The Development of a Computer Based Modelling Environment for Upper Secondary School Geography Classes

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Abstract

This thesis describes the development of a specification for a computer based modelling system in geography. The modelling system will be for use in upper secondary school geography classes. The classroom approach to geography reflects the developments within the broader academic discipline. By adopting a systems analysis approach, it is possible to represent models on the computer, from the full range of geographical approaches. The essence of geographical modelling is to be able to use a computer based environment to manipulate, and create, the inter-relationships of the components of a geographical system.

The development of the specification for the modelling system, follows an eleven step methodology. This has been adapted and modified from the Research and Development Methodology. It includes a formative evaluation of the prototypes in classroom trials.

The possible forms of representation of geographical ideas on the computer are considered. Procedural and declarative models are developed, as prototypes, on a range of software tools. The software tools used, for the initial developments, are the Dynamic Modelling System, spreadsheets and the language, Prolog. The final prototype is developed in a Smalltalk environment. Consideration is also given to the use of both quantitative and qualitative methods of modelling.

Model templates are identified which give an underlying structure to a range of geographical models. These templates allow the students to build new models for different geographical areas. Proposals are made for a staged approach which addresses the introduction and use of modelling in the geography classroom. These stages move through the use of simulation, through the modification of the underlying model, to the transfer of the model template to different areas and finally, the building of new models.

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Acknowledgments

I would like to acknowledge the contribution made by David Riley, at the time at Kings College, Chelsea. He acted as an independent interviewer. He conducted the PUDDLE and DMS interviews with the students and produced the subsequent transcripts.

CHAPTER ONE - INTRODUCTION

Introduction to the Thesis

This thesis illustrates the stages in the design and development of a geographical modelling system prototype. The modelling system encompasses a wide range of geographical examples taken from the systems approach to geography. The target for the use of the system is the geography classes of the upper years of secondary education. Emphasis in the development is placed on the manner in which geographical examples may be represented in the modelling environment.

Chapter One defines modelling in the context of educational software systems and introduces the ways in which information and knowledge may be represented in educational software. The justification for the study of modelling as a research topic is then discussed. The research work is then placed in the context of current educational practice. First, in terms of the use of Computer Aided Learning (CAL) in the classroom, and secondly, in the classroom application of computer systems to geographical education.

Chapter Two reviews the literature in the area of the investigation by addressing two principal themes. First, the evolution of the systems approach in geographical education is related to developments within the discipline of geography. The second principal theme considers the development of modelling. This theme draws out significant milestones in the representation of ideas on computers and the reasoning mechanisms that are used by computer based systems to derive conclusions. Particular emphasis is placed on the links between simulation and modelling. The final section of Chapter Two draws together the state-of-the-art developments, by linking the status of geographical ideas, with the representation and reasoning methods available with modern software systems.

The methodology used in the thesis is discussed in Chapter Three. The first section of which describes the Research and Development Methodology as pioneered by Borg and Gall (1979) in the USA. Additional supporting evidence and variations of the methodology used by other projects are also given. The second section identifies the adaptation of the methodology for this research. The methods of data collection and analysis are given within the overall framework of the Research and Development Methodology. The third section of Chapter Three explains the details and contents of each of the steps within this research. These steps include the planning of the development, the necessary decisions that were identified along the way, as well as the identification of the areas in which data collection was required.

Chapter Four details the findings from the four classroom based activities, the data for which was collected in a variety of ways including video, open interviews and student logs. Each activity is described in terms of specific objectives. The details of the students and their backgrounds are also stated. The amount of teacher involvement is also described. For each session a description of the results is presented, followed by an analysis of the collected data. The results are placed in the context of the development of this research and are also related to the broader area of geographical education.

Chapter Five has a brief summary of the research and then discusses the results and their implications. Conclusions are drawn from the findings of both, the intermediate data collection, and the work completed with the prototype of the product. In keeping with the overall context of the research, discussion of the specification for the product is also included. A discussion of the methodological limitations and difficulties that arose in the execution of the study is then presented. The last section of Chapter Five addresses the implications of using the final modelling product with upper school geography classes. Opportunities for further research, that have been identified as a result of developing the specification for the modelling environment, are given at the end of the chapter.

The thesis has a glossary of terms and appendices that detail the collected data, including the transcripts of the interviews.

The Definition of Modelling

Modelling in a broad sense may be defined in several ways :

1. " to frame a theory of a structure "
2. " to give shape to an immaterial object or argument"
3. " to plan "
4. " to bring to a desired or desirable form or condition "

(OED, 1979)

These definitions have formed the basis of modelling for geographers. Skilling (1964) suggested that models could be a theory, law, an hypothesis or a structured idea. Within these suggestions the model could take the form of a rule, relation or equation. Chorley and Haggett (1967) state that a model is a simplifying structure of reality that presents supposedly significant features or relationships in a generalised form. Meadows and Robinson (1985) concur with a view that a model is a set of generalisations or assumptions about the world.

Nichol (1988) identifies the essence of modelling in the humanities as the identification and abstraction of the determining elements and their relationships. He adds, the identification of the relationships in analogous situations, leads to the principle of generalisation. He suggests that a model within the humanities will normally contain the elements of time and place, that are then associated with various objects. The objects may be things, animals, features or people. The relationships may be described as the interaction between the objects.

The development of a computer based modelling system requires a view of how the geographical knowledge, that is to be modelled, may be represented on the computer. If a model is to be used in a simulation mode or as a tool for prediction, then in addition to the method of representation, there is the need for a description of how the software will derive solutions. Barr and Feigenbaum (1981) develop the idea of the representation of knowledge on a computer from the stand-point of evaluating human actions. They argue that knowledge is ascribed to people if they behave intelligently. In a similar manner, knowledge may be ascribed to programs. Barr and Feigenbaum consider the representation of knowledge to be a combination of data structures and the interpretation procedures. If these procedures are used appropriately, they will lead to knowledgeable behaviour. Data structures indicate the characteristic attributes of each element within the domain, for example, the locational and temporal properties of a geographical feature.

The Study of Modelling

The justification for the study of computer based geographical modelling in education may be given from two perspectives. First, it can be argued that modelling may give an increased facility for the student to be involved in problem solving. Second, that during a problem solving process there is the potential for the student to derive more creative solutions.

Webb and Hassell (1988) argue that computer based modelling offers a number of opportunities for the enhancement of learning. Children can construct, test and evaluate concrete representations of their own mental models. Weeb and Hassell base their hypothesis on Kelly (1955) and Osborne and Wittock (1985) who suggest that, when learning a new concept, the learner forms a model in their mind. This model is then assimilated into the learner's overall framework by establishing links with other concepts. Such a theory of learning is 'constructivist' and has been strongly argued in the educational environment by Piaget (Magoon, 1977).

There has been a trend in recent years for emphasis to be placed on problem solving and the associated tasks of decision making in the curriculum. Typical examples being the Geography 16-19 Project, Naish (1976,1985) and the ideas put forward by Law and Smith (1987). The Non-Statutory Guidance for Technology in the National Curriculum, DES (1990A) states that Information Technology can enable pupils to focus on the skills of analysis, evaluation, prediction and the formulation of hypotheses. Progression for pupils within Technology in the National Curriculum is suggested to be based on the Information Technology capability, one aspect of which is modelling. The Guidance defines a computer model as a representation of the real world and states that pupils should use, investigate, manipulate and alter designed computer models.

Ginsberg (1985) suggests that a fundamental requirement for learning is an active engagement and commitment in manipulating thoughts. Studies reviewed by Carroll (1984) which investigated user interfaces for novice computer users, suggest that such learners prefer an active role. They prefer, as a learning strategy, to initiate problem solving as opposed to performing conventional rote drill and practice exercises.

Millwood et al. (1987) argue that modelling activities may help learners in three ways. First, they may help both learners and teachers to recognise each other's mental models of processes and problem solving. Second, when the user builds a model and tests it, then the results may be used to evaluate their models. Finally, a modelling system offers the chance to publicly express and share models with others. Various other authors have deemed that problem solving by model building is an appropriate method for developing understanding. Emphasis has often been placed on mathematical models, but many of the application areas for these models are in geography. For example, the modelling of traffic flow through the Humber Tunnel, James and McDonald (1981) and the travelling time to school, Close (1985).

The potential creativity for lateral solutions to problems may be considered, both in terms of new learning methods, as well as working within an environment that has structured and progressive tools. Ridgway (1988) argues that many Intelligent Computer Aided Instruction (ICAI) systems act in the same manner as the simulations of standard Computer Assisted Learning (CAL). The process, that acts as the basis of the system, is hidden from the view of the user. He argues, that by revealing to the learner the structure of the facts and rules of the knowledge base, some different styles of learning are possible. He cites the distinction between wholists and serialists, Pask (1976), as two distinct ways of learning new material. Wholists prefer an overall top-down approach, that takes a broader and more generalised view, while serialists build an overall structure from the separate examination of the detailed components. Ridgway adds that, the examination of the knowledge structures that are to be acquired, may bring the advantages cited by Ausubel (1968). That is, the learner can select the most appropriate method for solving the particular problem under scrutiny.

Thus, Ridgway argues for greater transparency of the knowledge base. A consequence of which, is the need for the facts and rules to be made into a form that is accessible to the user.

Technology in the National Curriculum, DES (1990B) states that Information Technology can enhance teaching, by first, making learning more practical, and second, by giving access to new experiences. The document expresses the view, in the section on modelling, that pupils should be able to speculate about appropriate outcomes to models. They should therefore be able to move on and examine the consequences of using complex models. The document further argues that modelling can help to underpin the continuity and progression in the National Curriculum for Information Technology. This can be demonstrated, first, by moving from familiar to unfamiliar problems and, secondly, by applying the more advanced skills of developing new ideas and thereby, communicating information in a coherent form.

