaching

Jones (1970 and 1981) and Cross and Roy (1975) highlight a number of design methods suited to the exploration phase:

user trips
user research
information search
objectives tree
counterplanning
interaction matrix
interaction net

However, whilst all these methods are generally useful and could help subjects decompose the design problems into manageable cycles, they are not really explicitly related to the contexts which underpin this issue. The teaching strategies related to this aspect of the design task should encourage subjects to identify, explore and conclude sub-elements of the problem. An hypothesise-and-test type strategy may be useful in this context:

1 Make statement
2 Exploration the element identified
3 Make judgment - i.e. accept or reject

Issue 4 - Integration

This operator related to the generation of new partial or whole solutions to the problem based upon a previous exploration of the sub-problems. The expert designers seemed to apply this operator at key phases within the protocol, usually after completing a series of exploratory cycles. In the protocol of the second expert designer (Pro 4), integration occurred during a process of developing design ideas through drawing and modelling. The modelling phase seemed to provide a means of drawing together and testing a partial solution to the problem. In other words, the subject appeared to be freely moving between the reflective and active and active abilities described by Kimbell et al (1991).

None of the novice designers applied this operator in the more straight-forward practice problem. However, it was used by two of the novice designers in the main problem. Perhaps this illustrates that with more complex tasks, integration provides a means of structuring design activity. However, because of the solution-led strategies described above, integration was used in a very limited way in the main problem and tended to result form the justifying or detailing process. The subjects did not using reflective and active abilities in the way described by Kimbell et al (1991).

The operator was difficult to identify in a single segment of the protocol and tended to be more observable within a longer phase of the transcript. This will need to be considered in the evaluation of the coding system.

Conclusion 4 - Integration

Expert designers apply operator 'C' - Integration after developing a series of exploratory cycles. The use of this operator seems to provide a means of drawing together aspects of the exploration into new partial or whole solutions.

Novice designers use the process of integration to provide detail to sub-elements of an holistic solution which is developed at the outset of the process. In simpler design tasks, the holistic solution developed at the outset seems to be detailed enough to allow the subject to merely describe and justify decisions rather than generate an exploratory phase which could result in a new partial or whole solutions.

Issue 4 - Implications for teaching

The teaching strategies for this aspect of designing seem to closely linked with procedures for widening the search space and developing exploratory cycles. Jones (1970, 1981) suggests a range of techniques for combining sub-solutions into alternative designs. These include value analysis, checklists and selecting criteria. Cross and Roy (1975) describe two design methods which may be useful in this context:

Forced connexions provide a way of "generating innovations by searching for possible connexions that do not precisely exist between components of a product or system."

New combinations provides a means of "describing new combinations of alternative components that may not previously have been combined into a product or system."

Issue 5 - Solution validation

This operator was difficult to identify in an individual format and seemed more apparent within groups of operators. This therefore had the effect of making it difficult to code as often it was possible to make a dual coding. For example, when solution validation appeared within an exploratory cycle it could, on occasions, have been coded as either operator 'H' or 'E'/'F'. This problem was compounded by the coding of operators 'A' -

Problem restatement and 'B' - Problem elaboration and refinement during the process. Towards the end of the expert designers' protocols, it became difficult to distinguish between these operators and operator 'H' - Solution validation.

This is probably because evaluation and validation occur throughout the process. Akin (1979) uses this to refute the analysis-synthesis-evaluation cycle by suggesting that these aspects of designing can occur in any order. This problem of distinguishing between evaluation and validation was addressed by Hertz (1992) who suggested that "evaluation is a process comprising an analysis and synthesis, which might be a conclusion". On the other hand, he states that a verification "comprises an enquiry and a conclusion".

Taking these issues into consideration and linking solution validation with problem restatement, elaboration and refinement, it was clear that the expert designers undertook a more explicit form of solution evaluation and validation. They also seemed to use validation procedures throughout the process. These were coded as problem restatement or elaboration in the first stages and gradually moved through an evaluatory cycle before adopting a solution validation strategy in the latter stages. In other words, the evaluation process is in fact the verification of small elements of the problem, which may or not be included in the final solution. The validation process is a check on whether the design matches a predefined goal (Hertz, 1992) and results in a decision to accept or reject the proposed design.

The novice designers only seemed to make explicit use of the evaluation and validation procedures towards the end of the protocol, and this often only occurred after prompting by the researcher. It seemed that the subjects had validated the solution during the development of the holistic solution concept at the outset of the process and used the remainder of the protocol to provide details of sub-elements. In other words, to justify the decisions made at the outset.

One of the novice designers made use of operator 'H' throughout the practice problem. However, in the main problem the explicit application of the operator was less evident. This may have been due to the more complex nature of the task embodied in the main problem and suggests this aspect may need to be considered when deciding teaching strategies. It was interesting to note that this subject was estimated by staff of the school to be the weakest of the three novice designers.

Conclusion 5 - Solution validation

Expert designers use evaluation and validation throughout the process. The activity changes from evaluation related to the identification of constraints to a more complex evaluatory process within the exploratory cycles. In the final stages the validation and verification of the solution is more explicit.

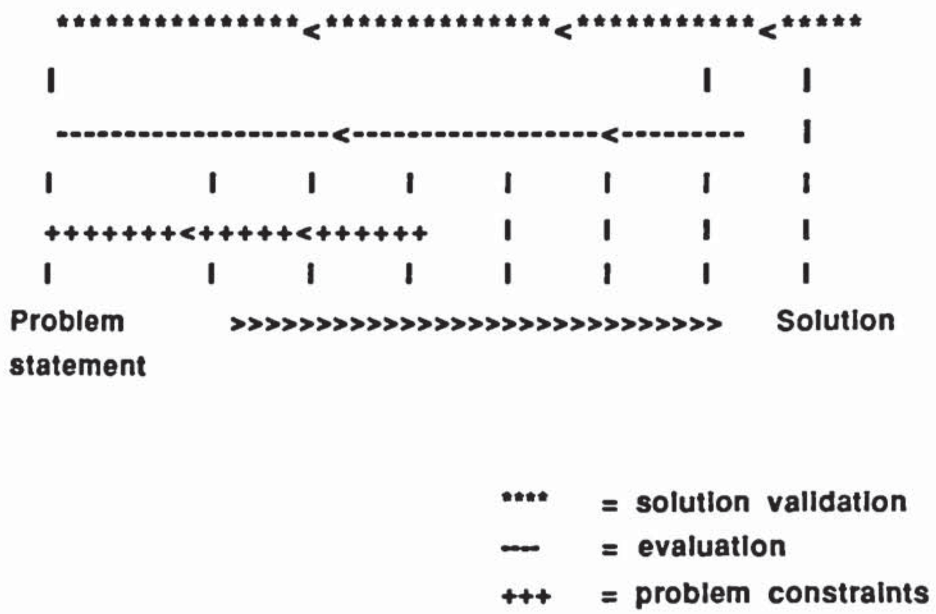

Figure 67 - Expert designers - solution validation

The novice designers made little use of solution evaluation and validation in the more complex main problem, even after prompting during the development of the protocol. In the more straightforward practice problem, one novice designer used evaluation and validation throughout the process, perhaps suggesting that these skills can be developed if the task is not too demanding for the subjects.

```
   *           **            *       <      * <    **

   --           -       -  <  --     - <    I      I

   +    +  <   +                     I      I      I

   I            I                    I      I      I

Problem       >>>>>>>>>>>>>>>>>>>>>>>>>>       Solution
statement

                                   ****    = solution validation
                                   ----    = evaluation
                                   +++     = problem constraints
```

Figure 68 - Novice designers - solution validation

Issue 5 - Implications for teaching

Jones (1970, 1981) and Cross and Roy put forward a number of design strategies which could be used as a basis for developing teaching strategies related to solution evaluation and validation:

Performance specification involves writing an accurate description of the performance required in a design solution, so as to allow an appropriate degree of freedom to the designer, and to allow an objective evaluation of any proposed solution.

Checklist provides a simple method of evaluating solutions against a set of previously established criteria.

Selecting criteria involves deciding how an acceptable design is to be recognised.

Ranking and weighting is based upon comparing a set of alternative designs using a common scale of measurement.

Issue 6 - Information search

Operator 'G' related to the use of technological knowledge within the design problem solving process. It was therefore not surprising that expert designers demonstrated a greater use of this operator. This information was observed in a number of forms:

* knowledge of materials and processes
* ergonomic and anthropometric knowledge
* knowledge of the psychological aspects of human behaviour

Often the application of operator 'G' was noted within an exploratory cycle. On occasions, this resulted in problems over dual coding. That is to say, segments were capable of being coded either as operator 'E' - solution elaboration and testing, or as operator 'G' - information search. In order to overcome this problem it was decided to code the initial application of technological and other forms of knowledge as 'G' on the first occasion, and as 'E' on subsequent occasions.

The expert designers also seemed to be able to draw upon a range of procedural or heuristic knowledge. Akin (1990) discovered that novices used declarative, or passive, knowledge to find a path to the solution, using a generate and test procedure. Experts on the hand, he suggests, choose:

> "a series of actions which they knew from past experience to work in certain cases. The acquisition of expertise, then, is shown to consist of transforming a declarative knowledge base into a procedural one."

Schon (1988) indicates that designers construct their design worlds not only by the shaping of materials but through interlocking processes of perception, cognition and notation.

However, the coding schedule for this project was developed in order to look at the way technological knowledge was used within the process, which would presumably be described as declarative or passive knowledge. The limitations of this interpretation are discussed in the evaluation of the research design in the final section of this report. The use of heuristic and procedural knowledge is considered within this section.

The novice designers seemed to lack a broad technological knowledge base and relied upon very general and shallow sources of information within the problem solving process. In one of the practice problems, it was clear that knowledge of processes and materials relevant to the design task enhanced the problem solving process. This perhaps illustrates the dilemma of many design and technology teachers who find it difficult to balance the teaching of craft skills and technological knowledge with design-based approaches.

The nature of the task also seemed to affect the way operator 'G' was applied. For example, within Pro 4, the activity was based upon designing through modelling and the subject was able to demonstrate a range of knowledge related to the processes and materials implied within this task. The practice problem was simple enough to allow some of the novice designers to demonstrate basic knowledge of the relevant processes and materials. The structure of the main problem, on the other hand, seemed to require the full attention of the novice designers in order to develop design ideas. Consequently, low level technological knowledge was used by all of the novice designers. In contrast, the expert designer (Pro 3) demonstrated a depth and breadth of technological knowledge throughout the process.

Conclusion 6 - Information search

Expert designers draw upon a range of technological knowledge at key stages of the design process, often within a cycle of exploration. This knowledge relates to materials and processes, ergonomic and anthropometric data, and also to the psychological aspects of human behaviour. The depth of knowledge provides a means of exploring a range of design ideas.

Novice designers also use technological knowledge throughout the process. However, this is often very shallow and general in nature, even when considered within the context of novice designers. The has the effect of narrowing the potential search space of novice designers.

The nature of the task seems to affect the novice designers ability to apply technological knowledge. This is particularly true with complex design problems.

Issue 6 - Implications for teaching

It seems clear that novice designers need a knowledge base and the design and technology vocabulary which will come from the development of this knowledge in order to solve even fairly simple problems. A number of teaching strategies can be considered:

1 Development of D&T vocabulary seems to be an important aspect of this issue. The pilot National Curriculum Standard Assessment Tasks (SATs) for design and technology (MEGNAP D&T, 1990) which the researcher has been involved in evaluating, put forward the notion of generating a design and technology vocabulary for each project.

2 Parallel development of knowledge and information related to materials and processes also need to directly linked to individual projects. Allied to this issue is the need for novice designers to simultaneously develop appropriate practical skills.

Issue 7 - Heuristics

This was a difficult issue to assess and, as a result, a number of questions were raised which could form the basis for future research. Heuristics relate to rules of thumb or general plans of action and need to be contrasted with an algorithmic view of design (Stauffer and Ullman, 1988) which is based upon a well-organised plan which utilises logical reasoning. The more dynamic heuristic approach is often used by designers and may be derived from design habits which prove successful over time (Akin, 1990). This heuristic or procedural knowledge is often informed by declarative knowledge.

On the limited evidence available about this aspect in this research project, it appears that expert designers mainly use the strategies of means-ends-analysis and hypothesise and test. Pattern matching was also used by the first subject (Pro 3), perhaps suggesting that the broader experience and knowledge of the expert designers provides a framework for analogical thinking.

The novice designers also used means-ends-analysis in places. However, the most prominent strategy observed was hill-climbing which was used at the outset of the problem by all three subjects. This straight-in-single-solution strategy provided a means of allowing the novice designers to get started on the problem. However, hill-climbing was not used as a means of widening the search space at key points during the process. Rather it was only used to provide a starting point in the initial phase. In most cases it was not used after the initial application. Nevertheless, one of the novice designers (Pro 7) demonstrated this strategy on several occasions throughout the practice problem. Consequently the subject was able to generate a wide search space for further exploration. The complexity of the main problem may have made it difficult to use this strategy.

Conclusion 7 - heuristics

The expert designers mainly use the strategy of means-ends-analysis and hypothesise and test. Pattern matching was used one of the subjects. These strategies seemed to indicate a methodical and linear approach to the design process.

The novice designers all started the process by using hill climbing which provided a solution concept at the outset. This straight-in-single-solution provided a basis for further exploration and justification. The novice designers also made use of means-ends-analysis during the exploratory phase.

Issue 7 - Implications for teaching

The is clearly as issue which requires further research. However, teaching strategies and design methods can be identified to help in the development alternative heuristics for novice designers. For example, Cross and Roy (1975) put forward a number of techniques for enlarging the search space:

- Borrowing ideas from other contexts
- Asking "Why-why-why?"
- "Word play"
- "Analogies"
- "Letting your mind wander"

These methods, if combined with more systematic search techniques, such as means-ends-analysis and hypothesise and test, could provide a framework for developing procedural or heuristic techniques.

Issue 8 - The role of drawing and modelling within the design process

Both the expert and novice designers seemed to use drawing and modelling to enhance design thinking. The drawing of subject 1 (Pro 3) was detailed and systematic and comprise 50% writing in the first stages. The drawing was mainly involved with the exploration of initial ideas. However, in the later stages there was evidence of drawing for synthesis. The second expert designer (Pro 4), used drawing in the early stages to help in the development of the initial solution concept. Consequently, this drawing also tended to be broad and conceptual rather than detailed and exploratory. Nevertheless, it was clearly aimed at developing first ideas. The subject used modelling to both synthesise ideas and also to explore sub-elements of the problem. Because of the nature of the task, this detailed exploration using modelling seemed to replace the systematic drawing and writing demonstrated by subject one.

The novice designers used more simplistic and unsophisticated forms of drawing. Often this drawing seemed to be retrospective in that it appeared to provide a record of thinking rather than an aid to the process of thinking. The subjects generally used notes to provide detail to the drawings. Much of the drawing was for synthesis, but on occasions detailed elements were explored. Two of the novice designers showed evidence of using modelling to move from concept to format.

The work of the novice designers suggested that they had not been taught explicit methods of drawing for analysis and first ideas. However, the use of drawing and modelling to support design thinking may have been influenced by the nature of the task. Kimbell et al (1991) report that in some cases the nature of the tasks can affect the confidence and complexity of communication. There was evidence from the practice problem of an ability to demonstrate drawing for analysis and first ideas in a less complex design task.