The Educational Context of the Research

This research has been developed within an educational context that may be viewed from two perspectives. The first perspective is the various ways in which computers have been used in the classroom to facilitate learning. The second perspective is the relationship between geographical modelling and the development of Computer Aided Learning (CAL) in geography classrooms.

<u>The Facilitation of Learning in the Classroom</u>

During the late 1970s various writers, for example, Kemmis, Atkins and Wright (1977), Hooper (1977) and Rushby (1979), identified broad classifications for the way in which computers could facilitate learning in the classroom. Shepherd et al. (1980) and Kent (1982) applied these ideas to the learning of geography and derived a fourfold classification based on a student centred approach to the use of CAL. The first part of the classification is based on an instructional paradigm that originated with programmed learning. The more modern variants of which, are based on questions and answers that are described as drill and practice. Programs, such as HURKLE and PLATO, would be included in this paradigm. The second part of the classification, the revelatory paradigm, is when a data store is used for the rapid retrieval and manipulation of information. The data may be spatial, non-spatial or a combination of the two. Examples of this paradigm include SYMAP for computer mapping, NEIGHB for spatial summaries, CORR for non-spatial correlation coefficients and QUERY for information retrieval. The third paradigm, conjectural, is when the computer is used to run simulations. These may be prescriptive, LIMITS, descriptive RUNOFF, or a game POVERTY. Kent (1985) argues that these methods of data analysis and exploration remove time consuming and mentally undemanding activities. This allows the students to concentrate on the discussion of results and the drawing of conclusions. The final part of the classification, the emancipatory paradigm, is when the student constructs a program to solve a particular problem in the geographical domain. Abbott (1980) suggests that the boundaries of the four paradigms are blurred, and that there is a continuum from instructional to emancipatory. The latter allows the student more ability to control learning, and therefore to be able to make more learning decisions.

In addition to the fourfold classification of the student centred approach, Shepherd et al (1980), also suggest that the computer may be used in a teacher centred approach. Examples of this approach include both, glass box programs and electronic blackboards such as DEWDROP. The distinction between the student centred and teacher centred approach was further developed by Shepherd who proposed a model of student, teacher and computer. This model has four divisions, the gatekeeper, the barrier, the diversionary and the partnership, Figure 1.1.

A slightly different classification was proposed in the AMMA report (1982) which identified five main uses of electronic equipment in the classroom. Two of them, the use of the calculator and electronic control, do not involve the direct use of the computer. The remaining three uses, cover a broad application of computers in the classroom. Data manipulation, through storage and retrieval, was one main use. A second closely related use, focused on the computer as means of communication through such software as word processing or teletext style programs. The third use was the adoption of CAL software in subject lessons.

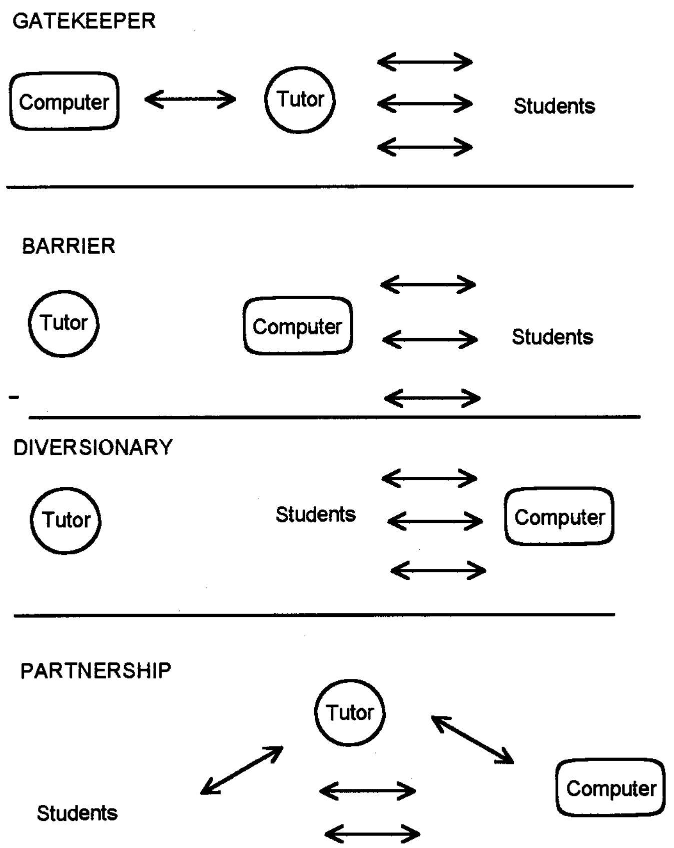

Figure 1.1 Student - Tutor Model (Shepherd et al, 1980)

Relationship to the development of CAL

The second perspective of the relationship, between the development of the research and the educational context, focuses on how modelling relates to the development of CAL programs in geography. The original links between geography and computers can be traced to three projects, the National Development Programme in Computer Assisted Learning, (NDPCAL), the Geographical Association Package Exchange (GAPE) and the Computer Assisted Learning in Upper School Geography Project (CALUSG).

Boardman (1985) identifies that at the beginning of the 1970s the mainframe computer was the focus of interest. Batch processing was a more practical proposition for schools. Statistical analysis and the handling of numerical data were tasks well suited to such facilities. The culmination of this trend was CALUSG, Data in Geography, Robinson et al (1979). In 1973 the Schools Council funded the beginning of the Computers in the Curriculum Project. By 1979 it had produced eight geography programs that were based on simulations and the manipulation of input parameters. Many of the simulations were in the form of games, for example, the mapping of market areas in MILL, which calculated the costs for various locations of windmills. Other similar styles of software accompanied the GYSL NELCAL (1983). Decision making simulations accompanied People on Earth, Robinson and Jackson (1984). The geographical process of locating a factory was developed by ITMA, and was called TRANSPOTS, (1982). Freeman (1981), in a study of Hertfordshire Schools, identified the most popular programs to be PEOPLE, HURKLE, RAIL, ROUTE, QUERY and NEIGH.

The Objectives of the Research

The development of modelling has followed from the range of computer based learning activities that have been identified above. In the early to mid 1980s, the computer became established in the classroom as a method for the facilitation of learning. This led to the identification of the objectives of this research which are :

- to investigate the underlying structure of geographical problems and to determine how they may be openly represented on the computer
- to demonstrate that a range of geographical models can be implemented in a computer based modelling environment
- to show that students can utilise a computer based modelling environment in geography lessons
- to indicate ways in which access can be given to model construction and model manipulation on a computer based system
- to produce a specification for a computer based modelling system in geography

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CHAPTER TWO - REVIEW OF LITERATURE

PART ONE - MODELS IN THE DEVELOPMENT OF GEOGRAPHY

Introduction

During the 1960's there was the beginning of a widespread adoption of a new paradigm for geography. The new paradigm, often called the quantitative revolution, became established in academic geography in the early part of the 1970s and became a significant movement in school based geographical education. From that time academic geography has continued to strongly influence school geography and many teachers became aware of activities in the research frontier of the subject, Robinson (1985). The systems approach to geography, which is a major step in the development of models, was part of the development of the new methods and tools that were associated with the emerging paradigm.

The Sub-division of Geography

Ambrose (1973) identified four main themes in geography that are relevant to geographical education in schools. The four themes are :

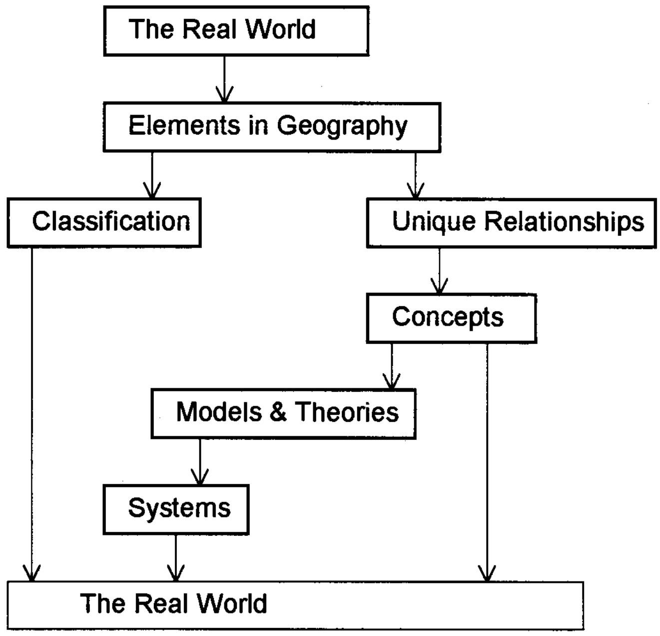
- the identification of the various sub-divisions of geography and the nature by which they are interlinked
- the development of a conceptual structure from the prevailing factual basis
- the emerging importance of values and the identification of subjective and objective knowledge
- the methods and tools that can be used to draw valid geographical conclusions

The traditional modes of study in geography emphasised facts which described the distribution of geographically relevant features, usually in a regional context. There was little discussion of the processes by which the features evolved, Ambrose (1973). The traditional mode of school geography was represented by Long and Roberson (1966) who wrote " we have nailed our flag to the regional mast, it behoves geomorphologists, historical geographers, quantifiers, perceptionalists and all other specialists ... to ponder carefully Mackinder's remarks on the unity of the whole subject."