Conclusion 8 - Drawing and modelling

Expert designers use drawing in the first stages of the process to aid analysis and the development of first ideas. The drawing is often detailed and systematic and supported by written notes. Depending upon the nature of the task, modelling may also be used to aid thinking during the exploration of the problem. However, when this occurs, drawing is still, used to provide first ideas. In the latter stages, there was evidence of drawing and modelling for synthesis. Drawing and modelling seemed to provide a means of enhancing thinking and occurred throughout the protocols. Sophisticated drawing and modelling techniques were demonstrated by the expert designers.

The novice designers tended to develop conceptual solution drawings early in the process and then proceeded to add detail to the drawings. Perhaps reflecting the design strategies discussed below in which the novice designers are shown as developing holistic solution concepts at the outset and then using the exploratory phase to add detail to the solution selected. The drawings were often completed after ideas had been verbalised rather than as the protocol was being developed. The drawings were generally unsophisticated.

Issue 8 - Implications for teaching

Novice designers need to be taught specific drawing and modelling techniques which are appropriate to different phases of the design problem solving process. Schenk (1991) identifies three key phases of this process and the procedures which may be appropriate at each stage. It should be noted that the work of Schenk relates to expert designers and would need to be modified to suit novice designers:

	{	accepting and passing on briefing
Preparation phase -------	{	
	{	collecting reference material
	{	analysing first ideas
Main creative phase -----	{	synthesis/development
	{	presentation/evaluation/revision
	{	commissioning art work
Production phase --------	{	
	{	preparing for production

Perhaps the most important need is for novice designers to develop quick drawing techniques to aid thinking. Laseau (1980) describes such techniques as graphic thinking which can aid communication between the brain and drawing via hand and pencil. The diagram below illustrates Laseau's view of graphic thinking. From the experience of the researcher, this is an important skill for developing in novice designers.

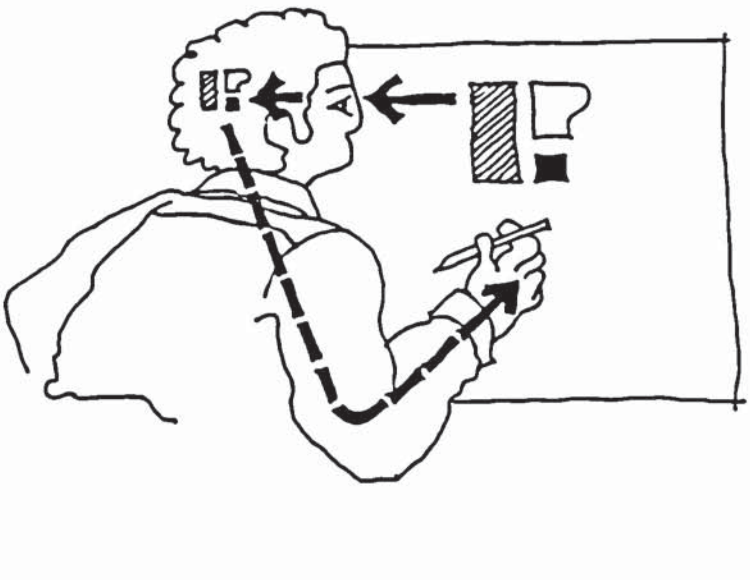

Figure 69 - Thinking through drawing

Issue 9 - General Design Strategy

Design problem solving can be seen as an essentially modular process in which in an 'ideal' situation the designer would follow a set path. That is to say, the process would start with a problem statement which broadens through the designer identifying and developing the constraints embodied in the problem statement. The statement and constraints provide a reference point throughout the process. The designer then diverges, or widens the search space, in order to provide a range of design ideas. Holistic solution concepts may be developed at this stage. A period of exploration then occurs in which sub-elements are explored within small cycles. The designer then converges upon holistic solutions which are evaluated before the final solution is validated and accepted. This process is similar to the anaysis-synthesis-evaluation model. The diagram below illustrates this 'ideal' process:

Problem statement > Analysis of problem statement >> Divergence > Exploration> Convergence > Solution concept Validation> Solution

Figure 70 - 'Ideal' model of the design process

The analysis-synthesis-evaluation model of the design process has been modified by a number of researchers (Hillier et al, 1972; Lawson, 1979; Darke, 1984; Roozenburg and Cross, 1991). However, Roozenburg and Cross suggest that whilst the analysis-synthesis-evaluation model can be rejected, no well-formulated consensus model of the design process exists.

The findings of this research project also indicate that most designers, whether expert or novice, do not work in an 'ideal' way. The components, or modules, of the process can arise in any order. It seems, however, from this research and previous research with expert designers, that certain patterns can be identified within these expert designers. For example, subject 1 (Pro 3) produced a pattern which seemed to be based upon a recurring use of the identification of problem constraints and exploratory cycles with solution validation taking place at the end of the process. The process started with an analysis of the problem statement which was followed by the development of an overall solution concept at an early stage within the process (3/18). Darke (1984) describes this reduction or narrowing down of possible solutions as conjecture or conceptualisation of a possible solution. She suggests that this solution concept or 'primary generator' provides a starting point and a way into the problem. In the case of subject 1, the analysis was very careful and systematic and seemed to suggest that the subject was working in a problem-focused manner (Lawson, 1979) for a great deal of the protocol before eventually gradually moving towards a solution-focused approach. Evaluation seemed to be taking place, in different forms, throughout the process (see conclusion 1).

The second expert designer (Pro 4) followed a similar pattern to subject 1 in the first stages of the process. That is to say, an analysis of the problem statement provided a basis for developing an holistic solution concept. This perhaps supports the view of Akin (1979) who suggested that expert designers can often use cues in the environment to evoke precompiled solutions which the provide a starting point for further analysis and exploration. The subject then widened the search space before exploring elements of the problem space. Finally, the subject converged upon a solution which was then validated against the criteria embodied in the problem statement. Again, evaluation seemed to be taking place throughout the process.

A very different design strategy could be identified within the protocols of the novice designers. Conjecture was used at the very start of the process to develop holistic solution concepts which were then explored and given detail before finally being validated. It was clear that this development of a 'primary generator' at the start of the process was not used as a basis for providing a way into the problem (Darke, 1984), but often as a single conceptual solution which was given detail during the exploratory phase. This solution-focused approach (Lawson, 1979) found in novice designers within the field of general design education is supported by Kimbell et al (1991) who suggest that it is not uncommon for pupils to believe that, almost from the start, they have a complete solution sorted out in their mind.

Conclusion 9 - General design strategy

Expert designers develop a complex search space in which evaluation and validation procedures play a major role in identifying sub-elements for exploration. The process of exploration is preceded by the development of holistic solution concepts which are generated after an initial analysis of the problem statement. The exploratory cycles are detailed and productive and provide a means of considering alternatives and developing new solutions to the problem through a process of integration. The strategy tends to be very much problem-focused in the early stages, with the constraints identified in the problem statement being continually developed and extended throughout the process:

		Analysis of		Holistic										
Problem	>	problem	>	solution	>	Exploration	>	Convergence	>	Solution	>	Validation	>	Solution
		statement		concept						concept				

Figure 71 - Expert designers framework for designing

Novice designers tend to operate an holistic-synthetic strategy in which an overall solution concept is developed at the outset. The remainder of the process involves a shallow exploration followed by a justification, or detailing, of the elements of the solution. The constraints embodied in the problem statement are rarely used to help the subject move through the search space. The evaluatory procedures are not explicit and limited use is made of solution validation. The strategy is very much solution-focused:

Problem >>>>>	Holistic solution >>>>> concept	Exploration/ >>>> justification	Validation >>>>>>	Solution

Figure 72 - Novice designers framework for design

7.2 General educational implications

Two key issues provided the motivation for this research project. Both were based upon the experience of the researcher in teaching novice designers. The first issue was related to unease about models of the design process upon which much teaching was based in secondary schools. The assessment procedures used within external examinations compounded this problem and often implied a linear and systematic teaching method, with novice designers often retrospectively satisfying the demands of assessment.

The second issue was related to the first and was based upon an intuitive feeling by the researcher that teachers of design and technology should adopt teaching strategies which reflect the natural cognitive style of the novice designer. The purpose of this section is to consider the educational implications in terms of these issues.

The model of the design process discussed above suggests that designers, whether expert or novice, often follow an unsystematic approach when solving design problems. That is to say, the approach is clearly not based upon the traditional analysis-synthesis-evaluation model which seems to form the basis for much teaching in secondary schools.

A number of teaching strategies based upon a range of design methods have been suggested in the discussion above. These have been identified in terms of the issues highlighted within the protocols of the expert and novice designers. Collectively, these design methods could provide the basis of a teaching strategy within an individual project for novice designers. The main problem used within this project provides a framework for demonstrating the way in which these teaching strategies and design methods could be used within an actual design project. It should be emphasised that the example illustrates only one way of approaching a task of this nature. The central message is concerned with the need to explicitly teach design methods as part of the general education of novice designers.

Teaching Strategy - Example

Choose an appropriate theme and design a board game which has an average play time of no more than twenty minutes. Test a series of prototypes and record the result. If possible include designs for three dimensional playing pieces made from card, together with a visually presented set of rules. Make suggestions for packaging and advertising.

GCSE - CDT (Kimbell et al, 1987)

Stage 1 - Analysing the problem statement

Read the problem statement carefully. Try to identify the issues (constraints) you will need to consider when solving the problem. A start has been made for you:

1 *Appropriate theme*
2 *Board game*
3 *Play time no more than 20 minutes*
4 ______________________________
5 ______________________________
6 ______________________________

Consider other issues/constraints which could be considered. For example:

1 *The size of the board game*
2 *The material it could be made from*
3 ______________________________
4 ______________________________
5 ______________________________

Try to consider these issues/constraints when you are designing the board game. You may find them particularly useful during stage 4 - exploration.

Stage 2 - Developing a wide search space

1 *Use the problem statement to brainstorm the problem in a group of 4/5. This will involve trying to be as creative as possible and thinking of as many ideas as possible which are associated with the problem in a short period of time.*

2 *Write down on a sheet of paper any ideas which come to you about the problem. Make sure that you use a separate sheet of paper for each different idea. Now evaluate the ideas with the rest of the group taking one idea at a time and trying to further develop it. Remember, you should not criticise any idea, no matter how crazy it appears to be.*

3 *Reconsider the constraints in the problem statement. Can they be further extended?*

Stage 3 - Developing a structure for exploration

Sort out the ideas from the brainstorming activity into groups or patterns which are similar to each other. Discard any ideas which you don't want to use. You may find that it is possible to highlight a number of subproblems and sub-issues which are linked to the subproblems. The example below shows how one aspect could be developed. You may find that it is possible to develop a number of sub-issues on a large sheet of paper:

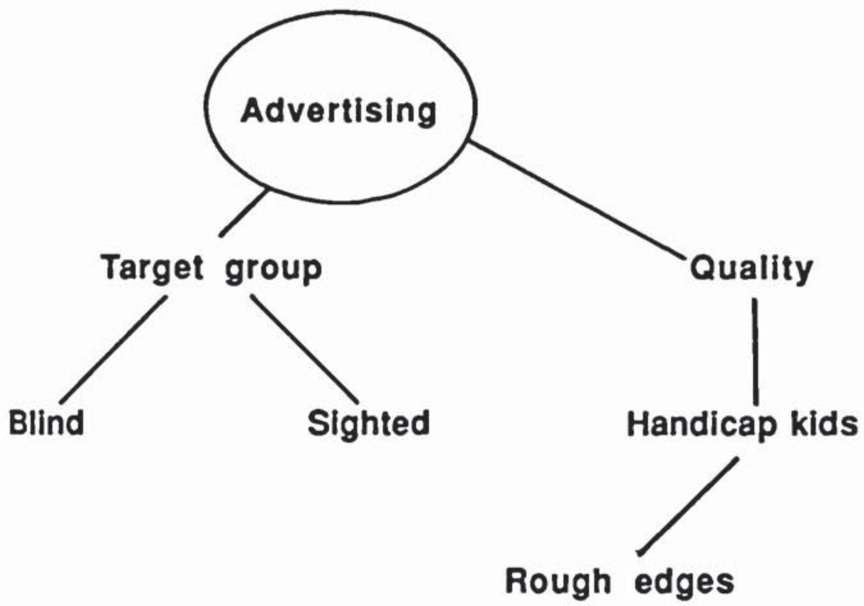

Figure 73 - Developing sub-issues

Stage 4 - Exploring the ideas generated

Using quick sketches and written notes, explore the ideas and sub-issues highlighted in stage 3. Try to explore as many ideas as possible. The example below shows how this approach can help you to develop design thoughts:

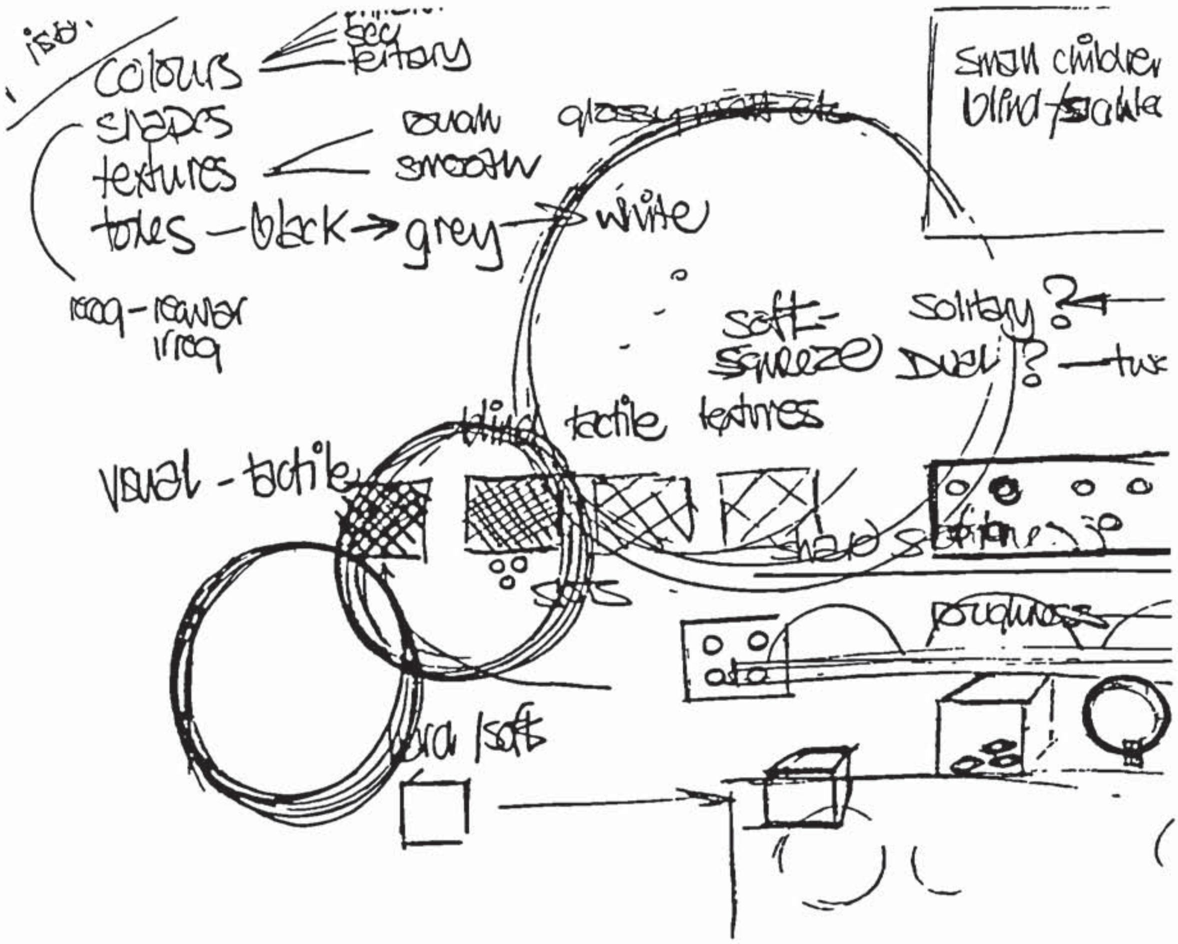

Figure 74 - Rapid sketching technique

Stage 5 - Developing solutions

Pick out the best ideas and try to make them into two or three whole solutions to the problem.

Stage 6 - Evaluation, selection and validation

Evaluate each of the solutions generated and select the one which satisfies most of the constraints highlighted in stage one:

Has it got an appropriate theme?
Is it a board game?
Is the play time less than 20 minutes?   etc.

Stage 7 - Developing the selected idea

Develop more detailed drawings of the selected solution. This may include:

orthographic drawings
detailed drawings of aspects of the solution
presentation drawings

Foundation skills

There may be a need for teachers of design and technology to consider the development of basic foundation courses based upon the principles of the foundation programmes developed as prerequisites for undergraduate study in art and design.These undergraduate foundation courses, often based upon the Bauhaus school of design (Sparke, 1987; Cross, A. ,1983; O'Neil, 1990), attempt to provide an understanding of the "basic properties of materials, colours, textures, structures and composition". In other words, they provide a framework for design activity.

Foundation or core skills for novice designers working within key stage three of National Curriculum will need to be developed in parallel to the design and teaching processes described above. These may include:

1 The development of rapid drawing skills for exploring initial ideas. These 'drawing for thinking' skills need to be developed through a series of short, sharp activities.

2 The development of a design vocabulary suited to the task.

3 The development of technological knowledge appropriate to the task. This may include information about tools, materials and processes which may be required in the project.

4 The development of practical skills linked to the design task. High quality realisation is a central feature of design and technology within the National Curriculum. The lack of genuine opportunities for realising design ideas is causing great concern amongst teachers of design and technology and HMI (TES, 1992). The focused tasks of the National Curriculum pilot Standard Attainment Tasks (SATs) (MEGNAP D&T, 1990) attempt to address this problem.

Whilst it is recognised that the design methods described above do not reflect the behaviour identified in either expert or novice designers in this project, it is felt that the novice designers need some sort of systematic procedure to stop them jumping into the development of a single solution concept at the outset of the process. The researcher started this project by thinking that teaching strategy should match the natural cognitive style of the novice designer. However, this view was modified during the research and it is now felt that novice designers require a clear framework for design problem solving. Opportunities will exist within this framework to accommodate natural cognitive styles and short-cuts will become clear to the novice designers as expertise is developed. In other words, as procedural knowledge is acquired.

7.3 Evaluation of the research plan

The purpose of this section is to review the research plan. First of all the suitability of protocol analysis for research of this type will be considered. The coding and segmenting procedures will also be reviewed. The focus will then be upon an evaluation of the other forms of data collection and analysis used within the project. Consideration will also be given to suitability of the design tasks used within the project. Finally, the theories which underpin the research will be reviewed.

Verbal reports as data

A key question in this research plan is whether the data collected from verbal reports provide a true record of the cognitive processes. Issues related to relevance, testability and completeness have been considered in the review of literature and an argument for accepting verbal reports as data has been put forward (Miller, 1978; Nisbett and Wilson, 1977; Smith and Miller, 1978; White, 1980; Ericsson and Simon, 1984). The requirement in this section is to consider how experience within this project can add to this debate.

It is clear that the semi-experimental nature of this project could provide an artificial environment for the collection of verbal data. Subjects are expected to attempt a design task within a set period and at the same time talk aloud as they solve the problem. Within this project, the verbalisations were recorded by television and video cameras. This could obviously affect the subjects and it was clear that some of the novice designers were nervous about having to 'perform' in this way. Does this procedure affect the data acquired from the verbal protocols? Does this data provide a true record of design thinking?

It is difficult to state categorically that the development of verbal protocols does indeed capture the essence of the cognitive processes. However, some of the findings of this research do seem to concur with research using different methodologies and also with research based in different subject areas. For example, the behaviour of expert designers in this project seems, in places, to replicate that identified by other researchers (Akin, 1979, 1988; Eckersley, 1988; Darke, 1979; Cross and Roozenburg, 1991). Similarities in behaviour can also be found with the work of expert-novice differences in physics (Chi, Feltovich and Glaser, 1981; Chi, Glaser and Rees, 1983), particularly in terms of the use of the problem statement and problem/solution-focused strategies.

Whilst these similarities do not provide conclusive evidence that data from verbal protocols provide an accurate representation of mental activity during the design process, they do suggest that this is the case. The experience of the researcher in teaching both expert and novice designers would also suggest that the verbal data collected for this project provides an accurate picture of design problem solving behaviour.

The sample

The size of the sample used in the research also needs to be considered. The method of selecting the sample and the problems of generalising from this small sample are discussed in Chapter 4. The requirement at this point is to reflect upon the effect of the sample size after the collection and analysis of data. It appears that the sample of five has provided a genuine opportunity to compare problem solving strategies of novice and expert designers. The small size of the sample has been balanced by the density and depth of the data. Whilst generalisations from the data may be difficult, it seems that the research has been able to contribute to the body of knowledge related to the problem solving strategies adopted by expert and novice designers, particularly in terms of the latter group. However, the development of methods of protocol analysis which could be used with larger samples would advance this area of research.

The nature of the task

The nature of the task used in this research project is outlined in Chapter 3. The need in this section is to reflect upon whether this design task proved to be suited to the purpose for which it was intended.

The task seemed to generally suit the requirements outlined in Chapter 3. It seemed to allow subjects to participate in genuine design and technology activity rather than in a simplified task developed specifically for the 'experiment'. The constraints embodied in the problem statement allowed comparisons to be made between individual problem solving strategies, and the task seemed to be broad enough to allow subjects to work in a natural way. However, it was noticeable that the novice designers seemed to find it easier to work with the less-complex practice problem. The first expert designer (Pro 3) also had some difficulty in moving to overall solutions. The main problem may have been too broad and hence had too many constraints for the novice designers to work with in the short time available for the collection of data. Perhaps this suggests that a simpler task, similar to the one used in the practice problem, could be more useful in a research context. The task based upon modelling which was undertaken by the second expert designer (Pro 4) could also be considered in a research context. However, both tasks used by the expert designers were reviewed after the data collection and it was felt at that stage that the board game project would be suitable for the novice designers. In spite of these concerns, it appears from the data collected that the issues raised did not have too much effect on the research project.

The coding system

The coding system used within the research project implies a model of the design process. These codings were evolved from previous research and appeared during the encoding process to provide a reasonable basis for categorising behaviour. However, it became clear that further amendments could be made. For example, operator 'G' - Information search provided a narrow view of the use of knowledge during the process. It was decided at the outset that this category would represent the initial application of technological or other forms of knowledge to help the development of sub-solutions. This aspect was seen to be important because of concern that teachers of novice designers were finding it difficult to develop teaching strategies which simultaneously developed design skills, craft skills and technological knowledge and understanding. However, it became clear during the project that further aspects could be considered. For example, Schon (1988) discussed knowledge in terms of strategies, rules, types and operators. Akin (1988) suggests that the acquisition of expertise is shown to consist of transforming a declarative knowledge base into a procedural one. Whilst these issues are touched upon in the section on heuristics, it seems that future research could consider ways of widening the coding system to accommodate these broader interpretations of the nature of knowledge.

The exploratory cycles identified within this research project provide another area for further development. The cycle found in expert designers comprised the use of operator 'A' - Assertion, followed by operator 'E' solution elaboration and testing, with operator 'F1' concluding the cycle. It seems that further work could be undertaken in developing and defining these operators. In particular, category 'E' - Solution elaboration and testing provides a very broad and almost a 'catch-all' coding. Consequently, a large percentage of segments from both expert and novice protocols were classified within this category.

Operator 'C' - Integration provided a means of identifying when the exploration of sub-problems had resulted in the generation of new partial or whole solutions. In other words, it indicated when the designers were converging from a phase of exploration into a potential solution to the problem. The coding system did not include an operator which identified the start of a widening or divergence of the search space by the designers. It may be, of course, that both these aspects of divergence and convergence are too difficult to capture in a single operator. It seems that these aspects should be considered through groups or operators.

The heuristics, or general plans of action, relate to the strategy being used within a particular phase of the problem solving activity. An attempt has been made within this research project to identify the heuristics used by expert and novice designers. However, this aspect could be further developed in future research. Methods for integrating this aspect into the coding system could also be considered.

In light of these findings, how could the coding schedule be modified for future research? An amended schedule, based upon the issues and conclusions discussed above, is illustrated below. This coding schedule could provide a framework for future research:

A Problem restatement
B Problem elaboration and refinement
C Holistic solution development/conjecture
D Assertion
E Exploration
F Inference
G Convergence or integration
H Solution concept
I Validation
J Use of technological knowledge
K Use of procedural knowledge

Segmenting

The transcript of the verbal protocols had to be segmented into small, manageable units ready for coding. The basis of how this was undertaken is discussed in Chapter 5. The purpose of this section is to review how the segmenting phase operated in practice.

Segmentation was undertaken using pauses, hesitations and synatically complete phrases as cues for identifying instances of the general process. Nevertheless, in spite of careful consideration being given to this aspect there were times when it was difficult to make segmentation decisions. This sometimes occurred when a pause suggested separate segments, but the content of the protocol indicated a single segment. The work of the independent sampler helped to overcome some of these problems and indeed, as discussed in Chapter 5, there was a high degree of correlation between the segmenting of the researcher and the independent sampler. However, it may have been helpful if all areas of the protocol which were difficult to segment could have been considered by the researcher and two independent samplers.

Encoding

The nature of the encoding procedure and possible further developments are considered in this section. An evaluation of the coding system is provided above. These coding procedures, which are also discussed in chapter 5, obviously have a great impact on the encoding process.

The use of a second encoder helped to improve the validity and reliability. However, validity and reliability may have been further improved if two independent coders had been available to work with the researcher during the process of encoding. Access to a computer program to help in the process of encoding could also have been considered. Eckersley, (1998) discusses the use of a computer program called CODEPRO which utilised three paid encoders to assess the reliability of the instrument.

Pauses and prompting

In several of the protocols, it was possible to identify a number of pauses and hesitations during the process of verbalisation. With the first expert designer (Pro 3) these tended to vary from 3-20 seconds and occurred throughout the protocol. Towards the end, it appeared that the subject was struggling to keep going. Ericsson and Simon (1984) also found that occasionally subjects report that their minds are blank.

Pauses were also evident throughout the protocol of the second expert designer (Pro 4). These pauses tended to be shorter than those observed in the protocol of the first expert designer and they seemed to reflect a period when the subject was modelling in card. Prompting by the researcher was not used for either of the two expert designers. Ericsson and Simon (1984) suggest that a prompt such as 'keep talking' has the potential to maintain the momentum of the protocol without affecting the process. The impact of not using prompts with the expert designers is unclear. However, in spite of this problem, both expert designers produced detailed and comprehensive protocols.

It was decided after evaluating the first session of data collection with the expert designers that prompting should be used with the novice designers. It was clear that they were rather more nervous and cautious about the process and prompting helped to keep momentum in the protocols. Again, the term 'keep talking' was mainly used as this seemed to be less directive and did not require a direct answer to the researcher as questions such as 'what are you thinking about now?' may have produced (Ericsson and Simon). The evidence from the previous research mentioned above suggests that this prompting enhanced rather than reduced the quality of data.

7.4 Future research

This research project has attempted to provide insights into the design problem solving behaviour of expert and novice designers. During the project it has been possible to identify a number of potential areas for future research. The aim of this final section is to discuss these possibilities from a range of areas associated with the project. These will include possible developments in protocol analysis and suggestions for specific research related to design methodology within the school system.

Eckersley (1988) suggests that much work remains to be done in order to establish protocol analysis as a valid research tool in the area of design. There would certainly seem to be scope for further developing research into comparisons of the cognitive processes used by expert and novice designers. This may be linked to larger samples, which is a potential weakness of this and previous research using protocol analysis. This issue has been highlighted by Davies and Castell (1992) who suggest that the small number of subjects used within protocol analysis make it difficult to explore general statistical regularities in the design process.

However, as any researcher who has used protocol analysis would testify, the strength of the approach arises from the depth and density of the data obtained from the small samples. The work is very labour intensive and increases in the sample size would be likely to require a modified research methodology, perhaps based upon more active use of computer technology. The development of software to aid this process provides an obvious area for future research. The further developments of the coding systems discussed above also provides a potential area for future research.

The role of heuristics and design strategies within the protocols has been touched upon in this research project. Akin (1979) linked this work with protocol analysis based upon a coding system discussed in chapter 2. However, little work has been undertaken in this specific area in recent years and consequently the use of protocol analysis to look at heuristics and design strategies could form part of future research. Akin (1990) links this debate to the nature of design knowledge and suggests that expertise is acquired when declarative knowledge is transformed into procedural knowledge. Schon (1988) used protocol analysis to consider the patterns of reasoning and the use of design rules. There would seem to be a great need to expand research in these areas, particularly in relation to the forms of knowledge used by novice designers.

Another area for research could involve comparing the findings from other research methods with protocol analysis. This would involve a very broad based research plan which would simultaneously allow the collection of data from a selected sample using protocol analysis and other research methods. This would allow for the concerns of writers such as Davies and Castell (1992) to be addressed. They suggest that there is a need to move from traditional accounts of human problem solving, which can lead to second order descriptions of the design processes, to accounts of cognitive behaviour which "stress the culturally and environmentally situated nature of human cognition."

Perhaps the most important area for future research is concerned with the teaching strategies and design methods appropriate for novice designers, particularly those working within key stages 2 and 3 of the National Curriculum in the subject area of design and technology. The dearth of research in this area is highlighted in chapter 1 and reinforced by the researchers inability to find research projects related to the design problem solving behaviour of novice designers. Kimbell et al (1991) conclude that there has been a conspicuous lack of fundamental research in the area of design and technology with school pupils. They indicate a need for research to focus upon the nature and development of design and technological capabilities in school pupils.