Graves (1975) points out the controversy alluded to by Long and Roberson is concerned with how regional geography is defined. Areal differentiation and its associated positions, was rejected by research workers who wished to employ the analytical and predictive techniques previously developed in the social sciences. However, Graves continues that the functional region is still an important integrating concept in geography. When investigating spatial organisation systems, ecosystems, and complex regional systems, the concept of formal regions is a useful way of classifying areas required for specific purposes by planners and research workers.

Further criticisms of the traditional approach to geography are given in "New Thinking in Geography", DES (1972). First, by emphasising the uniqueness of each area, the traditional method depends largely on memorisation, because it lacks a sufficient framework of general concepts. The second criticism focuses on the failure of the regional approach to differentiate between significant and irrelevant materials. This is caused by a stereotypic approach to all issues. Third, it fails to demonstrate many of the similarities that exist over wide areas of the earth's surface. And finally, it presupposes that valid boundaries may be drawn around regions of a multi-functional character. The report also adds that the regional approach accepts vague generalisations when analytical techniques are available to provide greater precision and may even yield possibilities for predicting future events. To replace the traditional view a methodological model is suggested. Figure 2.1

Bennetts (1973) states that the organising concepts that have been the most prominent in school geography have been the study of man and land or regions. He argues each of these concepts have been interpreted at a naive level. He concludes that teachers were beginning to appreciate that the opportunity exists to introduce a more highly developed spatial organisational concept and that students can be introduced more consciously to theory and probabilistic explanations. Beddis (1973) argues that a suitable structure for the formulation of a geography curriculum would be to select the fundamental concepts in the discipline and organise them within area based studies.



Structure of School Geography
(DES 1972) **Figure 2.1**

Fitzgerald (1973) accepts Beddis's general position about fundamental concepts, but suggests a systematic rather than an area based approach. He considers it possible to select a number of systematic topics, identify the principal concepts, and build them into a matrix of different concepts with varying levels of difficulty.

Boden (1976) identified the move, from regionalisation to systematic studies, in terms of a two fold subdivision of academic geography. The two divisions are physical and human. Within each of these he identified the particular traits that diffused into school geography. The physical geography, associated with description and the Davisian model, was superseded by the new methods and tools approach of Chorley and Haggett (1967). Within human geography the descriptive rational economic man approach was gradually replaced with man as decision maker with imperfect knowledge.

The systematic approach was often in the form of themes, that brought together common topics, e.g.. water supply. This gave the basis for focusing on problem areas with such applications as GYSL (1974). Also, at University level geography, there was a rise in Applied geography, the school oriented version of which can be found in such projects as the 16-19 Project, Naish (1976,1985). The focusing on topics, also led to a more disciplinary based approach, including not only geography, but aspects of other social sciences. Boden (1976) indicates that a characteristic of the whole trend was the move away from determinism, to the field of geographical enquiry where man was the principal focus. A further development, allowed by the systematic approach, was that of concentric studies and the concentric curriculum. The different scales used were local, national and global as in the 14-18 Project, Schools Council (1978), Tolley and Reynolds (1977) and Orrell (1985), and Geography in the National Curriculum, DES (1991).

The systematic approach to geography was gradually introduced into the school curriculum. The DES (1974) survey identified three principal approaches to geography, the conceptual approach, the systematic approach, and the regional approach. The survey gave the following percentages of the type of geography curriculum in the schools :

18% - conceptual   23% - systematic   46% - regional

In addition to the regional and systematic approaches, a third view of geography focused on concepts or central ideas, that are at the heart of the discipline. Ambrose (1973) identifies that much of geography involves studying repeating patterns of spatial distribution. Such distributions have significant regularities in time and space. These can then be mapped, explained and future circumstances predicted. Ambrose argues that geography should make explicit such processes rather than implicitly assuming them as part of an underlying description.

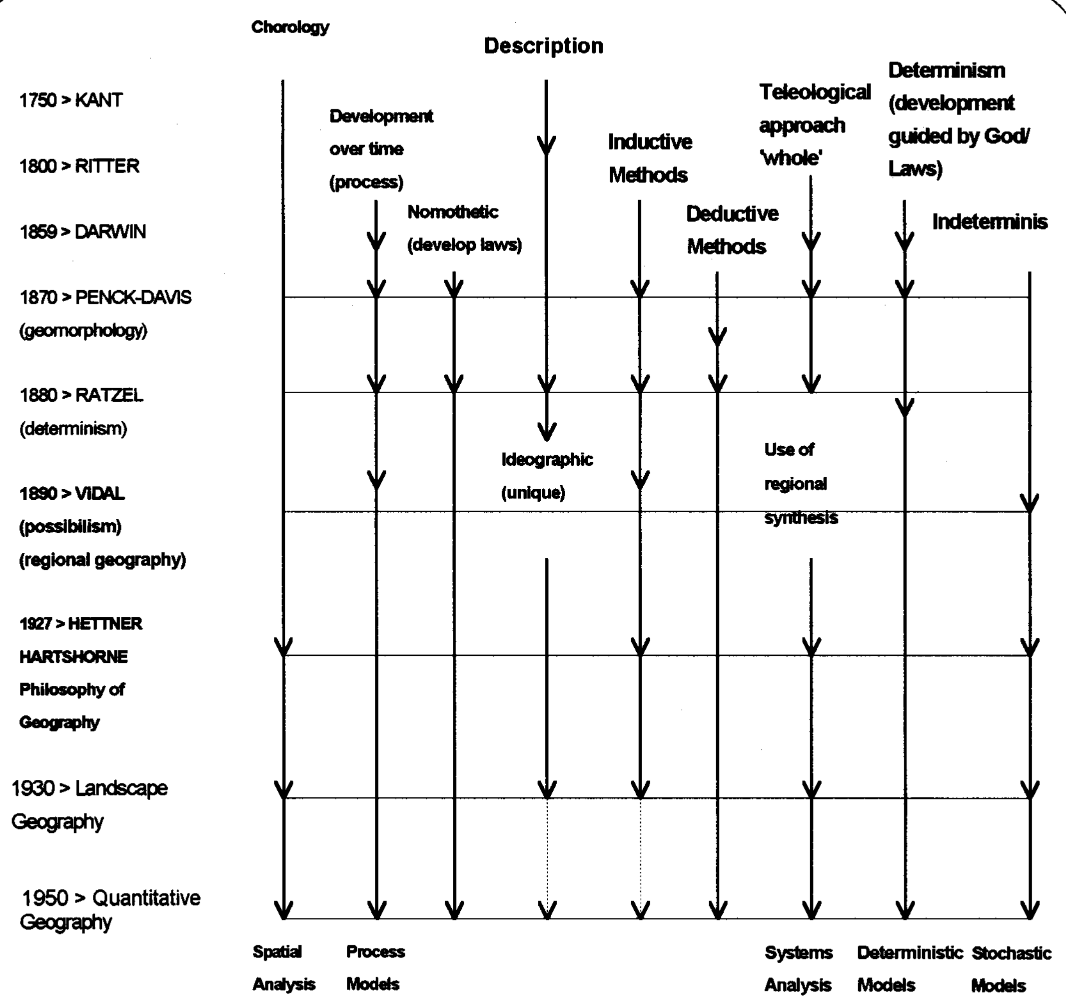
From the concept of regularity in time and space, Ambrose (1973) identifies two geographical principles, distance and spatial implication. The distance principal is, regardless of how distance is measured, an interaction between two locations. This concept has been developed in geography by transferring the gravity model from physics. The spatial implication principle states that , once an event has occurred at a location, the probability of other events occurring nearby is either increased or diminished. This principal emphasises the cumulative and dynamic processes of space and time.

Boden (1976) states that most geography lessons have a common purpose that reflects the literal meaning of the word geography. The lessons describe and attempt to explain the locational nature of the features at or near the earth's surface. Abler et al (1971) state questions about location, spatial structure and spatial process distinguish geography from the other sciences.

Boden (1976) identifies various sub-divisions of conceptual studies based on the clarity of terms, that can be clearly qualified and related to each other. For example, relief slope distribution is a conceptual term that can be qualified with actual measurable values. Theories are, according to Boden, an attempt to understand the more complex conceptual ideas. They can be developed in two ways. First, by starting with real life and constructing a hypothesis that can be tested by the collection of data. From the data a generalisation can be constructed and a theory evolved. The second approach is to begin with a normative theory, based on what ought to be, and then to investigate the real world to substantiate the theory. He cites the examples of 'busiest places', which may be approached by either manner, and which can lead to central place theory.

Robinson (1985) identifies two central conceptual ideas , the friction of distance and accessibility. These both help in the understanding of spatial processes and structure. The teaching of these concepts became a central theme of school geography during the 1970s and they were integrated into many new materials. Newby (1985) adds that the quantitative revolution in Geography was closely associated with the spread of spatial analysis throughout the discipline. Slater (1982) states that the strengthening of an appreciation of the spatial viewpoint, through such devices as nearest neighbour analysis, was a fundamental gain for geography. The identification of geography as a spatial science became a less hollow claim, and the spatial concept became central to many geographical exercises. The Christaller and Von Thunen graph models, explain and generalise, in a visual way, spatial relations and variations. Also developed were aspects such as spatial literacy, which gave the ability to understand spatial implications. Consideration was also given to the results of interacting variables, such as, the supply and demand of a variety of consumer goods and services across an area or landscape. The assessing and defining of relationships numerically is now prominent in geography at all levels. Such numerical models, as Huff and Reilly, are functional explorations significant to geographical studies, for their spatial consequences. "The gain in spatial literacy has been important and worth while and should not be misunderstood" Slater, (1982).