Three principal areas can be identified for further research within an educational context. The first relates to building upon the work of the Assessment of Performance Unit (Kimbell et al, 1991) and others to explore the design methods and design behaviour used by novice designers. The APU project was principally aimed at furthering understanding of assessment methods, which are obviously centrally linked to teaching methods. As stated in chapter 1, design and technology lacks the research base found in other subjects such as mathematics and science. Research similar to that which looked at expert and novice differences in physics (Heller and Reif, 1984; etc.) needs to be established in order to look at the cognitive processes and design methods used by novice designers. The role of protocol analysis as a diagnostic tool might also be considered. There may also be opportunities for future research to consider the use of verbal protocols as a teaching method. That is to say, using verbal protocols to develop a large search space which can then be explored using drawings and notes. The researcher has some experience in using this technique.

The second potential area for research is concerned with the raising of awareness and staff development of teachers of design and technology . This could be related to design methodology and associated teaching methods. There is considerable opportunity for research into the perceptions and concerns of teachers, which could help to inform the development of training programmes and materials.

The third potential for future research concerns the issue of the assessment of novice designers, particularly in relation to National Curriculum and external examinations. Many experienced teachers of design have concerns that novice designers often solve problems twice - once to solve the problem and secondly to satisfy the requirements of assessment. This issue is highlighted by Jeffrey (1990) who suggests that pupils who write up design folios at the end of the project "can be made to describe a logical, systematic procedure which has more to do with the assessment framework than the actual development of design ideas in the project."

7.5 Concluding remarks

In conclusion, the research project has provided empirical evidence of the design problem strategies employed by expert and novice designers. In particular, it has made a significant contribution to understanding about the way novice designers within general education solve design problems.

Little research has been undertaken into the differences between expert and novice designers and consequently research methods have had to be developed which are suited to these two groups. Suggestions for the teaching of design methods have been made and a framework for future research has been put forward. It is clear that there is an urgent need for further research into the behaviour of novice designers.

However, perhaps more fundamental questions arise within the context of general education. How do teachers cope with the implications of the Education Reform Act (1988) and at the same time continue to develop subject expertise in specific areas, such as those concerned with design methodology? How can teachers, during a period of great pressure, find time to debate issues such as the nature of design problem solving?

Mathias and Jones (1988, 1989a, 1989b, 1989c,1989d) suggest that teacher appraisal can help to develop the notion of 'teacher as researcher'. They indicate that the mandatory framework for classroom observation could provide a forum for addressing the issues discussed above. Mathias and Jones further suggest that teacher appraisal has the potential to "set free and direct the creativity of teachers" and consequently maximise the potential of a largely untapped human resource in terms of the issues which form the focal points of this project. What is clear within the context of general education, is that research into the problem solving strategies of novice designers is largely virgin and uncharted territory. Great opportunities and challenges exist for those who are prepared to venture into this terrain.

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Appendix 1

Transcript - Protocol 3

Phrase	Protocol 3	Code
3/1	Choose an appropriate theme	A
3/2	and design a board game	A
3/3	which has an average play time	A
3/4	of no more than twenty minutes	A
3/5	Test a series of protypes	A
3/6	record the results	A
3/7	If possible include designs	A
3/8	from 3D playing pieces	A
3/9	Include designs from 3D playing pieces	A
3/10	So we're going to be picking it up	B
3/11	in hands maybe	F
3/12	Together with a visually presented	A
3/13	set of rules	A
3/14	Packaging and advertising	A
3/15	Choose an appropriate theme	A
3/16	Design a board game so	A
3/17	look up board games	B
3/18	I've got portable	D
3/19	cars	D
3/20	Um	
3/21	it's got to be in a case	B
3/22	Put it in an envelope	F
3/23	Pause (3 seconds)	

Phrase	Protocol 3	Code
3/24	Play time	A
3/25	Leave the play time	F
3/26	Pause (4 seconds)	
3/27	Right	
3/28	Appropriate theme	A
3/29	Themes	B
3/30	Um um	
3/31	Themes	B
3/32	Ah	
3/33	If we go to um	E
3/34	just basic	E
3/35	I've got colour shapes	G
3/36	textures,tones	G
3/37	Pause (4 seconds)	
3/38	How about black to grey	F
3/39	with um	
3/40	from it and it and shades	G
3/41	black to grey to white	F
3/42	Pause (4 seconds)	
3/43	Textures	E
3/44	We've got rough, smooth, glossy, matt	G
3/45	etc	
3/46	Colours	G

Phrase	Protocol 3	Code
3/47	Choose an appropriate theme	A
3/48	an design a board game so	A
3/49	Pause (8 seconds)	
3/50	If it's portable	E
3/51	it's got to be	E
3/52	fairly small	F1
3/53	Compact better word	G
3/54	because it could be	E
3/55	it could be big	F1
3/56	but fold down	C
3/57	Pause (4 seconds)	
3/58	Design a board game	A
3/59	Pause (6 seconds)	
3/60	OK we've got all of the big	E
3/61	all of the big things	E
3/62	what we've got to decide	E
3/63	is the um the target	G
3/64	the target group for the game	F
3/65	so	
3/66	Pause (5 seconds)	
3/67	because that will determine the um	E
3/68	that will determine the intellectual	G
3/69	scope of the game	F1

Phrase	Protocol 3	Code
3/70	So	
3/71	we've got from	E
3/72	small children to er	E
3/73	mature adults	F
3/74	Pause (5 seconds)	
3/75	I think bearing in mind the um	E
3/76	Pause (11 seconds)	
3/77	Bearing in mind	E
3/78	we've got a limited time	E
3/79	I think we'll go for small	E
3/80	small children	F
3/81	and we could have a	E
3/82	clue back to these	E
3/83	ideas	F
3/84	We could have um	G
3/85	We could have primaries	G
3/86	colour, primary colours	F
3/87	secondary colours, tertiary colours	G
3/88	We could have um	E
3/89	shape recognition	F
3/90	We could have regular, irregular shapes	G
3/91	Pause (6 seconds)	
3/92	We need some sort of reward	F

Phrase	Protocol 3	Code
3/93	Pause (3 seconds)	
3/94	So is it to be um	E
3/95	solitary game	G
3/96	or a dual game	G
3/97	two players	E
3/98	Now if it's two players	E
3/99	the reward is winning	F1
3/100	If it's solitary	E
3/101	what's the reward	E
3/102	Reward	E
3/103	What's satisfaction	F
3/104	Um	
3/105	We could have um	E
3/106	Pause (3 seconds)	
3/107	We could have some sort of	E
3/108	Um er	
3/109	reward built into the game	F1
3/110	You know like um flashing lights	D
3/111	Oh no that's perhaps a bit inane	F1
3/112	We'll stick to um	E
3/113	Pause (4 seconds)	
3/114	No we we'll leave out	E
3/115	that type of thing	F

Phrase	Protocol 3	Code
3/116	Pause (8 seconds)	
3/117	No the reward could simply be	E
3/118	the complete satisfaction of completion	F1
3/119	of actually doing it	C
3/120	So we've got um	E
3/121	Pause (4 seconds)	
3/122	We've got a game	E
3/123	to go for twenty minutes roughly	B
3/124	We've got themes	B
3/125	a limit of	E
3/126	I've stuck to a limit of	E
3/127	fairly limited range	F
3/128	Mainly working on er visual	G
3/129	um qualities	G
3/130	But hopefully there's some	E
3/131	Um	
3/132	intellectual sort of value to it	G
3/133	if you like	F1
3/134	Er	
3/135	Things that um	E
3/136	Pause (5 seconds)	
3/137	Things that are useful to know	F
3/138	Pause (3 seconds)	

Phrase	Protocol 3	Code
3/139	Design a board game	A
3/140	To play in no more than twenty minutes	A
3/141	Pause (12 seconds)	
3/142	Well	
3/143	Pause (8 seconds)	
3/144	Stereotype board game	E
3/145	What is there	E
3/146	there's draughts, chess	E
3/147	that type of thing	F1
3/148	Pause (14 seconds)	
3/149	But there's no reason why	E
3/150	it has to stay on the flat	G
3/151	We could have	E
3/152	we could be talking of	E
3/153	Um	
3/154	Pause (4 seconds)	
3/155	sphere	G
3/156	Or we could be	E
3/157	we could be er	E
3/158	looking at three dimensional	G
3/159	three dimensional series	E
3/160	of three dimensional boards	F1
3/161	Pause (11 seconds)	

Phrase	Protocol 3	Code
3/162	A bit like a rubic cube thing	C
3/163	So we play around	E
3/164	Pause (5 seconds)	
3/165	Instead of up and down	F1
3/166	We could have um	E
3/167	Pause (7 seconds)	
3/168	a pyramid	G
3/169	Um	
3/170	Or we could have	E
3/171	Pause (17 seconds)	
3/172	What I want is novel	E
3/173	or appealing	F
3/174	Pause (4 seconds)	
3/175	and it's got to be packaged	B
3/176	Pause (3 seconds)	
3/177	When it's packaged	E
3/178	I want to be able to see	F
3/179	Pause (4 seconds)	
3/180	When it's packaged	E
3/181	I want to be able to see the thing	E
3/182	So that people know what they're buying	F1
3/183	So if we're looking at packaging for um	E
3/184	for this type of thing	E

Phrase	Protocol 3	Code
3/185	could possibly be looking at vacuum formed clear plastic	G
3/186	for this type of thing	F1
3/187	May-be	F
3/188	Um	
3/189	Pause (4 seconds)	
3/190	Like this type of thing	C
3/191	Pause (16 seconds)	
3/192	Um	
3/193	Pause (11 seconds)	
3/194	So if we go back to um	E
3/195	Pause (4 seconds)	
3/196	Go back to the tones I think	E
3/197	Tones	F
3/198	Test the series of prototypes	A
3/199	and record the results	A
3/200	Well that'll be bloody difficult	B
3/201	because I haven't got a	F1
3/202	Pause (2 seconds)	
3/203	MUTTER	
3/204	Tones can be made up	E
3/205	like this	F
3/206	Pause (12 seconds)	
3/207	Um	

Phrase	Protocol 3	Code
3/208	Pause (7 seconds)	
3/209	Er	
3/210	Pause (4 seconds)	
3/211	Test the series of prototypes	A
3/212	and record the results	A
3/213	Early days	B
3/214	It's early days to do that	F1
3/215	Pause (12 seconds)	
3/216	Let's go back	E
3/217	We can't test	E
3/218	Um	
3/219	any prototypes	E
3/220	before	E
3/221	Pause (3 seconds)	
3/222	before we know	E
3/223	a bit more closely	E
3/224	where we're going	F1
3/225	So we've got a game	B
3/226	and we're going on	E
3/227	Is it a visual game	E
3/228	or tactile	G
3/229	Could be both	F1
3/230	Could be for blind children	G

Phrase	Protocol 3	Code
3/231	Could be for blind children	E
3/232	could be a tactile game	F1
3/233	Pause (3 seconds)	
3/234	Tactile game	G
3/235	Pause (7 seconds)	
3/236	Could be er	E
3/237	could be textures	F1
3/238	Blind children	E
3/239	tactile game and a series of	E
3/240	a series of um	E
3/241	um counters or blocks	G
3/242	or whatever you want to call them	F
3/243	Um	
3/244	that can be graded	E
3/245	in texture	G
3/246	and then	E
3/247	Pause (3 seconds)	
3/248	they could be	E
3/249	Pause (3 seconds)	
3/250	like so	F
3/251	and then once	E
3/252	they're graded in texture	E
3/253	they need to	E

Phrase	Protocol 3	Code
3/254	Pause (3 seconds)	
3/255	to be located	E
3/256	in our board somewhere	F
3/257	So we could have	E
3/258	a type of thing	E
3/259	which is in keeping with	E
3/260	the um blocks	F1
3/261	Like a long tray	G
3/262	Probably something like so	F
3/263	and then now	E
3/264	we're going to	E
3/265	The child's got to know when it's right	F
3/266	When he's done it right	F
3/267	So we could have	E
3/268	I know it's rather crude	F1
3/269	but we could have a series of	E
3/270	Um	
3/271	slots on the underside of these	G
3/272	squares	F
3/273	We could have a series of slots	E
3/274	or pegs	G
3/275	So we could have for instance	E
3/276	we could have four little pegs	E

Phrase	Protocol 3	Code
3/277	on this one	E
3/278	on that one there	F
3/279	and then we could have	E
3/280	four little pegs here	E
3/281	three there	E
3/282	and so and so forth	F1
3/283	three there	E
3/284	on that one	E
3/285	and then two and one	F1
3/286	So that there was only	E
3/287	one way of putting	E
3/288	the thing the squares in	F
3/289	and	
3/290	Um	
3/291	These pegs correspond to	E
3/292	the order of roughness or smoothness	G
3/293	in ever decreasing order like this	F1
3/294	OK	
3/295	Now they've got to	E
3/296	they've got to feel the um	E
3/297	they've got to feel these things	F
3/298	so let's look at shape	G
3/299	they're feeling	E

Phrase	Protocol 3	Code
3/300	Let's look at shape	E
3/301	if they're feeling	F
3/302	There's cubes	G
3/303	cubes round	E
3/304	cubes sharp edges	G
3/305	spheres	G
3/306	Spheres	E
3/307	Pause (5 seconds)	
3/308	Spheres spheres	F
3/309	They'd be able to feel	E
3/310	the little pegs	F
3/311	Ah but they'd be able	E
3/312	to feel the pegs anyway	E
3/313	wouldn't they	F1
3/314	because they'd be able to	E
3/315	feel the pegs on the	E
3/316	underside of this thing	F1
3/317	So in theory	E
3/318	they could cheat	F
3/319	by feeling the pegs in the cube	E
3/320	and then feeling the pegs in the	E
3/321	in the hole	F1
3/322	Um	

Phrase	Protocol 3	Code
3/323	Pause (18 seconds)	
3/324	Um	
3/325	Pause (9 seconds)	
3/326	Oh I'm trying to think of a way	E
3/327	try to think of a way around this	E
3/328	round this cheating thing	F
3/329	It's not a	E
3/330	It's not a	E
3/331	It's not a bad sort of notion	F1
3/332	with these um	E
3/333	textured sort of	E
3/334	Pause (3 seconds)	
3/335	pieces	C
3/336	and they're 3D pieces as well	F1
3/337	Pause (13 seconds)	
3/338	Um	
3/339	Pause (5 seconds)	
3/340	I'm stuck	
3/341	Stuck	
3/342	Pause (12 seconds)	
3/343	*Design a board*	A
3/344	Pause (16 seconds)	
3/345	Conscious now that having got into a	E

Phrase	Protocol 3	Code
3/346	possibly narrow sort of approach	E
3/347	through this	F
3/348	it's a bit of a	E
3/349	of an alley	E
3/350	I've got stuck in it	F1
3/351	May be	
3/352	Pause (4 seconds)	
3/353	May be it's not a good idea	F1
3/354	Pause (7 seconds)	
3/355	May be we need to actually see	E
3/356	some blind children	E
3/357	to do something like this	E
3/358	to actually be with them	F1
3/359	Pause (13 seconds)	
3/360	and if we could have um	E
3/361	Pause (4 seconds)	
3/362	We	
3/363	We could have um hard and soft	G
3/364	couldn't we	F
3/365	We could have hard and soft	E
3/366	Pause (4 seconds)	
3/367	so that we could have say	E
3/368	a hard cube or whatever	F