The National Curriculum for Geography, DES (1991), has five attainment targets that can be broadly aligned with the three fold division of regional, systematic and



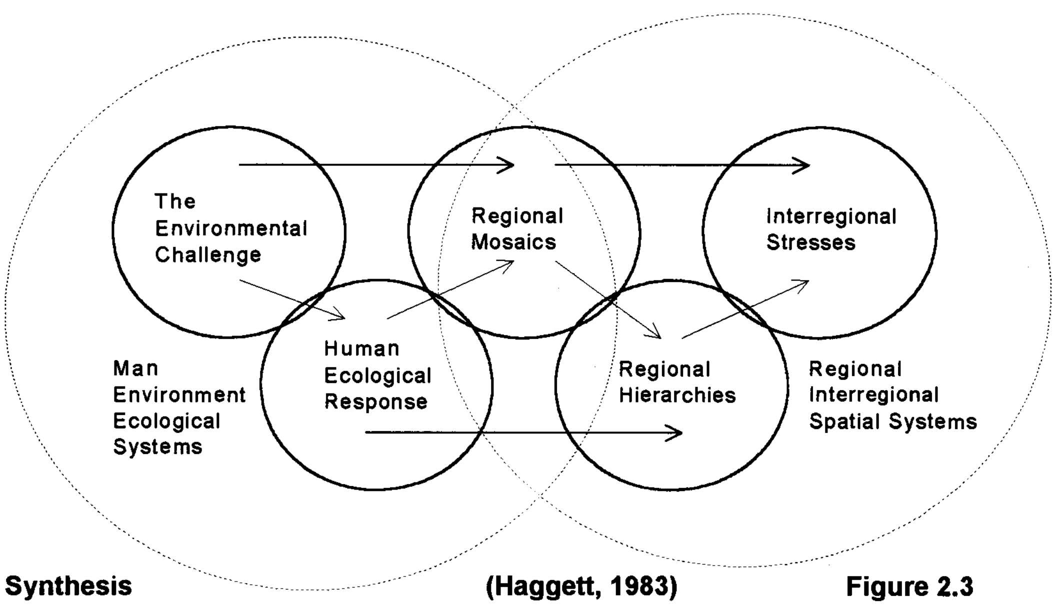
Historical Development **Figure 2.2 (Holt-Jensen, 1988)**

conceptual geography. Attainment Target One, entitled Skills, addresses the skills of spatial literacy that were identified under the conceptual approach. The systematic approach to geography can be aligned with the Attainment Targets for Physical and Human Geography. The Attainment Target of the Knowledge and Understanding of Locations, addresses the regional perspective, with the final Attainment Target, Environmental Geography, considering the ecosystems approach.

The Synthesizing Approach to Geography

A view that geography is a synthesizing subject has always been basic to the philosophy of the discipline. Holt-Jensen (1988) indicates that throughout the history of Geography there have been various pioneers who have sought to synthesize aspects of the subject, Figure 2.2

The holist view of geography has become widespread and Haggett (1983) presents the whole spectrum of geography in modern context. It synthesizes at two levels, first by bringing together the different traditions and themes within the discipline. And secondly by stressing the role of Geography as a whole in relation to neighbouring subjects. Geographers are concerned with the structure and interaction of two major systems. The ecological system links people and their environment. The spatial system links one region with another, in a complex interchange of flows. The two systems are



Synthesis **(Haggett, 1983)** **Figure 2.3**

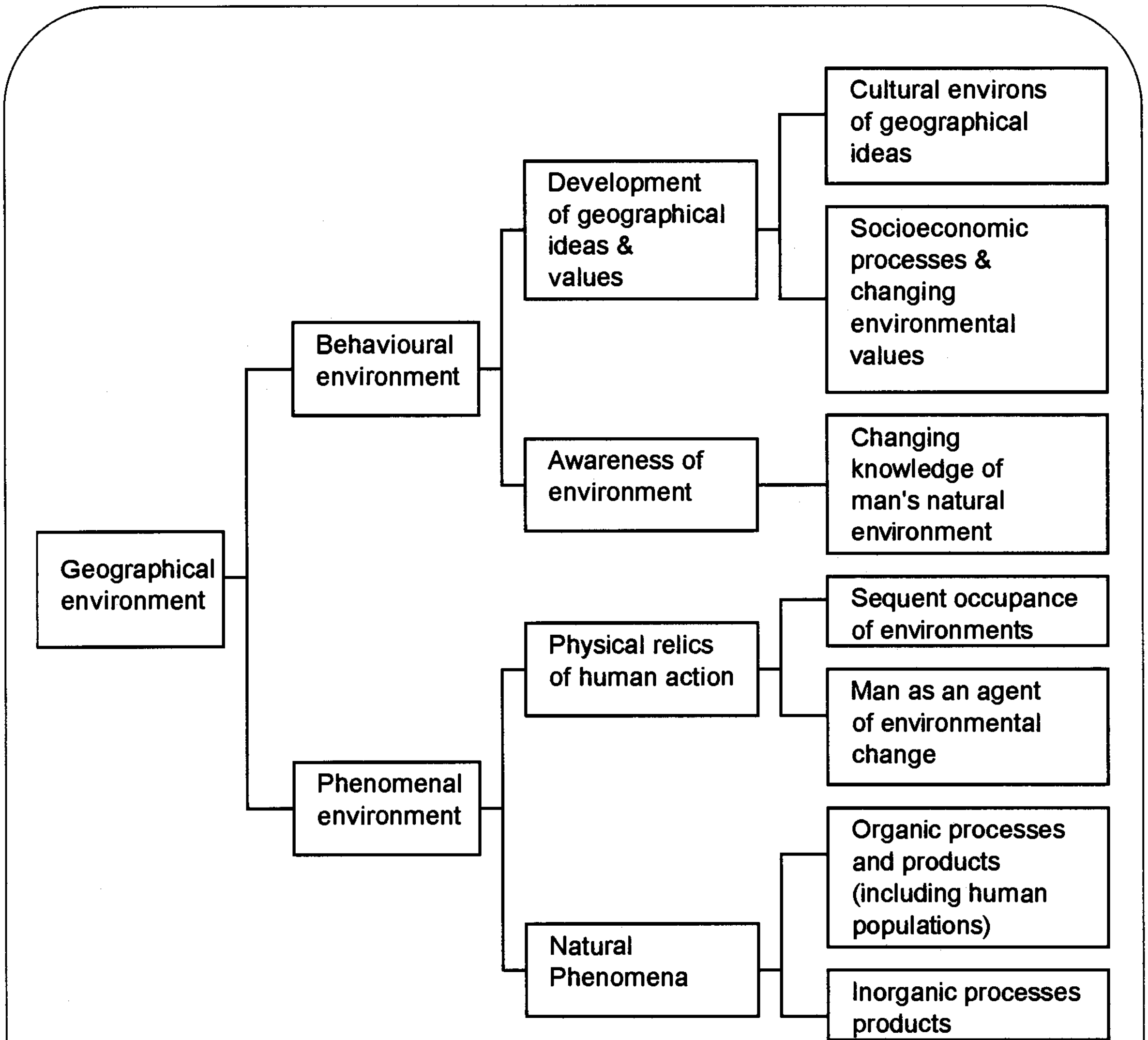
not separate but overlapping. The five parts are like the atoms in a molecular chain. The internal structure and linkage between them, and between the outer two systems can be explored. The five circles are superimposed on the two outer systems, Figure 2.3. Johnson (1985), Taylor (1985), Bennett (1985), and others envisage a future for holistic geography with physical-human relations at the core.

Ecosystems Approach

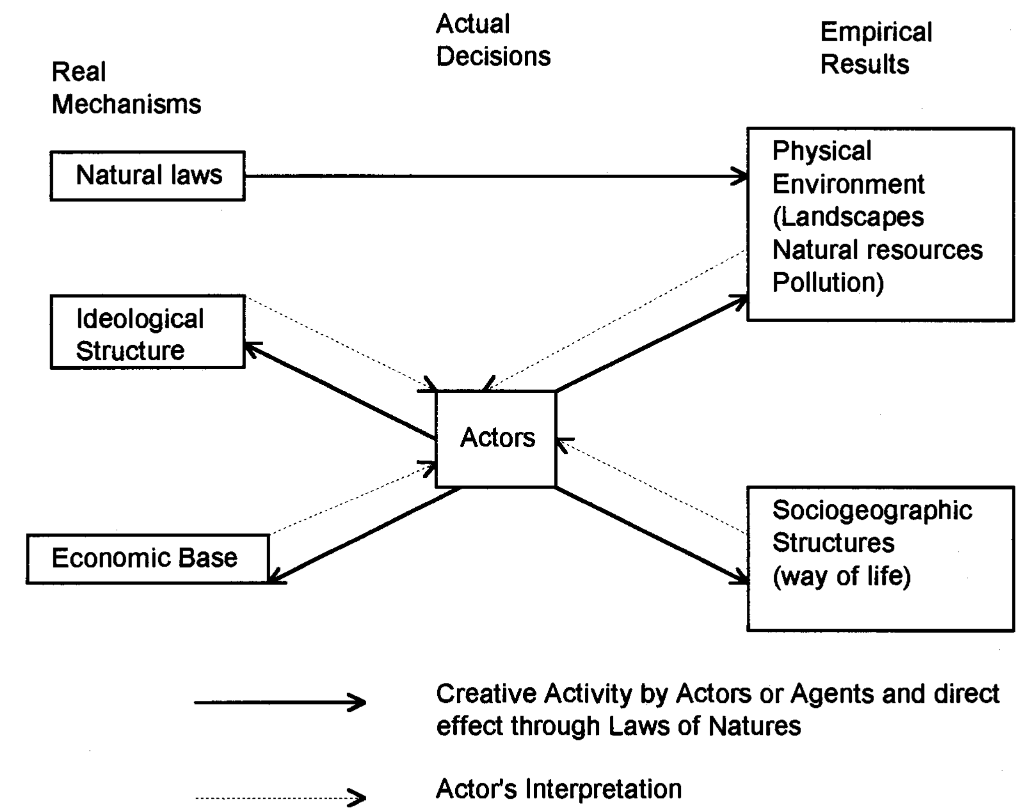
Holt-Jensen (1988) points out that formalised systems theory has only been directly applied to geography since the paradigm shift. However, systemic thinking has been closely associated with a functional analysis viewpoint, where geography has been viewed as human ecology. The development of systems ecology led to the concept of the ecosystem. An ecosystem consists of the biological community at a specific place and the environmental and physical circumstances that influence, and are influenced by, that biological community. The most critical aspects of the ecosystem are the circulation function, and the nature of change and development of the ecosystem. The facility to investigate vastly different scales of ecosystems, ranging from a puddle to the globe, has been an attractive feature of this approach. Holt-Jensen (1988) suggests that one of the most significant results of the study of ecosystems has been the models of circulation that have been developed and described, e.g. the nutrient cycle.

Stoddart (1967) shows that the ecosystem concept has four properties that are of interest to geographers. First, they are monistic in that they bring together the world of man, animals and plants within a single system, so the interactions can be analysed. This analysis can be mainly completed using quantitative techniques. The ecosystems approach stresses the functions and characteristics of the whole system rather than any particular relationship within it. In doing so it by-passes both the discussion of determinism and the conflict between human and physical geography. The second property of interest is the structured nature of the system, that can be described in an orderly rational and understandable way. Third, the function of the system includes three basic elements, the permanent throughput of materials and energy, the cycling process and the levels of stability. Finally, the ecosystem is a type of general system that can use the developing theories of systems analysis.

There have been various classifications and identifications of the geographical basis for the ecosystems approach. Kirk (1963) describes geographical environments in terms that provide a starting point for a discussion of systems, in which both physical and social science theories and concepts are relevant, Figure 2.4. Another view, in which human issues form a central focus, is the realist explanatory model, Figure 2.5. Simmons (1979) presents an overview of the ecosystems of the world ranging from those least affected by humans to the most urbanised systems.



Geography and the Environment (Kirk, 1963) **Figure 2.4**



Realist Explanatory Model (Holt-Jensen, 1988) Figure 2.5

The Values Approach to Geography

Systems analysis has been applied to, the combination of social and technical change, and economic development. Within these systems humans have had a more central role. This has led to systems with stronger feedback loops and the identification of controlled systems. Controlled systems, based on spatial implication principles, adopt a more behavioural approach to human actions. Humans make decisions in an environment that is perceived in an imperfect and fragmentary way. Such perceptions can result from varying motivations towards the immediate environment.

Boardman (1985) identifies three themes in the approach to geography based on the perception of human interaction and the control of the environment. Humanistic geography shows concern for the geographies of individuals as they experience places, Ley and Samuels (1979). At school level, humanistic approaches to the subject encourage pupils to interpret, evaluate and criticise their environment. Pupils are asked to make personal responses and to consider the values and attitudes that accompany their responses. A humanistic thread is apparent in the modules of the Geography 16-19 Project, Naish (1976,1985). In the Guiding Concepts "Evaluation and Prescription", the questions 'how ought' are posed, with such issues being addressed as the quality of life, welfare, conflict and planning. Robinson (1985) saw the growth of humanistic geography to be more explicitly linked to its philosophical roots rather than spatial analysis. He suggests the majority of classroom work derives from the study of the local area and from pupil's own experiences. Humanistic geography adds a dimension to studies by bringing classroom learning into the 'real' world of pupils' experiences and minds.

The second theme identified by Boardman (1985) is welfare geography, that analyses space, often using quantitative techniques. The resulting patterns of geographical variations are employed to raise issues of justice and equity, Coates et al (1977).

The third theme is behavioural geography. This focuses on the behaviour of individuals and the ways in which they respond to the stimuli provided by space and place, Gold (1980). Lowenthal (1973) identified the interests of the individual in the environment, with motivation being the central concern, and the study of value judgements therefore becomes significant. In economic geography Wolpert (1964) introduced the optimiser and satisficer concepts of 'economic man'. Optimisers correspond to 'economic' man whilst the 'satisficer' are anxious to succeed but not to the exclusion of other considerations. Robinson (1985) considers that some of the many decision making exercises, found at all levels of school geography, were inspired by the behaviourists.

The Methods and Tools of Geographical Analysis

Harvey (1969) identifies six recognisable forms of scientific explanation in geography. The six forms are:

- cognitive description
- morphometric analysis
- cause and effect analysis

- temporal modes of explanation
- functional and ecological analysis
- systems analysis

Cognitive description is the simple description of what is known from an ordering and classification of data that has been collected. Harvey argues this is the lower order of explanation. However, he does concede that advocates of hermeneutic methods in the humanistic schools of thought, often stress cognitive description. The quality of explanation, when using cognitive description, owes more to depth of cognition rather than technical procedures.

Morphometric analysis is a special form of cognitive description where systemisation and classification develop from a geometric and spatial co-ordinate system. This form of explanation permits network analysis so that predictive and simulation models are possible.

Cause and effect analysis is the identification of the principal aspects that can explain observed phenomena. Causal laws may be discovered by the hypothetic-deductive method. Complex cause and effect explanations may be built using multiple regression and factor analysis. The causality laws may be strictly deterministic or can include probability.

The addition of temporal modes to the cause-effect explanation provides scientific procedures for describing or explaining phenomena in relation to their development over time. The analysis of events and possible states of phenomena contribute to these explanations.

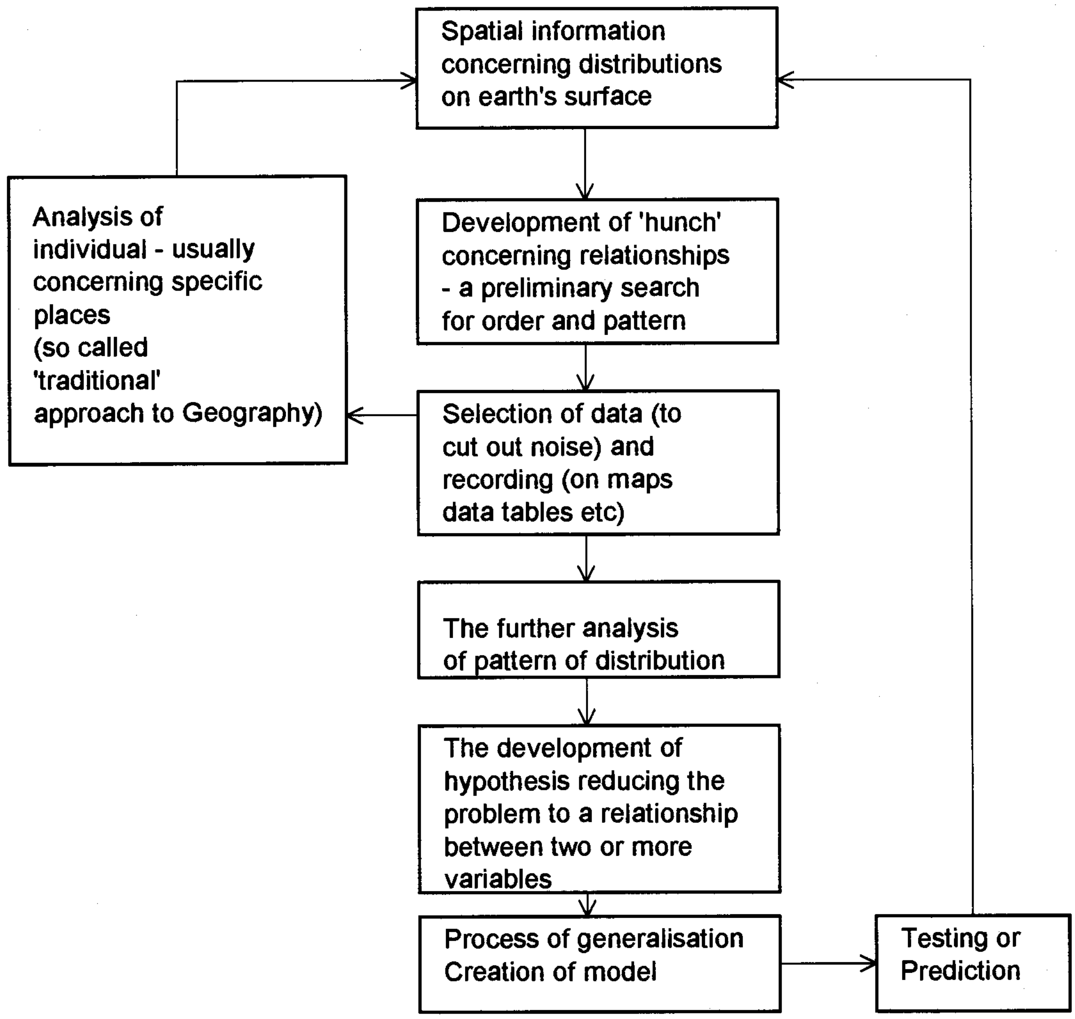
The functionalist philosophy of scientific explanation in geography seeks to replace the cause and effect analysis with expressions that emphasise relationships. These relationships are functionally described and replace the more mechanical explanations of cause-effect analysis. The functionalist approach considers a range of phenomena that can be analysed in respect of a system. The system, and therefore the grouped range of phenomena, has a specific purpose and the individual phenomenon must be understood in the context of the whole. The methodological strength of functionalism, lies in the support of the reciprocal relationships and conditions, that comprise the feedback mechanisms in complex systems or organisational structures. However, a functional explanation is not a sufficient condition for explanation, as it may be only one of many possible functional associations, thus it may demonstrate what is necessary not what is unique.