Phrase	Protocol 3	Code
3/369	then we could have um	E
3/370	range it through	E
3/371	to a real springy one	G
3/372	Squidgy type	G
3/373	that will be fun to squeeze	F1
3/374	Pause (6 seconds)	
3/375	Um	
3/376	Pause (13 seconds)	
3/377	May be it could just be one	E
3/378	Pause (4 seconds)	
3/379	May be it could just be one item	F
3 380	Um	
3/381	There's some way	E
3/382	that you could squeeze in	F1
3/383	Pause (8 seconds)	
3/384	nice soft corners on it	G
3/385	Pause (3 seconds)	
3 386	and then you could	E
3/387	squeeze it the other way	F
3/388	Pause (10 seconds)	
3/389	That's not quite	E
3/390	a board game is it	F1
3/391	but er	

Phrase	Protocol 3	Code
3/392	Pause (6 seconds)	
3/393	Wonder if it matters	F
3/394	Pause (6 seconds)	
3/395	Tactile hard soft	E
3/396	Textures	F
3/397	Pause (18 seconds)	
3/398	These would have to be big	E
3/399	not really small	F1
3/400	A series of	E
3/401	Pause (4 seconds)	
3/402	A series of	E
3/403	A series of balls	E
3/404	or spheres	E
3/405	each with different textures on	E
3/406	so that er they could be big	E
3/407	they could be bigger than that	F1
3/408	They could be in two hands	G
3/409	then they could be this big	E
3/410	and they could be textured	E
3/411	they could be textured to varying degrees	G
3/412	and then they must	E
3/413	be nice if they were soft	F1
3/414	that you could squeeze them	E

Phrase	Protocol 3	Code
3/415	and then there's no danger of	E
3/416	any of them getting thrown or um	E
3/417	or er either thrown at other people	G
3/418	or thrown at windows etc	F
3/419	They could be big enough	F
3/420	to hold in two hands	H
3/421	Pause (15 seconds)	
3/422	So we're not so much	E
3/423	We're not so much looking at	E
3/424	a board game	E
3/425	are we	F1
3/426	We're looking at more a sort of	E
3/427	just a tactile toy	F
3/428	So I've strayed away from er	E
3/429	title a little	F1
3/430	Pause (9 seconds)	
3/431	Before um	E
3/432	If we split the	E
3/433	If we split these	E
3/434	If we split these balls in half	F
3/435	and	E
3/436	we had	E
3/437	some way of joining them together	F

Phrase	Protocol 3	Code
3/438	and	
3/439	Pause (16 seconds)	
3/440	It's hardly a board game though is it	F1
3/441	Pause (14 seconds)	
3/442	Um	
3/443	Pause (4 seconds)	
3/444	Almost inclined to just	E
3/445	disregard this	E
3/446	board game business	E
3/447	I think	F1
3/448	We could have er	E
3/449	We could have this sponge	E
3/450	So we'd have to research	F1
3/451	to research into er plastics	G
3/452	Um	
3/453	Pause (2 seconds)	
3/454	I don't know off-hand	E
3/455	Want some sort of foam	G
3/456	that has a plastic quality	F
3/457	Pause (9 seconds)	
3/458	Um	
3/459	Pause (5 seconds)	
3/460	Now we're looking	E

Phrase	Protocol 3	Code
3/461	at packaging and advertising	A
3/462	Pause (6 seconds)	
3/463	Um	
3/464	Packaging and advertising	B
3/465	Well what have we got we've got um	E
3/466	advertising	F1
3/467	well for a start there's no	E
3/468	Pause (6 seconds)	
3/469	This sort of toy could be for um	E
3/470	To go out to this target group	F1
3/471	Could be blind	E
3/472	Could be blind but	E
3/473	it could also be just	E
3/474	sighted	F1
3/475	Blind and sighted	G
3/476	couldn't it	F
3/477	In fact it could be	E
3/478	Yeh	
3/479	It could be of special appeal to blind	E
3/480	kids	F1
3/481	It could be for sighted kids as well	C
3/482	So	
3/483	Um	

Phrase	Protocol 3	Code
3/484	Whatever the packaging and advertising	B
3/485	The quality of this	C
3/486	Um	
3/487	Handicap kids toys syndrome	D
3/488	Rough edges etc	G
3/489	Pause (10 seconds)	
3/490	Um	
3/491	Pause (4 seconds)	
3/492	Come along	
3/493	Very conscious that there's no um	
3/494	Pause (4 seconds)	
3/495	This has gone	E
3/496	this isn't really in some way	E
3/497	answering the question	F1
3/498	Pause (2 seconds)	
3/499	Because we've looking at um	E
3/500	3D playing pieces	A
3/501	Well we/ve got that	F
3/502	Made from card	A
3/503	Well that doesn't matter	F1
3/504	But with a visually presented set of rules	B
3/505	Well we've not really got any rules as such	F
3/506	because the the um	E

Phrase	Protocol 3	Code
3/507	The the	
3/508	The main	E
3/509	thing with the game is um just enjoyment	G
3/510	rather than having visual rules	C
3/511	I wonder if that matters	F1
3/512	Pause (2 seconds)	
3/513	I suppose if this is an exam	
3/514	then it's er	
3/515	possibly out of order	
3/516	Pause (6 seconds)	
3/517	Um	
3/518	Pause (13 seconds)	
3/519	Stuck	
3/520	Pause (4 seconds)	
3/521	Stuck	
3/522	Pause (20 seconds)	
3/523	Um	
3/524	Press on from this um	E
3/525	Press on from this thing	E
3/526	I need a name for this	F1
3/527	So we need a name which is	E
3/528	We need a name which appeals to kids	G
3/529	that kids can say easily	F

Phrase	Protocol 3	Code
3/530	and we need a name	E
3/531	which is appropriate	E
3/532	for the product	G
3/533	Um	
3/534	And which kids'll like	F1
3/535	Pause (7 seconds)	
3/536	I can't think like um	E
3/537	'Squeeze' 'Squidgy'	G
3/538	or something like that	F
3/539	Pause (12 seconds)	
5/540	'Sponzo'	C
3/541	Um	
3/542	Pause (11 seconds)	
3 543	Colours colour	E
3 544	What colour's it going to be	E
3 545	Is it going to be one colour	E
3 546	We primary colours perhaps a yellow	G
3 547	Pause 10 seconds)	
3 548	Let's take this sphere	E
3 549	Pause 6 seconds)	
3 550	Could it be broken in two	F1
3 551	Pause (16 seconds)	
3 552	Um	

Phrase	Protocol 3	Code
3/553	Still stuck on this board game thing	
3/554	Pause (10 seconds)	
3/555	One of the things to	
3/556	come out of this is how um	
3/557	difficult it must be	
3/558	for kids to er	
3/559	for kids in school	
3/560	to actually come into an exam	
3/561	and do this in	
3/562	I don't know whatever they get	
3/563	two hours or whatever	
3/564	Pause (10 seconds)	
3/565	MUTTER	
3/566	Pause (8 seconds)	
3/567	I've a feeling of disappointment in some ways	
3/568	Not being able to	
3/569	call on any other	
3/570	call on anything else	
3/571	and come up with some	
3/572	better ideas	
3/573	Me that is	
3/574	Pause (10 seconds)	
3/575	MUTTER	

Phrase	Protocol 3	Code
3/576	Pause (3 seconds)	
3/577	3D playing pieces	A
3/578	So if we had um	E
3/579	Going back to this er	E
3/580	this thing of tactile	F
3/581	If we go back to this board here	E
3/582	and we had them in order of um	E
3/583	squidginess say	F
3/584	We had hemispheres	G
3/585	So that would be a plan view	E
3/586	Like so	F
3/587	and then the side elevation would be	E
3/588	Here we've got some sort of board	E
3/589	which can	E
3/590	is yet to be decided upon	F
3/591	Side elevation	E
3/592	Like this	F1
3/593	So we have these in decreasing order	G
3/594	of hardness softness	F
3/595	Pause (3 seconds)	
3/596	How about um	E
3/597	Instead of a board	E
3/598	How about	E

Phrase	Protocol 3	Code
3/599	a board which is more in keeping	E
3/600	with the shapes	F1
3/601	with the hemispheres so we have	G
3/602	a series of	E
3/603	locations round here	G
3/604	and these er hemispheres fit in	E
3/605	Like so	E
3/606	on to this thing	F1
3/607	Or we could even have	E
3/608	instead of this	E
3/609	Instead of this being a board	E
3/610	it could actually be a sphere	G
3/611	couldn't it	F1
3/612	So instead of it being a disc	E
3/613	it would actually be a sphere	C
3/614	and then in the sphere	E
3/615	there could be um	E
3/616	there could be depressions	G
3/617	Um yes depressions	E
3/618	running around	E
3/619	So we'd have something like this	F
3/620	OK	E
3/621	and then	E

Phrase	Protocol 3	Code
3/622	er etc	E
3/623	There's too many in that isn't there	G
3/624	There's too many	F1
3/625	And then into the depressions	E
3/626	could fit these	E
3/627	small spheres	F
3/628	that er um	E
3/629	have this tactile quality	G
3/630	So we'd have	E
3/631	one big or one biggish	E
3/632	sphere	E
3/633	and then we'd have all these smaller ones	F1
3/634	Um	
3/635	Pause (10 seconds)	
3/636	and then when it's knocked down	E
3/637	it would actually be	E
3/638	fun to play with in its own right	F1
3/639	Rattled around on the floor etc	G
3/640	and this	
3/641	Pause (7 seconds)	
3/642	Um	
3/643	I've got	E
3/644	this thing I've got	E

Phrase	Protocol 3	Code
3/645	All the balls	E
3/646	have got to go inside	E
3/647	this big sphere	F
3/648	in twenty minutes	E
3/649	So are welooking at	E
3/650	same size hollows	G
3/651	or are we looking at	E
3/652	small and big	G
3/653	in which case obviously	E
3/654	the other balls would have to be	E
3/655	small and big	F1
3/656	Pause (14 seconds)	
3/657	Packaging	B
3/658	Could be packaged separate	B
3/659	or together	G
3/660	We'd better	E
3/661	better er um better package together	E
3/662	because it is more compact	F1
3/663	but then we'd need an illustration on the front	G
3/664	to indicate	E
3/665	the fact that the um smaller balls	E
3/666	came out of the big one	C
3/667	Pause (7 seconds)	

Phrase	Protocol 3	Code
3/668	and we could build in this tactile thing	F
3/669	Pause (2 seconds)	
3/670	So it's difficult to er	E
3/671	well impossible to model in card	F1
3/672	Need to be modelled in er	E
3/673	Would need to be modelled in foam	G
3/674	or or may be in	E
3/675	in timber	G
3/676	Um	
3/677	So we've got this	E
3/678	We've got this big sphere	F
3/679	with a series	E
3/680	of small	E
3/681	spheres	F
3/682	different sizes that fit in	E
3/683	or even just the same size	F1
3/684	So it's fun to put them in	E
3/685	It's fun to fit them in	F1
3/686	and once they fit in they would um	E
3/687	they would go sort of half in	E
3/688	so	
3/689	they would be like that	E
3/690	there	F

Phrase	Protocol 3	Code
3/691	Be like that	E
3/692	and these	E
3/693	and these would be um	E
3/694	about um	E
3/695	scale size	G
3/696	about this big	E
3/697	and then we'd have to measure out	F
3/698	Pause (14 seconds)	
3/699	I think we've got too many there	F1
3/700	Could get lost	E
3/701	So they may be couldn't run right	E
3/702	up to the top and the bottom	F1
3/703	So we'd have one hole	E
3/704	one hole in the top there	F
3/705	Pause (4 seconds)	
3/706	and then we'd have the big sphere	E
3/707	and then we'd have	E
3/708	holes running round	E
3/709	Pause (3 seconds)	
3/710	l'ke so	F
3/711	So we'd have perhaps a dozen	G
3/712	maybe a dozen small	E
3/713	We d have maybe a dozen holes	F

Phrase	Protocol 3	Code
3/714	and then we'd have these	E
3/715	these other small balls which should be of	E
3/716	this squidgy material	F1
3/717	And we could look at colours	E
3/718	Then we could have um	E
3/719	We could have different colours	F
3/720	We could have	E
3/721	We could go back to this thing of colours	E
3/722	and we could have the	E
3/723	the actual holes	E
3/724	the the depressions	E
3/725	we could have matching with the	E
3/726	the colours of the ball	F
3/727	couldn't we	F1
3/728	So if there was a blue depression	E
3/729	it would fit a blue ball	F1
3/730	So it would be aimed at probably	E
3/731	Um I don't know	E
3/732	Perhaps three	G
3/733	three years old	F1
3/734	Need to find out	E
3/735	About three years old	F
3/736	Ish	C

Phrase	Protocol 3	Code
3/737	So we've got a board	B
3/738	and it is being constrained by this question	E
3/739	this idea	F
3/740	So we've got this board	E
3/741	in the in the sphere	E
3/742	and we have um	E
3/743	we've got 3D playing pieces	F
3/744	So if I was presenting this	E
3/745	we would need a coloured	E
3/746	We would need a coloured illustration	G
3/747	a coloured illustration of the pieces	F1
3/748	OK	
3/749	We would need um	E
3/750	We would need er	E
3/751	a sort of scale drawing	E
3/752	but we've already talked about that	F1
3/753	We would need plans for um	E
3/754	a pack	E
3/755	of we said that vacuum foam	G
3/756	Er we would need	E
3/757	a transfer of pack illustration	G
3/758	So we're looking at er	E
3/759	Well we're looking at	E

Phrase	Protocol 3	Code
3/760	Mind you no	F
3/761	If the pack was clear	E
3/762	it would be clear whats inside anyway	F1
3/763	So then we would need a name	E
3/764	We would need the name of this thing	F1
3/765	So it would be something like "SQUIDGO"	G
3/766	or something	C
3/767	Er	
3/768	Pause (3 seconds)	
3/769	Er I'm conscious here of having	E
3/770	whooshed through this thing	F
3/771	Er	
3/772	and being very sort of um	E
3/773	Pause (4 seconds)	
3/774	narrow in approach	F1
3/775	because of	E
3/776	the constraints of this question	E
3/777	and also the time	E
3/778	we've had to do it in	F1
3/779	There's no um	E
3/780	reflection time	E
3/781	You know that type of thing	F1
3/782	Pause (8 seconds)	

Phrase	Protocol 3	Code
3/783	A set of rules	B
3/784	Well there's no rules as such	E
3/785	is there	F1
3/786	Self-explanatory	H
3/787	Pause (5 seconds)	
3/788	and this thing	E
3/789	Pause (4 seconds)	
3/790	this type of thing	E
3/791	could be	E
3/792	this principle could be extended	E
3/793	to um	E
3/794	the tone thing	F
3/795	you know whereby you have er	E
3/796	different toned spheres	G
3/797	that fit into the	E
3/798	the depressions and the tones match up	F1
3/799	So it's sort of tone recognition	H
3/800	Although that would obviosly be beyond	E
3/801	such a small child	E
3/802	probably anyway	F1
3/803	Pause (13 seconds)	
3/804	Small compact	F
3/805	OK	