One critical feature of the paradigm shift in geography was the introduction of new methods for arriving at sound geographical conclusions. The last of Harvey's (1969) six forms of scientific explanation is systems analysis. Proposals to use systems analysis in geographical explanation developed in the 1960's and early 1970's and were based on the use of general systems theory in geography. Chorley (1973) observed that the applications of systems analysis to geographical explanation was greeted by some as a conceptual breakthrough and by others as a jargon ridden statement of the obvious.

Boden (1976) indicates that traditionally geographers collected data by observation and then processed the data by a descriptive cause-effect model. He argues that this led to the structure of explanation called environmental determinism. The rise of more scientific processes, involved many different approaches, with direct observation being only one facet, Ambrose (1973). The full list of scientific processes, includes problem definition, hypothesis formation, and the subsequent testing of the hypothesis by observation and the analysis of data. Boden (1976) grouped the procedures of scientific method as either inductive or deductive. He stated that, defining the problem and collecting data, to give an explanation, was inductive, whilst hypothesis derivation and testing was deductive. He justified the use of quantified data by arguing that mathematics allows the relationships to be shown more precisely than words. Robinson (1985) added that there has been a coincident growth in quantification and computing, which had occurred in the border field of social science since the 1960s. This reinforced and helped to establish the scientific approach in geography. It included hypothesis testing, statistical rigour, and the search for laws and generalisations. Newby (1985) reinforced this theme, as he considered that the identification of regions as the main purpose of geography was rejected. He argued that the quantitative methodology could be adapted to a wide range of situations that geographers conventionally investigated. Even if laws were not derived, with this approach, there was at least the development and evaluation of theory.

Newby (1985) argued that geography needed to be presented in schools as an organised entity. However, Ambrose (1973) points out the spatial and scientific aspects of the 'new' geography, encouraged some paradoxical elements into the development in school geography during the 1970s. The style of enquiry that is most appropriate for the study of economic processes and patterns takes place at a scale that submerges the individual human elements. Conversely, the educational requirement of concrete experiences, led to the emphasis of field work and local geography. Slater (1982) points out that in schools, as a result of the introduction of the scientific aspects of geography, there was an increased thinking about such matters as changing land use. This was considered in relation to the cost of rent or accessibility to markets. Robinson (1985) adds that the techniques accompanying the new approach became a dominate feature of 'A' level work and cites examples of Tidswell (1976) and Everson and Fitzgerald (1969). Fitzgerald (1973) summarises the changes, when he gives the diagram that compares the traditional method and the new scientific method. Figure 2.6

Fitzgerald (1973) points out that a problem facing geographers, is not how the tools of analysis operate, but which is the most appropriate in the circumstances. Within the statistical areas, he indicates the popularity of correlation and regression, with, for more complex issues, the use of multivariate techniques including factor analysis. For the measurement of distribution he indicates the nearest neighbour technique and contiguity ratios. Within the broad area of location analysis, various forms of geometrical and topological ideas are used to forge relationships between the human and physical aspects. Robinson (1985) adds that much of this work was simplified so that it could be used in lower school geography. In addition to the mathematical tools outlined, Fitzgerald noted a trend towards the use of simulation, particularly the development of the clear expression of the process within the simulation. He writes



Comparison between Traditional Method and Scientific Method in Geography
Figure 2.6 (Fitzgerald 1973)

"these are essentially models of developing situations which conform to certain rules of an abstracted and simplified form of reality". He warns of the difficulties of the formulation of rules, in that they can easily become a distortion and not a simplification. However, he considers that there is educational benefit to be derived from discussing ways in which the simulation does appear to mislead, which therefore, focuses attention on the real nature of the process. He points out the simulation can be utilised through operational games. He identifies that, within games, there is a random element that can be considered to be philosophically problematical, but can lead to stochastic models, such as those that are Monte Carlo based. Walford (1973) outlined the development of games and their availability for the classroom. At the time they were all paper based but the more widespread availability of the computer saw many of them become computerised. Walford identified four styles of games that were available. First, role playing exercises that were informally designed models and were often based on decision making. These gave rise to the many decision making techniques introduced into the school curriculum. The second group is the mathematical models that were often Monte Carlo based, and took the form of diffusion exercises. The third of Walford's groups was the individual exercises, such as the location of towns, with often opposing groups giving decisions and justifications. The final group of games were the operational games of running rival companies to secure profits.

Fitzgerald (1973) concludes his discussion of the various tools available to the geographer by stating that the real task of the geographical analyst is to reach a better understanding of how man is organising himself in space. In some cases this is to help produce more rational, efficient and socially desirable land use patterns by the planning profession. The tools of the trade are essential elements in reaching this understanding, but they should not constitute the direction of advance or the ultimate aims of geography.

Hilton (1982) summarises the methods and techniques in schools and relates them to the development of geography. He identifies four academic trends. The contraction of the area of study, both in size of the phenomena studied and the time scales, he closely associates with quantification methods. The latter he views as a trend that passes from morphometric analysis to the identification of processes and relationships. The third of his academic trends cites the difference in the physical and human nature of the time scales, and thus focuses on the problem of projections and future predictions. The final trend is the move towards process studies, with a range of scales, in physical geography. The four trends he describes are characterised by, a theoretical structure for which he cites Chorley (1978), the concept of modelling from Chorley and Haggett (1967) and the development of systems thinking in the subject, Chorley and Kennedy (1971).

From the characteristic methods outlined, Hilton (1982) derives implications for school geography. The contraction of the area of study has resulted in data based activities principally focusing on enquiry based learning. The quantification trend is the simplification of the core components of measurement within academic geography. The issues of physical and human time scales, he indicates, are addressed by the ecosystems approach and cites the various scales and opportunities offered by the hydrological cycle. The final aspect of process he considers to be the links between the human and physical aspects of the subject and these are typified by the 16-19 project, Naish (1976,1985).

Systems Analysis In Geography

Introduction

Systems analysis is a strategy for extracting relevant information from a part of reality and modelling it to produce an analytical description that highlights certain features. A model or abstract view is constructed, this can then be compared with reality, and if a successful match is identified, it can be used to predict the evolution and development of the real system. Initially the system is described, and consideration is given, to the nature and purpose of the models that will represent the real system.

Since 1940, there have been positive attempts to address the problem of representing large dynamic systems, that have a high degree of internal connectivity, Ashby (1966). Much of the systems work has stemmed from the first general systems theory suggested by von Bertalanaffy (1971). A general system is a higher order generalisation of a multiplicity of systems, that have been identified across different scientific areas. The aim of geographical investigation is to describe and explain the world that is perceived. Holt-Jensen (1988) suggests that the world comprises of unique but not singular places. Each place is formed through a unique interpretation of a general structure and that structure may be represented as a model of a system from the real world.

During the late 1960's, in conjunction with the beginnings of the new mathematical and methodological methods, arose the need for a framework to give an overall structure to geographical investigations. The systems approach quickly emerged as one of the most appealing candidates, White et al (1984). Harvey (1973) noted that there was a very close connection between the strategy of systems analysis and the general attempt to analyse the complex systems of geography. In particular the strength of systems analysis lay in its ability to deal with phenomena that were highly interconnected. As geography had a strong multivariate basis, the systems framework offered a sound basis for description and analysis. Johnson (1983) states that both conceptual and technical issues could be resolved by adopting a systems approach. He argued that such an approach is based on a positivistic view of science and could be reasonably applied to the theory, modelling and complexity of the human world.

The Definition of a System

There is a variety of definitions of a system. Hall and Fagan (1956) suggest " a set of elements, together with the relations between the elements and among the states". Huggett (1980) chooses a more simple form," a system is a set of interrelated parts". Hagget (1983) takes another simplified form," a set of components and the relationships between them". Johnson (1983) introduces the idea of the properties of the items within the system when he defines," a system is a set of elements each with certain attributes that are linked in a particular way, with the nature of the links not only determining the operations of the systems but also its evolution". The emphasis of systems as applied to the real world is given by James (1972)," a whole (a person, a state, a culture, a business firm), that functions as a whole because of the interdependence of its parts". A final definition links the idea of a system to the geographical world, "a system is a means of dismantling the environment for analysis and so be able to reassemble the parts to give an integrated synthesis", White et al (1984).

Given the complexity of the real world, only part of it may be considered at any time. As such, geographers identify the problems associated with defining the boundaries of the system under consideration. Elements in the real world that can change are called variables. The restriction of a system to a set of elements implies that systems are bounded, Huggett (1980).There are three types of variables, first, those that are totally external to the system, secondly those that are totally internal to the system and thirdly, those that cross the boundary of the system. Those variables that are totally external are assumed to remain constant and have no effect on the system under study, Harvey (1969). Huggett (1980) identifies those variables that are outside of the system but impact on it, as exogenous, whereas the variables totally within the system are endogenous. For example, in a drainage basin system, the rainfall is exogenous and the soil wetness is endogenous. Hagen (1961) indicates that in order to study systems effectively they must be closed. A system that interacts with its environment is an open system, therefore, all systems of 'real' life are open systems. But for the purposes of analysis it is necessary to make some intellectual construct that either totally cuts off or minimises the impact of the system's environment on the system.