Phrase	Protocol 3	Code
3/806	So if we go up to the beginning again	E
3/807	because this has been	E
3/808	I feel that this has been	E
3/809	a bit of a narrow sort of	E
3/810	thing	F1
3/811	What have we got	E
3/812	from board games	B
3/813	We've got er	E
3/814	Pause (3 seconds)	
3/815	packaging we've got folding up	E
3/816	into something else may be	F
3/817	Um	
3/818	Pause (8 seconds)	
3/819	So we've got dual purpose	F1
3/820	something dual purpose	H
3/831	Pause (19 seconds)	
3/832	Trying to um er search	E
3/833	for some	E
3/834	new set of direction	F
3/835	Pause (7 seconds)	
3/836	Something a bit more	E
3/837	novel or exciting or	F
3/838	Um	

Phrase	Protocol 3	Code
3/839	Pause (8 seconds)	
3/840	Perhaps at the moment	E
3/841	as this thing has actually	E
3/842	been exhausted may be	F1
3/843	Pause (16 seconds)	
3/844	Um	
3/845	Sort of half dried up	F
3/846	of ideas	F1
3/847	Pause (21 seconds)	
3/848	I wonder if these things would float as well	F1
3/849	Play in the bath	H

Appendix 2

Transcript - Protocol 4

Phrase	Protocol 4	Code
4/1	Right let's have a look	F
4/2	Pause (2 seconds)	
4/3	Project one	A
4/4	using a sheet of A4	A
4/5	design and make a book support	A
4/6	which could be used	A
4/7	for revision/study	A
4/8	and then be stored in an A4 folder	A
4/9	Right book support	E
4/10	Pause (4 seconds)	
4/11	Well it's got to be the sort of book that you'd be	B
4/12	you'd be studying with	F
4/13	Er	
4/14	Probably about	E
4/15	about the same sort of size as this sheet	F
4/16	So it's got to be quite tall	E
4/17	and also angled up	G
4/18	I think so that you can	E
4/19	possibly stand the book up	F1
4/20	and then view the book while you're	E
4/21	while you're writing down	E
4/22	or drawing sketching whatever	F1
4/23	Let's have a look	E

Phrase	Protocol 4	Code
4/24	Er	
4/25	Pause (2 seconds)	
4/26	Book support	A
4/27	and then be stored in an A4 folder	A
4/28	Right	E
4/29	Obviously it can't be bigger than A4	E
4/30	if it's got to go in an A4 folder	F1
4/31	so	
4/32	This is an A4 sheet	G
4/33	so this is its maximum	F1
4/34	Pause (2 seconds)	
4/35	Er	
4/36	Pause (2 seconds)	
4/37	So it needs needs flaps on the side	G
4/38	or on the base that can	E
4/39	that can bold down	E
4/40	so that it can be stored flat	F1
4/41	So so	E
4/42	a quick look at this	E
4/43	Pause (7 seconds)	
4/44	Roughly A4 size	G
4/45	slight slightly smaller than A4 size	F
4/46	with er	E

Phrase	Protocol 4	Code
4/47	Pause (2 seconds)	
4/48	flaps at each side like this	E
4/49	going down here	F
4/50	Er	
4/51	Pause (4 seconds)	
4/52	That'll give it an angle	E
4/53	so that the book can be supported	F1
4/54	Pause (2 seconds)	
4/55	so you can look at it like this on this angle	G
4/56	and have plenty of space in front of you	E
4/57	for	E
4/58	for working on	F
4/59	Um	
4/60	Pause (2 seconds)	
4/61	Right	E
4/62	Now there's nothing to this	F
4/63	if these	E
4/64	if these were folding flaps	E
4/65	there'd be nothing on this	E
4/66	to make it stand	F1
4/67	part of the flaps'd	E
4/68	tend to fall outwards or inwards	G
4/69	so	E

Phrase	Protocol 4	Code
4/70	we'd have to have a supporting	E
4/71	Pause (2 seconds)	
4/72	supporting flaps on the inside	F1
4/73	which	E
4/74	could fold from this	E
4/75	from this bottom edge here	F
4/76	but would need	E
4/77	Pause (2 seconds)	
4/78	er a temporary attachment to the sides	F
4/79	which could be	
4/80	attached and detached as necessary	E
4/81	to enable it to fold	F1
4/82	Pause (4 seconds)	
4/83	Er and a permanent attachment	E
4/84	on this face here	C
4/85	Pause (5 seconds)	
4/86	Right let's just check this again	F
4/87	Using an A4 sheet	A
4/88	Pause (2 seconds)	
4/89	design and make a book support	A
4/90	which could be used for revision/study	A
4/91	and then be stored in an A4 folder	A
4/92	Pause (3 seconds)	

Phrase	Protocol 4	Code
4/93	Right	E
4/94	I think that's worth	E
4/95	worth having a look at that	F1
4/96	It would have to be joined	G
4/97	Pause (2 seconds)	
4/98	As we're using an A4 sheet here	E
4/99	Pause (4 seconds)	
4/100	we'll have to use separate sheets	E
4/101	for the flaps	F
4/102	These can be permanently joined	E
4/103	by scoring and bending	G
4/104	and then gluing	E
4/105	these two side pieces	F
4/106	and then	E
4/107	and the same	E
4/108	the same for the front section of the bottom	F1
4/109	but the er the joining part here and here	E
4/110	which has to be detachable	G
4/111	so that it can be folded down into the	E
4/112	into the A4 transportation folder	F1
4/113	will have to be made from some other	E
4/114	other device	F
4/115	unless I've got	E

Phrase	Protocol 4	Code
4/116	Let's have a look at the card	F
4/117	Pause (12 seconds)	
4/118	We'll assume that's the main body of the	E
4/119	the support	E
4/120	We'd want to have something like that angle	F
4/121	Pause (6 seconds)	
4/122	I'll use this white stuff	E
4/123	It's slightly thicker	F1
4/124	Pause (8 seconds)	
4/125	If we look at one side section first	E
4/126	It's going to stand to stand up	F
4/127	Pause (2 seconds)	
4/128	possibly	E
4/129	that kind of angle	E
4/130	No greater than that	F1
4/131	Probably forty five degrees	G
4/132	Pause (3 seconds)	
4/133	We'll try that anyway	F
4/134	Pause (2 seconds)	
4/135	Let's measure down this side	E
4/136	Pause (8 seconds)	
4/137	Eight	E
4/138	and a quarter	E

Phrase	Protocol 4	Code
4/139	Pause (6 seconds)	
4/140	Now we need to er	E
4/141	not to forget the	E
4/142	the attachment flap	F
4/143	which we'll leave an inch for	G
4/144	Pause (2 seconds)	
4/145	or a second line parallel to that	E
4/146	Pause (4 seconds)	
4/147	one inch further down	E
4/148	Pause (11 seconds)	
4/149	and an inch here for the flap	E
4/150	Pause (5 seconds)	
4/151	Right now we'll achieve what we've got in the sketch	C
4/152	Pause (4 seconds)	
4/153	Certainly not	F1
4/154	Yes it might do	G
4/155	Right we'll we'll cut that out and just	E
4/156	just give that a quick test	F
4/157	and see if that	E
4/158	achieves	E
4/159	the desired	E
4/160	angle on the front face	F1
4/161	Pause (6 seconds)	

Phrase	Protocol 4	Code
4/162	Right the er	E
4/163	flap obviously needs scoring so that we can build that back	G
4/164	Pause (2 seconds)	
4/165	Let's have a quick go at that with the back end of the knife	F
4/166	Pause (9 seconds)	
4/167	Right	E
4/168	Pause (2 seconds)	
4/169	Now	E
4/170	That achieves a good angle	F
4/171	Pause (4 seconds)	
4/172	That'd sit quite nicely with a book	E
4/173	against it	F1
4/174	Pause (2 seconds)	
4/175	But would it fold flat into an A4	E
4/176	Pause (3 seconds)	
4/177	Yes it does	F1
4/178	So in actual in actual fact we could er	E
4/179	make another one of those the other side	F1
4/180	same dimensions	G
4/181	Pause (4 seconds)	
4/182	OK	
4/183	Pause (2 seconds)	
4/184	Chop that one out thus	E

Phrase	Protocol 4	Code
4/185	I can hear voices in the background	
4/186	Pause (10 seconds)	
4/187	and an inch for the flap here	E
4/188	Pause (6 seconds)	
4/189	Fold that back	E
4/190	Pause (5 seconds)	
4/191	Opposite way of course	F
4/192	Right	E
4/193	we can just	E
4/194	Pause (2 seconds)	
4/195	visualise how it's going to	E
4/196	how it's going to lean	F1
4/197	just double check that it will	E
4/198	in fact fold into an A4	E
4/199	that one won't	F1
4/200	Pause (3 seconds)	
4/201	Right	E
4/202	we've got too much	E
4/203	too much and then too great a length there so	G
4/204	Pause (4 seconds)	
4/205	so that will need a little bit lopping off	E
4/206	so that it can still fold into the	E
4/207	into the A4 for transportation	F1

Phrase	Protocol 4	Code
4/208	Pause (4 seconds)	
4/209	Chop that off there	E
4/210	Pause (6 seconds)	
4/211	and that off there	E
4/212	Pause (2 seconds)	
4/213	I'll just quickly knock this	E
4/214	knock this model together and then we can sit and	E
4/215	have a think about it	F
4/216	Pause (3 seconds)	
4/217	See if it's er	E
4/218	Pause (2 seconds)	
4/219	can be modified in any way	F
4/220	or if even if	E
4/221	if it indeed fulfills the brief	E
4/222	At all	F
4/223	Pause (3 seconds)	
4/224	Now card's er great stuff for modelling	F1
4/225	it's really quick to work with and you get instant results	G
4/226	so it	E
4/227	it doesn't hurt to delve into this straight away	F1
4/228	Pause (2 seconds)	
4/229	have a quick try	E
4/230	Pause (5 seconds)	

Phrase	Protocol 4	Code
4/231	A bit of magic glue	E
4/232	Pause (11 seconds)	
4/233	First flap	E
4/234	Pause (4 seconds)	
4/235	and second flap	E
4/236	Right it's back to front	F
4/237	Typical	F
4/238	Pause (8 seconds)	
4/239	Just apply that to there	E
4/240	Pause (7 seconds)	
4/241	That gives us a	E
4/242	Typical	E
4/243	Wrong way round again	F1
4/244	Pause (4 seconds)	
4/245	He did say it was easy modelling with card	G
4/246	Well it might be a good idea to mark the right side	F1
4/247	Pause (2 seconds)	
4/248	Mark two	E
4/249	Try that	E
4/250	Pause (10 seconds)	
4/251	OK that's a bit more like it	F
4/252	Right	E
4/253	Now that's	E

Phrase	Protocol 4	Code
4/254	Pause (2 seconds)	
4/255	that would provide a support at an angle suitable for reading	G
4/256	or studying	F1
4/257	It also folds nicely flat into an A4 size	C
4/258	Pause (3 seconds)	
4/259	Right the next part	E
4/260	we ought to look at	E
4/261	is a	E
4/262	a support base	F
4/263	which will	E
4/264	in fact hold these two side together	E
4/265	because obviously under under any weight they're going to fold flat	F1
	PROMPT	
4/266	Up on the	E
4/267	on the brief	E
4/268	Using a sheet of A4 card now	A
4/269	this is	E
4/270	this is going to pose a problem	F
4/271	One sheet	E
4/272	as opposed to er one complete sheet	E
4/273	and several offcuts	F
4/274	Er	
4/275	I'll go back to my	E

Phrase	Protocol 4	Code
4/276	initial sketch	F
4/277	Now we could	E
4/278	presumably	E
4/279	Pause (4 seconds)	
4/280	still still use this	E
4/281	this same basic idea	F
4/282	with these two parts	E
4/283	round here	E
4/284	for support	F1
4/285	But	
4/286	Er	
4/287	Using one A4 sheet obviously this dimension here	B
4/288	would have to be much	E
4/289	much smaller	F1
4/290	in fact it's only going to come out to	E
4/291	inches	F1
4/292	So I wonder if there's any possibility	E
4/293	of er	E
4/294	still using	E
4/295	just one A4 sheet	F1
4/296	Obviously we don't	E
4/297	we don't want to be studying a	E
4/298	an extremely small book	F

Phrase	Protocol 4	Code
4/299	May be	E
4/300	attempting something that er	E
4/301	uses an A4 sheet or the other	E
4/302	or the other way round	F1
4/303	so it er	E
4/304	Pause (2 seconds)	
4/305	looks like this	F
4/306	You can still get it out of one sheet with a fold at the bottom	C
4/307	So	E
4/308	Pause (2 seconds)	
4/309	Get this kind of effect here	E
4/310	Pause (3 seconds)	
4/311	That would be really easy to do	F
4/312	and give	E
4/313	a moderate amount of support	E
4/314	to a book	F1
4/315	However there's no	E
4/316	no immediate means of er	E
4/317	Pause (3 seconds)	
4/318	stopping this	E
4/319	angled face from falling down flat under the weight of a book	F1
4/320	We still need some kind of side support like this	G
4/321	so this	E

Phrase	Protocol 4	Code
4/322	presumably this would be done	E
4/323	by decreasing the	E
4/324	the width here	F
4/325	and	E
4/326	folding	E
4/327	and may be folding that flap straight back	E
4/328	Let's have a look at that now	F
4/329	Pause (3 seconds)	
4/330	Just quickly	E
4/331	If we er	E
4/332	Pause (2 seconds)	
4/333	Bearing in mind it's got to support a book	F
4/334	it wants to be as	E
4/335	as wide as possible	F1
4/336	Pause (2 seconds)	
4/337	and the overall dimension here	E
4/338	is eleven and three quarters	F
4/339	So	E
4/340	Pause (2 seconds)	
4/341	if we lop er	E
4/342	say	E
4/343	two and a half inches off each side	F
4/344	Pause (6 seconds)	

Phrase	Protocol 4	Code
4/345	two and a half inches	E
4/346	Pause (4 seconds)	
4/347	just quickly	E
4/348	Pause (4 seconds)	
4/349	whip off a model of this just to see if there's any	E
4/350	Pause (2 seconds)	
4/351	technical difficulties in	E
4/352	making a flap	E
4/353	in this width of card	F
4/354	Pause (5 seconds)	
4/355	Let's rule this tick off	E
4/356	That's never two and a half inches	F
4/357	Pause (2 seconds)	
4/358	Optical illusion	G
4/359	Must be the board	F1
4/360	Right	E
4/361	Pause (4 seconds)	
4/362	Just quickly score down that	E
4/363	Pause (8 seconds)	
4/364	Here and here	F
4/365	Now one thing that springs to mind	E
4/366	is that I haven't done anything	E
4/367	about the	E

Phrase	Protocol 4	Code
4/368	the base	F
4/369	which obviously should be done first	G
4/370	Moderate amount of support	E
4/371	So we can give that two and a half inches as well	F1
4/372	That will only leave us	E
4/373	Er	
4/374	six inches	F
4/375	We'll try that	E
4/376	Only six inches for the book support	F1
4/377	Just quickly try that	E
4/378	Pause (4 seconds)	
4/379	Two and a half inches straight across the bottom	F
4/380	Pause (6 seconds)	
4/381	Right	E
4/382	Pause (8 seconds)	
4/383	Now that'll give us	E
4/384	a small amount of support	E
4/385	on the angle	F1
4/386	and on the base and that	E
4/387	would possibly be adequate	F1
4/388	Now the flaps need a	E
4/389	a first cut along here to	G
4/390	detach them from that base	F

Phrase	Protocol 4	Code
4/391	here and here	E
4/392	and we'll just	E
4/393	using the model we'll just	E
4/394	just see what sort of folds	E
4/395	we can get	F
4/396	what sort of support for the back	G
4/397	Pause (5 seconds)	
4/398	Right that works	E
4/399	that works quite well actually	F1
4/400	at least to determine	E
4/401	what angle to remove from here	E
4/402	Now forty five degrees seemed to work on this	G
4/403	on this other one	F
4/404	so we'll go for forty five degrees again	E
4/405	on here	F
4/406	So remove	E
4/407	Pause (3 seconds)	
4/408	two inches we'll try	G
4/409	Won't take me a second	F
4/410	if it's wrong	E
4/411	we can always modify that again	F
4/412	two inches up here	G
4/413	two inches up here	E

Phrase	Protocol 4	Code
4/414	Pause (6 seconds)	
4/415	Right	E
4/416	Pause (4 seconds)	
4/417	Quickly score that	E
4/418	Pause (3 seconds)	
4/419	and score that	E
4/420	Pause (6 seconds)	
4/421	Fold those back	E
4/422	Pause (3 seconds)	
4/423	Now this is er	E
4/424	Pause (5 seconds)	
4/425	beginning to look something like a	E
4/426	support	F1
4/427	Pause (2 seconds)	
4/428	Right	E
4/429	Now	E
4/430	Pause (2 seconds)	
4/431	These again need to be cut off	F
4/432	we can measure	E
4/433	visually	G
4/434	Pause (2 seconds)	
4/435	There	E
4/436	Pause (4 seconds)	

Phrase	Protocol 4	Code
4/437	and there	F
4/438	Right	E
4/439	Pause (6 seconds)	
4/440	Which face to cut off	E
4/441	That's the question	F
4/442	Pause (14 seconds)	
4/443	Got our angles	E
4/444	Right	E
4/445	it needs to come from there	E
4/446	Pause (3 seconds)	
4/447	back to there	F1
4/448	Pause (3 seconds)	
4/449	There's our excess	G
4/450	Pause (3 seconds)	
4/451	Right well	E
4/452	Just running it over quickly in my mind	E
4/453	it seems to	E
4/454	to fit the first part of the brief	F1
4/455	It's on a one A4 sheet	H
4/456	and it	H
4/457	and it does fold flat	H
4/458	Pause (2 seconds)	
4/459	so it could be stored	E

Phrase	Protocol 4	Code
4/460	back into an A4 folder	C
4/461	Pause (4 seconds)	
4/462	Let's hope we've removed the right piece	F
4/463	OK	E
4/464	Let's have another look at	E
4/465	this now	F
4/466	Pause (9 seconds)	
4/467	Something	E
4/468	something wrong here	F1
4/469	Pause (4 seconds)	
4/470	Got the right angle here	E
4/471	the right angle here	E
4/472	Yes that's OK	F1
4 473	Pause (3 seconds)	
4/474	R ght now	E
4/475	Some method of attaching it	E
4/476	Let's recheck the brief	F
4/477	Pause (2 seconds)	
4/478	Right now we've got one A4 sheet	A
4/479	Most of it	F
4/480	Book support	A
4/481	R ght	E
4/482	It does support books	E

Phrase	Protocol 4	Code
4/483	or it could support books	F1
4/484	Used for revision/study	A
4/485	and then stored in an A4 folder	A
4/486	So	E
4/487	it fulfils everything	F1/H
4/488	except	E
4/489	there's no provision for it to	E
4/490	attach attach itself	E
4/491	into a	E
4/492	into a solid support	F1
4/493	Pause (5 seconds)	
4/494	So	E
4/495	That gives us our angle	F1
4/496	These two	E
4/497	These two seams here are	E
4/498	fixed permanently anyway	F
4/499	and they hinge	G
4/500	that's OK	F1
4/501	These two	E
4/502	give it support laterally	G
4/503	and they need	E
4/504	some sort of temporary attachment	F1
4/505	Pause (3 seconds)	

Phrase	Protocol 4	Code
4/506	Right	E
4/507	Pause (3 seconds)	
4/508	Now	E
4/509	Possibly some sort of slot in the	G
4/510	side	F1
4/511	Pause (6 seconds)	
4/512	If we could	E
4/513	insert these two	E
4/514	which would prevent them from sliding out until they	E
4/515	until they were needed	F1
4/516	Right	E
4/517	Let's	E
4/518	try	E
4/519	try something down like that	F
4/520	Pause (4 seconds)	
4/521	Say to there	F
4/522	That should give us enough depth	G
4/523	Pause (3 seconds)	
4/524	Let's just re-check now	E
4/525	In its folded state if the outside flap came up like that	E
4/526	slotted in there	F1
4/527	that should	E
4/528	work	C

Phrase	Protocol 4	Code
4/529	Right we'll just try that	E
4/530	quickly	F
4/531	As I say	E
4/532	modelling with white card	E
4/533	is	E
4/534	very quick	F1
4/535	so you can	E
4/536	so if you make a	E
4/537	drop a clanger	F
4/538	you can always start again	E
4/539	start again	F1
4/540	No problem	F
4/541	Right	E
4/542	Pause (3 seconds)	
4/543	OK	E
4 544	That seems to	E
4 545	that seems to work	F1
4/546	We'll try we'll try the same on the other side	E
4/547	and see what	E
4/548	what the two work like together	F
4/549	Pause (6 seconds)	
4/550	Roughly	E
4/551	Pause (7 seconds)	

Phrase	Protocol 4	Code
4/552	Quick slot here	E
4/553	Right	F
4/554	Now something that er	E
4/555	does spring to mind	E
4/556	is that there's nothing at the front of the inclined face to	G
4/557	stop any book from sliding	E
4/558	outwards	F
4/559	That does in fact	E
4/560	actually stand up quite	F1
4/561	quite nicely like that	C
4/562	Pause (4 seconds)	
4/563	Right	
4/564	Pause (4 seconds)	
4/565	But as I thought	E
4/566	the book	E
4/567	or whatever your standing against it when your stydying	E
4/568	has a tendency to slip	E
4/569	slip forwards	F1
4/570	Pause (3 seconds)	
4/571	so it moght be a good idea to	E
4/572	Pause (3 seconds)	
4/573	have the whole thing on a	E
4/574	on a more gentle slope	F1

Phrase	Protocol 4	Code
4/575	Pause (3 seconds)	
4/576	That'll give it just enough incline	G
4/577	I've probably gone a bit too far here	F
4/578	anyway	E
4/579	so you're going to have trouble with writing and things like that	F1
4/580	So to	E
4/581	to modify this design	F
4/582	Pause (3 seconds)	
4/583	the folds would have to be at a greater angle here	G
4/584	Let's try that	F
4/585	Pause (3 seconds)	
4/586	We can try a three inch	G
5/587	a three inch	E
4/588	flap up here	F
4/589	a three inch fold	E
4/590	and see what sort of angle that gives us	F1
4/591	Score down that	E
4/592	Pause (3 seconds)	
4/593	and score that down here	E
4/594	Pause (6 seconds)	
4/595	Fold the two pieces in and once again check the angle	E
4/596	Now that lies a lot flatter	F1
4/597	Pause (2 seconds)	

Phrase	Protocol 4	Code
4/598	That could well be	E
4/599	the answer	C
4/600	It still bothers me that	E
4/601	there's no	E
4/602	no lip at the bottom	G
4/603	to support	F1
4/604	Let's let's re-check	E
4/605	See if there's any clue in this brief here	F
4/606	Book support which coould be used in revision/study and then be stored in an A4 folder	A
4/607	Right	E
4/608	Now	E
4/609	Book support	A
4/610	I mean why why would you need to support a book other than to	B
4/611	angle it	F1
4/612	when you don't need a book support	E
4/613	if you're going to put the the book	E
4/614	flat on the table	F1
4/615	Obviously it can just stay there	E
4/616	So	E
4/617	presumably to support a book	B
4/618	the only reason for that would be	E
4/619	to incline it so that you can	E

Phrase	Protocol 4	Code
4/620	you can have it open at the page you want	F1
4/621	and leave yourself space	E
4/622	Free to work here	E
4/623	or write notes or whatever	F1
4/624	and	E
4/625	not have to crane your neck over	G
4/626	if it was lying flat	H
4/627	So I think we're on the right track	E
4/628	but it still bothers me that there's no bottom support here	F
4/629	Now where were the two pieces I cut out	E
4/630	Had these been left in position	E
4/631	at this stage	F
4/632	with a new angle	G
4/633	there's still nothing they could	E
4/634	by way of support at the	E
4/635	front	F
4/636	Pause (5 seconds)	
4/637	They would just	E
4/638	they would just come up like that	F1
4/639	Pause (3 seconds)	
4/640	Now this is a problem	G
4/641	Er	
4/642	Pause (5 seconds)	

Phrase	Protocol 4	Code
4/643	Could it be that we need	E
4/644	another fold here	F
4/645	Back to the sheet	E
4/646	The sheet	F
4/647	Pause (6 seconds)	
4 648	Now we've got our	E
4 649	our flatter	E
4 650	less inclined	E
4 651	Pause (2 seconds)	
4 652	device	E
4 653	with supporting flaps	F
4 654	How about	E
4 655	Pause (5 seconds)	
4 656	an additional fold there	G
4 657	Pause (5 seconds)	
4 658	Yes that might	E
4 659	that might actually work	F1
4 660	So we'd need er	E
4 661	on the model	E
4 662	Pause (2 seconds)	
4 663	We'd need a fold out this way	E
4 664	at the base	F
4 665	and a fold back	E

Phrase	Protocol 4	Code
4/666	So	E
4/667	just quickly try that	F
4/668	Pause (3 seconds)	
4/669	Half inch out	G
4/670	half inch back	E
4/671	Now will that achieve anything	F
4/672	Well one way to find out is to quickly	E
4/673	slice through that and have a	E
4/674	look	F
4/675	Now this would	E
4/676	this would give a foot	F1
4/677	a foot sort of base support to the book	G
4/678	It would also be attached to the	E
4/679	to the unit itself	F1
4/680	so the unit couldn't slide back	G
4/681	Only problem is could the book slide away from the unit still	F1
4/682	That would give us that	E
4/683	kind of effect	F
4/684	Pause (4 seconds)	
4/685	which may	E
4/686	may work	E
4/687	It may work	C
4/688	Let's have a look	E

Phrase	Protocol 4	Code
4/689	it's still	E
4/690	It still looks slightly dubious	F1
4 691	Pause (2 seconds)	
4 692	No that seems as though it might	E
4/693	it might actually work	F1
4 694	Let's just modify the er	E
4 695	Cut these l'ttle bits out of	E
4 696	the card	F
4 697	What angle do we want these	G
4 698	on these now	F
4 699	We can draw that in by	E
4 700	Pause (2 seconds)	
4 701	pos t on'ng that	F
4 702	Pause (3 seconds)	
4 703	Sım'larly on the other s'de	G
4 704	th s ıs er	E
4 705	gettıng sma er and smaller by the minute	F
4 706	t's er	E
4 707	obviosly for a pocket s'ze book	F1
4 708	OK	
4 709	Pause (2 seconds)	
4/710	We'll chop that	E
4 711	Pause (2 seconds)	

Phrase	Protocol 4	Code
4/712	Chop that out	E
4/713	Chop that off	E
4/714	Discard that	E
4/715	Pause (3 seconds)	
4/716	and same on the other side	F
4/717	Pause (12 seconds)	
4/718	Now	E
4/719	Pause (6 seconds)	
4/720	Right now we're back at the er	E
4/721	back at a similar	E
4/722	stage as we were a few minutes ago	F
4/723	but we now have a front support for the base of the book	E
4/724	which theoretically should	E
4/725	prevent the whole thing from sliding apart	F1
4/726	Yes it seems to	E
4/727	work with a piece of card anyway	F
4/728	and er	
4/729	just to finish off this particular model	E
4/730	what we need to do now	E
4/731	is re-do the flaps	E
4/732	the support flaps for these side pieces	F
4/733	It will look something	E
4/734	something like that	F

Phrase	Protocol 4	Code
4/735	It is getting remarkably small	E
4/736	Could be a problem	G
4/737	could be a problem	E
4/738	We'll just quickly	E
4/739	Pause (3 seconds)	
4/740	finish off this particular model	F
4/741	re-examine the brief	E
4/742	see if there's anything we've missed	F
4/743	Then we can get back to a few more sketches to see if there's any	E
4/744	any other alternatives	F
4/745	That will tuck into there	E
4/746	and	E
4/747	that should tuck into there like that	E
4/748	Hey presto	F
4/749	Right	E
4/750	OK book support	B
4/751	It supports a book	H
4/752	Let's review the brief	E
4/753	Right we're using one A4 sheet	A
4/754	of card	A
4/755	OK	E
4/756	Book support	A
4/757	Right it will support something vaguely book-shaped	F1

Phrase	Protocol 4	Code
4/758	and it can fold down	H
4/759	into an A4 folder	F1
4/760	Right	E
4/761	Is there any other	E
4/762	anything we might have missed on this	F
4/763	Well it's not particularly pretty	G
4/764	but	E
4/765	there again it doesn't have to be	E
4/766	I don't think	F1
4/767	It seems to support reasonably	E
4/768	well	F1
4/769	Pause (12 seconds)	
4/770	Course it wouldn't support a world atlas that's for sure	F
4/771	Right	E
4/772	Er	E
4/773	So there we have it	H
4/774	Pause (6 seconds)	
4/775	See if there's anything	E
4/776	anything I could have improved	E
4/777	upon here	F
4/778	Pause (12 seconds)	
4/779	Um	
4/780	Not using these constraints I don't think	F1

Phrase	Protocol 4	Code
4/781	That seems to be	E
4/782	about as good as I can get	F1/H
4/783	The only other thing is	E
4/784	is there any way any other alternative way of supporting a book	E
4/785	apart from inclining it like this	F
4/786	I don't think they'd be any	E
4/787	point in supporting it flat	E
4/788	on the table	F1
4/789	So	E
4/790	One would assume from the brief	E
4/791	Pause (2 seconds)	
4/792	that an incline is necessary	F1
4/793	Right	E
4/794	And it seems to fulfil that	F/H
4/795	It can be ripped apart	F1
4/796	folded flat	F/H
4/797	and go into an	F1
4/798	an A4 folder	H
4/799	Right	E
4/800	OK	E
4/801	Right John I think er	E
4/802	I think I've got as far as I can go on that one.	F1

Appendix 3

Transcript - Protocol 5

PROTOCOL 5

Phrase		Code
5/1	I'm going to design a triangular shape	D
5/2	with a flat bottom	E
5/3	and pyramid edges	E/G
5/4	Then put the name on the card.	E
5/5	This shape would be easier	F
5/6	and wouldn't fall over	H
5/7	and would show the letters easily	H
5/8	and wouldn't take up that much space.	H
5/9	So If I make this 60mm deep	E
5/10	all sides are equal.	G
5/11	I need to fold this in half	G
5/12	20mm on each side.	G
5/13	I'll score a line on each side	E
5/14	and fold that to there and that to there	E
5/15	to give a triangle.	F1/F/G
5/16	Quite stiff card	G
5/17	would probably be best	F1
5/18	and tape to hold down the back part.	E