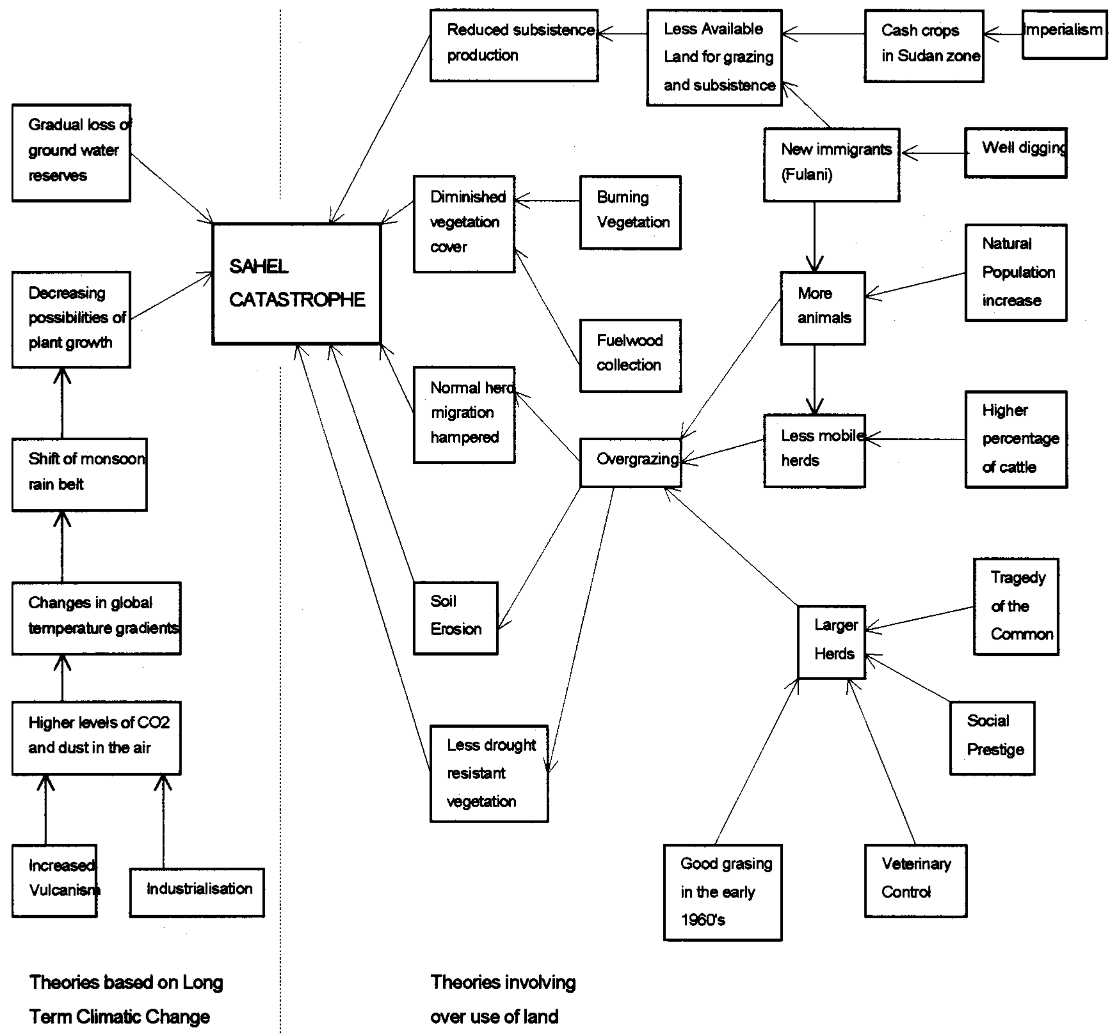
Systems are analysed into abstractions that represent the real world. The real system is composed of an endless number of variables that investigators, with different aims, may with good reason analyse in different ways. The abstraction, that forms the model of the system, may therefore be validly constructed from a number of different viewpoints, Holt-Jensen (1988).

Geographical Systems

Ackerman (1963) was one of the first geographers to point out the value of systems research. He expected systems engineering to play an increasingly larger role in coping with the social and economic changes caused by the development of technology. Harvey (1969) wondered how geographers, given the complexity and richness of the interaction with which they deal, could avoid using techniques and terminology specifically devised to attack complexity.

There have been identified a wide range of geographical areas to which systems analysis may be applied. Some have followed the traditional divisions within the discipline. Huggett (1980) considers human and physical systems, with further systems being identified that overlap the two divisions. Within human geography, he particularly stresses people and their spatial distribution, but also views the human geography world in terms of organisations that are formed to produce goods and services. He adds to this, the use of resources and the broad systems of agriculture. Pred (1967) emphasises the input-output form of systems analysis and its application to economic geography. The systems approach is applicable to the more traditional view of geography, that is, from the regional perspective. This identifies systems for spatial analysis of regions that include the synthesis of geographical factors in cities and urban areas. The systematic geographical theme of historical geography can be viewed from a systems approach through the development of various states that represent time scales. Within the realm of physical geography, Huggett (1980) identifies, as possible systems for study, landforms and their associated sediment transport and the spatial relationships of plants and animals, including their interaction with soil and vegetation. Other possible systems identified include, the hydrological cycle and the pattern of climate ranging from a local to a global scale. In addition to the use of systems in the separate divisions of the discipline, it is argued that synthesizing geographical systems are formed by the interaction of social, ecological and geological units. This interaction can then be described in terms of geographical laws, Huggett (1976). Chorley and Kennedy (1971) suggest that socio-economic systems are dominantly non-spatial, and interact with physical systems, that tend to be spatial, to form intersections between the two.

Various justifications have been put forward for using the systems approach in geography. Huggett (1980) identifies five salient points. First, the analysis of complex systems is beyond many of the current methods within geography. For example, theoretical ideas, such as central place theory, are simple single cause-effect models that are difficult to extend to the real world. A typical example of a complex combination of cause-effect relationships is given by Reenberg (1982) in the description of the desertification of the Sahel. Figure 2.7 identifies the possible causes and the linking of the physical, human and historical features. These are required as a means of describing the complex interrelationships between the factors.



Reasons for the Sahel Catastrophe (Reenberg, 1982)
Figure 2.7

The second of Huggett's justifications is that the construction of systems allows the development of a notion of levels of resolution within the system. The explicit statement of a hierarchical structure is incorporated within the system description. This, it is argued, can make a fresh attempt at assailing the scale problem within systems. For example, when the local level movement of people does not influence or directly interact with the macro level of migration. However, Holt-Jensen (1988) points out systems analysis is a relatively young discipline that needs further development to handle some of these complex geographical problems. The third of

Huggett's justifications, focuses on the openness of the various elements of the systems to examination and amendment. Fourth, he intimates the possibility of establishing 'macro' variables that could in turn establish 'macro' laws which might be one path to a sound geographical theory. Holt-Jensen (1988) adds that a systems model is a conceptual model and this helps us to understand the complex relationships in the geographical domain. His final point is that in the description of complex phenomena the consistent use of the systems approach imparts a terminological coherence.

The application of the systems approach to geographical domains requires a strategy. This will include both, a method for applying the systems structure, and criteria for deciding the particular aspects and view of the domain under consideration. A system is a set of objects, for which a very large number of potential states are feasible. The task of the geographer is to identify the feasible set of attributes, that can give rise to the drawing of suitable geographical conclusions. Ashby (1963) points out that real systems are characterised by an infinity of variables and different observers with different, or even the same aims, may make a wide variety of selection of the variables. Huggett (1980) suggests that systems analysis is not a lot different to normal scientific methods, as both require the specification of real world variables, and the hypothetical creation of the links between them..

The origins of systems manipulation focus on mathematical analysis. However, Holt-Jensen (1988) indicates that systems analysis may provide a useful systematisation of theories and structured ideas, but it is not necessary to refer to the rigid rules of systems analysis or mathematical implications in order to use the principles. He illustrates this idea with an example of a world map of iron ore production. The trade may be described in systemic terms, with the elements being the producing and consuming centres and the relations or links being the trading routes. The amount of iron ore depicts the various aspects of function and the maps show the situation at different time intervals and thus describes the development of the iron production and consumption system.

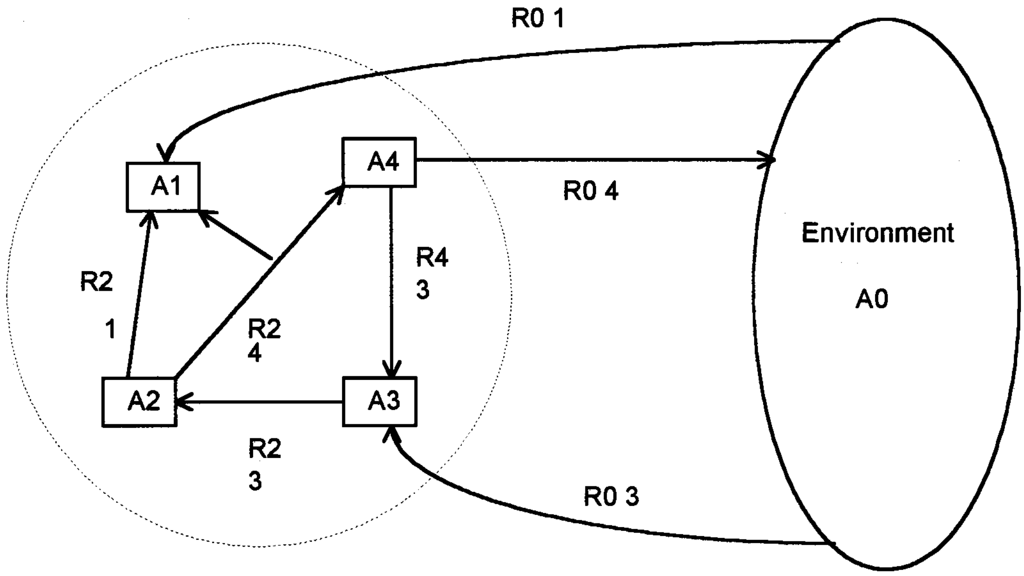
Composition of Systems Structure

The composition of the structure of systems describes the components that make up systems. The description of the hierarchical nature of systems is then added. The functions of the systems, when viewed from an external perspective, is then addressed and this is followed by the classification of the geographical systems.