Phrase		Code
5/19	I'll put the letters on	E
5/20	and fill up the whole space on the card.	F/F1
5/21	I'm thinking of what colours to use	E
5/22	that would stand out the best	F1
5/23	bright colours	E
5/24	or say a black around the actual letters	F
5/25	with a colour inside of them.	F
5/26	I'll just draw around this letter and colour it in it in green to see how it comes out.	E/F1
5/27	You could use a flatter piece of paper with a stand on the back	D
5/28	to hold that up	F1
5/29	but that could fall over easier	F1
5/30	and this (triangular shape) would stay still.	H
5/31	Normal paper might be able to hold it up	E
5/32	but it wouldn't be as strong.	F1
5/33	Cardboard would do it	E
5/34	or even a metal - a soft metal with the name engraved on it.	F
5/35	Tin	G

Phrase		Code
5/36	something that would bend quite easily.	F1
5/37	I'll colour these in so they'll stand out.	E/F
5/38	I was thinking would it stand out on the desk	H
5/39	or would it fall over or anything like that?	H
5/40	It would stand up straight I think	F
5/41	and the name would be straight on it.	F
5/42	You could glue it on the desk	F
5/43	or even put a weight inside and hold it down on the desk	F
5/44	and it would not move from there.	F1
5/45	I think it would solve the problem of putting the name on the desk.	H

Main problem

5/46	I could try a family game	D
5/47	for about 4 people,	E
5/48	something on the lines of chess.	D
5/49	Snakes and Ladders but three-dimensional.	D
5/50	Make a game where everyone starts by rolling a dice	E

Phrase		Code
5/51	and you have to get to a certain place by passing things like an adventure game,	E
5/52	starting from 2 to 4 players.	E
5/53	They all have an individual three-dimensional person on one big board	F
5/54	and I'll number it from one to whatever you finish on,	E
5/55	roll the dice until you land on a square	E
5/56	where you have to do something or answer a question out of the box.	E
5/57	So I'll design something we can use.	F
5/58	(I'll draw) normal people, men or women	E
5/59	this is a rough idea of what it will look like with a sword or gun in hand	E
5/60	make those three dimensional	E
5/61	but also with one person with something to hold it up on the bottom.	E/F1
5/62	Start with his feet	E
5/63	its got to be pretty muscular	F1

Phrase		Code
5/64	or strong, draw his muscles; needs to be brown in colour so I'll colour him in lightly.	G
5/65	I'm going to draw 2 men, 2 ladies,	E
5/66	with a weapon, a sword by their side.	E
5/67	Now for the size of the board and how many squares.	E
5/68	This is a picture of how I want it to look like say,	F
5/69	5 biggish squares on each line	E
5/60	so if there's 5 lines - 25 squares,	F1
5/61	and you have to get past 1, 2 3 4 5 and so on.	F
5/62	At the end you have to get the jewels, moneybags or whatever target you're aiming for	E
5/63	places where you need to think where it is- say in the jungle or undergrowth,	E
5/64	then have swamps, roadbridges you can swing across	E
5/65	and if you don't you fall in and have to go back to the start or back three squares.	C
5/66	You need people there to stop you	C
5/67	and you have a question box where if you get the question right pass on - if you don't go back.	C

Phrase		Code
5/68	I'm thinking about how to stand this person up	E
5/69	and how to fix it onto the board	E
5/70	fold bottom.	F1
5/71	Try drawing actual game bigger now	C
5/72	and deciding what goes where on it.	C
5/73	1, 2, 3, 4, 5 (drawing lines on card to make board).	C
5/74	We could have it on the theme of 'Indiana Jones'.	C
5/75	So we make this the start with a key in the corner.	E
5/76	'Q' equals a question,	F
5/77	actually draw on for swamps, say a tree.	F
5/78	So as you move on, if you don't land on that square you move on.	F1
5/79	Need to design a cover as well.	E
5/80	So a box could be for advertising on television or magazines	F1
5/81	'Be a Warrior Yourself and travel through the jungle'	F1
5/82	or 'Beat the ...(whatever it is).. to get to the jewels or money.	F1
5/83	Could even make the actual things on the board three dimensional	C

Phrase		Code
5/84	like the tree.	E
5/85	The rules have got to be simple really	E
5/86	because if they are too complicated people won't want to read through them before they play.	F1
5/87	Younger children want to just play,	F
5/88	so you need a dice.	F1
5/89	(I'll) make it for ages 5 to 12 or 14,	E
5/90	or maybe for adults.	E
5/91	The box needs to be exciting	E/F
5/92	to make it look good for people to buy it.	F1
5/93	We need to make a lot of things look w	F
5/94	Start to draw some more of the things,	E
5/95	a waterfall at the top falling down to square 22.	E
5/96	I think we need to make the people a bit smaller on the board,	H
5/97	about half the size and a bit thinner	H
5/98	We need to make them look mean.	H
5/99	The board out of some kind of wood	E
5/100	and varnish it.	E/G
5/101	I would make the people out of moulded plastic	E/G

Phrase		Code
5/102	and paint them	E
5/103	I suppose you could just draw the trees	H
5/104	and waterfall in ink	H
5/105	with a couple of questions with it.	H
5 106	You could then make the board three dimensional	D
5 107	with things over or through things	H/E
5 108	or supply plastic things so you could put them on yourself.	H/E
5 109	The rest would be just plastic.	G/H

Are there any other ideas for the board game that come to mind whilst you have been thinking about this?

5 110	I suppose you would have to use questions and dice	E
5 111	or smaller games.	E
5 112	Packaging does not need too be to big for the actual game	F
5/113	and so just make the box out of strong card	E
5/114	which slips over another box.	F
5/115	Another idea for a game could be on the theme of snakes and ladders	D

Phrase		Code
5/116	but with little cars,	E
5/117	put stops or oil on the road.	E

Appendix 4

Transcript - Protocol 6

PROTOCOL 6

Phrase		Code
6/1	What are indicators?	B
An indicator is something to show somebody's name, to indicate a name, like a name plate of some sort.		
What are you thinking of at the moment?		
6/2	The positioning of it	E
And where do you think it might be positioned?		
6/3	At the front	E
What are you drawing now?		
6/4	A scattergraph naming the points	E
6/5	the height of it	E
6/6	that it has to be small	E
6/7	that it can't get knocked over	F1
What are you thinking about now?		
6/8	What to do next. I'm going to draw some diagrams of one I know	E
6/9	and ones I can make up.	E
Tell us what you are doing.		
6/10	The trap ... which holds the name can be in the middle	E
6/11	and that stands at the front of the desk.	E
What are you doing now?		
6/12	Something that can be stuck on	G
6/13	or nailed in maybe.	G
What are you thinking about?		
6/14	Trying to think up an idea.	?

Phrase		Code
What is in your mind at the moment?		
6/15	I have to make an original design	F
What are you drawing at the moment?		
6/16	A circle name plate	D
6/17	I am thinking of something that will stand up	E
How can you make it stand up?		
6/18	By structuring it.	F1
Any images in your mind of possible designs?		
6/19	I am thinking of a tea or coffee cup.	D

Main Project

Phrase		Code
6/20	What is a prototype?	B
Prototype means a first attempt, a model.		
What are the images in your mind?		
6/21	Something to do with a hobby of mine.	D
Such as?		
6/22	Football.	D
6/23	It can only take 20 minutes	A
6/24	That it has to have a set of rules	B
6/25	Packaging.	B
What are you drawing?		
6/26	It is going to be a football	D
6/27	which needs a ball	E
6/28	players	E
6/29	questions.	E
6/30	The ball is a dice.	C
6/31	Questions for a goal.	C
What are you thinking of now?		
6/32	Whether it is supposed to be like questions	E
6/33	or like tiddlywinks or something like that.	E
What are you thinking of now?		
6/34	Something for an active game.	E
6/35	That it can't be boring.	F1
6/36	I think I will stick with the questions for goals.	C
What are you thinking about now?		

Phrase		Code
6/37	What sort of questions.	E
6/38	Who won the World cup in 1990?	E
6/39	Where was the World Cup held?	E

What is in your mind at the moment?

6/40	I am thinking up questions.	E
6/41	Who took Bryan Robson's place in the World Cup?	E
6/42	Who is England's top scorer?	E
6/43	Where do Tottenham play?	E
6/44	I'm now going to design a board game.	D
6/45	Try it as a square first.	E
6/46	Two piles of questions	E
6/47	and then a board that goes around	E
6/48	with things like free kicks	E
6/49	penalties, goals.	E
6/50	I'm just going around the squares and putting them on.	C

What are you thinking of now?

6/51	How to make the board look better.	E
6/52	The rules	D
6/53	one of them is that when you land on a free kickE	
6/54	you have another roll of the dice.	F1
6/55	When you land on a penalty	E
6/56	you take a penalty question	F1
6/57	and you can score a goal.	F1
6/58	When you land on an injury square	E
6/59	you miss a go.	F1

Phrase		Code
6/60	When you land on a plain square	E
6/61	then do nothing.	F1
6/62	When you land on half-time	E
6/63	you miss a go.	F1
6/64	The Packaging	D
6/65	It would be a box called 'It's a Goal!'	E
6/66	in blue marker pen.	G
6/67	There will be a picture	E
6/68	like a photograph type of a football pitch and a goal being scored.	C

What are you thinking about at the moment?

6/69	How to advertise it.	E
6/70	hat models to make.	E

What materials would you make this game out of?

6/71	Cardboard	G
6/72	and maybe a plastic ball as a dice.	G
6/73	Materials... plastic for the dice,	E
6/74	cardboard for the board	E
6/75	the questions, cards	E
6/76	pieces as plastic	G
6/77	I'm just thinking about how to advertise it.	
6/78	Advertise it on television, magazines.	

What are you thinking about at the moment?

6/79	What to do next	?

Can you think of any alternative ideas you could use for this board game?

Phrase		Code
6/80	In the way of its theme, no.	?
What thoughts are in your mind at the moment?		
6/81	How long have I got left?	?
Keep talking, last couple of minutes.		
What do you think of what you have designed?		
6/82	Could do better	H
How would you improve it?		
6/83	Take longer over it.	H

Appendix 5

Transcript - Protocol 7

Protocol 7

Phrase		Code
7/1	So it's an actual stand	B
7/2	for a name to go on.	B
7/3	I will do a metal frame	D
7/4	with a board	E
7/5	with the name on.	E
What sort of shape would the board be?		
7/6	Rectangle board	E
7/7	and arched metal frame	G
7/8	with the name on	E
7/9	with the name on it	E
7/10	and just some sort of rectangle box	E
7/11	to stand it on.	F1
7/12	Or I could do a rectangular piece of wood	D
7/13	with a slot in and the board coming out.	E
What sort of materials would be used?		
7/14	Plastic for the actual name	G
7/15	and wood or metal	G
7/16	or I could do a triangle	G
7/17	with the board resting on it.	F1
7/18	Or I could do something with slots	E
7/19	so you could slide the name in and out.	F1
What are you drawing now?		
7/20	Just ideas.	?
How would you put the letters on?		

Phrase		Code
7/21	Paint them on	G
7/22	or little box letters glued onto the board	G
7/23	Could have a rectangle plastic box	D
7/24	with a bulb inside	E
7/25	and when you turn it on the letters light up.	F1
7/26	Could have a metal frame	D
7/27	with a board	E
7/28	with a name on that rests on it.	E
Which of those ideas do you like best?		
7/29	The one with the bulb in that lights up the letters.	H
How would you make that?		
7/30	With some thin white plastic	G
7/31	that the light could shine through.	F1
7/32	Stick some black letters	G
7/33	inside with the bulb	E
7/34	when you turn the bulb on it could outline the letters	F1
7/35	My second choice would be the one with slots	H
7/36	because you can change the name	F1

Main Project

Phrase		Code
7/37	I think I will do a game where the characters have to get to a certain place	D
7/38	and first one to get there wins	D
7/39	I think I will use a spaceship	D
7/40	and you have to get to a certain planet	E
7/41	Earth	G
7/42	and you have to pass through different planets.	E
7/43	Could do an asteroid belt and a black hole.	G
7/44	Spaceships with two players	D
7/45	and I think I will do both spaceships different.	E
7/46	You could collect things along the way	E
7/47	to help you get through the black hole	F1
7/48	and shields	E
7/49	to stop the asteroids.	F1
7/50	You move by dice	E
7/51	and pick up cards on the way	E
7/52	with various problems	E
7/53	like being attacked by other spaceships or something	F1
7/54	Might have two choices like A or B	E
7/55	and have to look in the book	E
7/56	to see what happens	E
7/57	and if you die you start again.	F1

What materials would you use?

Phrase		Code
7/58	I think I will use wood for the board	G
7/59	and wood for the dice	G
7/60	or plastic	G
7/61	and paint or print the board on.	G
7/62	Use card for the game cards	G
7/63	I could look up in a space book	E
7/64	to see different planets	F1
7/65	and put them down in order	E
7/66	or I could do something like you need to collect something on the planet	E
7/67	to stop you blowing up	F1
7/68	and you pass on.	E
Tell us what are you drawing?		
7/69	Just drawing the spaceships.	
What sort of rules might there be?		
7/70	You can only use one dice	E
7/71	and you can cross over layers	E
7/72	You cannot jump squares or planets	E
7/73	and you cannot avoid asteroids or the black hole.	E
7/74	I could have different sets of rules	D
7/75	If you pick up a card with the enemy spaceship on attacking	E
7/76	and have more choices or battle cards.	E
7/77	Roll the dice or a certain number	E
7/78	it tells you whether you have won, lost of whatever	F1

Phrase		Code
Have another read of the sheet and see if there is anything else you need to think about.		
7/79	For the packaging	B
7/80	you would need a cardboard box	E
7/81	What is a prototype?	B
That means the first sort of model.		
Tell us what you are doing as you are doing it.		
7/82	I'm just drawing a stand for the spaceship	E
7/83	that the actual card slots in	F1
What are you doing at the moment Adam?		
7/84	Just about the colour of the spaceship	E
What colours are you using?		
7/85	I think I might use a red colour for the actual spaceship	E
What would the spaceship be made out of Adam?		
7/86	Cardboard	G
7/87	Just blacking in a few bits on the spaceship	H
7/88	First the main stand and draw a circle on	H
7/89	Stick the platform quite high	H
7/90	Stick a slot in.	H
What else do you think you need to think about?		
What would the board be made out of?		

Phrase		Code
7/91	Wood and fold it to stick it in a box	G
7/92	I think it would be printed with the stuff on it	E
7/93	The cards might be out of cardboard	G
7/94	or plastic and printed on.	G
7/95	Or I could make an obstacle	E
7/96	and stick it on the board	E
7/97	or enemy spaceship	E
What age group would this be for?		
7/98	8 upwards	F
Any other ideas for the board game apart from this one?		
7/99	I could do an adventure game	D
7/100	where you have to kill a monster	E
7/101	like Hero Quest or something like that.	G
7/102	I think for the packaging	D
7/103	a box, would have to be quite deep	E
7/104	in order to fit in all the things.	F1