A system consists of a set of fixed elements and the relations between those elements. Each fixed element has variable characteristics called attributes. Each set of attributes or properties may be general descriptors such as size, mass, colour etc. Some of the attributes may take a particular value at any instance in time. These attributes are described as state attributes and their combination gives the state of the element at a particular point in time. The combination of the states of the various elements, that comprise the system, give the overall state of the system. Ackoff (1976) differentiates between physical objects, that are components of concrete systems, and concepts that are components of abstract systems. The most important variables, for geographers, are spatial circumstances such as location, distance, extent and density. Space may be expressed in two dimensions with time adding a third dimension. However, as Holt-Jensen (1988) points out, it may be possible to give a basic explanation of a time space system, but it is a complex and difficult system to handle and manipulate satisfactorily.

The way in which an element may move from one state to another is the result of a process, White et al (1984). These processes will often give rise to flows, influences and reactions between elements. Such flows, where appropriate, may be quantified as varying thicknesses of lines. When diagrammatically representing systems, flows or events that enter a system from its environment will affect at least one element directly and then there may be an impulse that is carried through the system to affect other elements. Sometimes the status of all the elements will be affected and this will change the status of the system as a whole.

The set of internal connections between the elements can be called the relations between the elements. When a system is not closed, there is a set of connections between the various elements within the system and the environment that is external to the system. These connections may be called events. They refer to the events that take



A System and Its Environment

Holt Jensen (1988)

Figure 2.8

place in the environment and that impact on the system. The relations between the state variables or systems elements can be expressed, verbally, statistically or mathematically, Huggett (1980), Figure 2.8.

A series relationship is formed by single causal links. A parallel relationship occurs when two or more elements affect a third or inversely when one element affects two or more others. The third type of relation is when the element's attributes influence other parts of the same element and so a feedback relationship develops.

The function of a system is the external view of the system and how it operates. The function may be described in a variety of ways. A static system is defined as being resistant to any alteration in the environment and thereby will return to an equilibrium or a steady state behaviour, Harvey (1969). Adaptive systems will try to alter the system to a preferred state and can therefore be regarded as goal seeking. Dynamic systems are classified as having a feedback mechanism that results in the system changing itself through a series of states. Negative feedback is the description when the system attempts to return to a stable state, whilst positive feedback takes the system through a set of unrepeated states. Chorley (1973) maintains that real systems are neither in equilibrium or dynamic but that they lurch from one non-equilibrium state to another. White et al (1984) support this view and state that, associated with positive feedbacks, are thresholds for variables, past which they are capable of sudden and dramatic change. White et al (1984) go on to point out that all systems function in some way. With environmental systems, the function requires description in terms of the presence of some driving forces or source of energy.

Of particular interest to most system analysts is the idea of being able to structure a hierarchy of the domain under consideration. There are various ways of describing the view of levels within a system. Simon (1962) takes a threefold view, first, the environment which is the level outside of the system. Second, the level of interest, that is the description of the overall system itself, and third the level of the components within the system. Similar system hierarchies have also been identified by Hagerstrand (1967) and Gould (1969). A system at any level has what Koestler (1969) calls two faces, the face that shows the overall level of interest and the face that reflects the components of the system. Odum's (1971) view of a system involves viewing the system through a 'macroscope', that would have resolving power to focus in and scan the intermediary sub systems. Workable relations between high resolution sub-systems can then be used to predict the behaviour of the system as a whole. The latter can be depicted by the land phase of the hydrological cycle, with a series of storage components, through which incoming water is routed, Crawford and Lindsley (1966). Systems may be classified according to a description of the structure of the relations, including their internal complexity within the system.

Bennett and Chorley (1971) identify four types of system. Morphological systems consist of a web of relations between the system parts, with the strength of the relations, being given as some measure of statistical association. The relations between the elements are built up by observed association to produce positive or negative bonds. Such systems vary in the number of components of which they comprise and the strength of the links between them.

Cascading systems are those in which the system parts are linked by a flow of mass or energy or a combination of the two. The outputs of one element become the inputs of another. Inputs and outputs are controlled by regulators. Feedback loops may occur but may be lagged in time e.g. the hydrological cycle.

Process response systems are characterised by at least one link between a morphological variable and a flow in a cascading system. Process response systems stress the relationship between system form or structure and system process.

Control systems are process response systems in which the key components are controlled by humans. This intervention may take the form of restricting the levels of individual components in governing the flows or inputs and outputs, e.g. controlled bush burning.

Bennett and Chorley (1978) also identify a classification of systems according to an environmental framework. They give a rising degree of complexity, commencing with animals and their inanimate environment, moving through ecosystems, to a middle point of humans and ecosystems. The next grouping are social systems, with the most complex being socio-ecological systems.

Strategies for Building System Models

Huggett (1980) identifies four stages in the construction of a model of a system. The four stages are sequential steps from the initial phases of examining the domain through to matching the completed model with reality.

The first stage, the lexical phase, primarily establishes the vocabulary of the domain under consideration. This process commences with the identification of the hypothesis to be tested, or the questions that are to be asked about the domain. The second part of this phase is the placing of the boundaries, so that the relations across the boundaries to the elements within the system may be identified. If there are no such connections then a closed system has been delimited. Each element's attributes are then identified and defined.

The parsing stage, is analogous to the establishment of grammar rules and defines the relationships between the components. These relations may take many different forms and may be theoretical equations, empirical equations, statistical correlation or, for a non-mathematical model, textual descriptions.

The third stage, is the modelling phase that has two sections. First, the state variables and the relations are constructed to form a total model. The second section is to calibrate the model by giving values to each of the attributes and substantiating any constants in the system. This allows the model to be put into operation.

The final stage is the analysis phase, whereby the system is stepped through with inputs, the outputs and the change in states then occur. Comparisons with the real world can then be made.

There is a second view of model building, Meadows and Robinson (1985) view the types of models in terms of their generality and development. The first stage is a model that indicates a general understanding and shows a grasp of the principal questions and concepts. This broad model can then be refined into the second stage that considers the causes of the problems that have been identified. The construction of relationships then takes place. These indicate the description of the system for prediction and projection purposes. The final stage is the inclusion of the detailed, specific and accurate facts so that the resultant model may be compared with the actual world.

The Nature of Models

The development of the construction of a model in geography has been identified by a number of analysts. Skilling (1964) argued a model can be a theory, a law, an hypothesis or a structured idea. He also added it could be viewed as a rule, relation or even an equation. His final view of a model was as a synthesis of data. In terms of its composition he states a model could include reasoning about the real world by means of translation in space. This would give spatial models or, if time is included then historical models are possible. He concluded a model is a simplified and intelligible picture of the world. The simplified statements of this structural inter-dependence have been termed models. Therefore a model is a simplified structuring of reality, that presents supposedly significant features or relationships in a generalised form. Models are highly subjective approximations, in that they do not include all observation or measurements, but as such they are valuable in obscuring incidental details and in allowing the fundamental aspects of reality to appear. This selectivity means that models have varying degrees of probability and a limited range of conditions over which they might apply.

White et al (1984) adopt as a starting point, the manner in which the term model is used in every day speech. They state it has three distinct meanings, a replica, an ideal and to display. They consider that models derived for environmental systems can combine all three meanings. Thus, in order to simplify environmental systems, models or replicas can be constructed. To be useful, these models must idealise the system and display or make clear its structure and how it works. The relationships in the model will then map directly to the relations in the system domain. The types of relationships are spatial, distance, causation, conjunction and the succession of events. If models do not include references to processes, they may be taken to be a static description of the structure of the system. To understand the functional aspect of the system model, there is the need to identify the effect of these processes on the system. This mapping between the model and the processes within the system is necessary if the model is to be of use for predictive purposes, such as a drainage basin model to predict flood hazard.

White et al (1984) introduce a distinction between models that are perfect representation of systems that are called isomorphic, and those that are imperfect representations of reality which are called homomorphic. Each component within a homomorphic system may be viewed as a black box. The latter can be defined as any unit whose function may be evaluated without specifying the contents. A white box has most of the element states, relationships and processes identified within the model. The idea of a continuum from black to white box views, through grey, are discussed by White et al. The black-white box continuum has the advantages of providing a hierarchy of models at different levels of discrimination and secondly it allows specialist knowledge to be incorporated within a general model.

The Purpose of Models

Models are necessary to form a bridge between the observational and theoretical levels. They are concerned with simplification, reduction, concretisation, experimentation, action extensions, globalisation, theory formation and explanation, Apostel (1961). They act as a stepping stone from observation to the building of theories and laws, Chorley and Haggert (1967). Harvey (1973) accepts the latter, but also adds models can connect experience and imagination, as well as relating one theory to another theory.

Models are suggestive, in that a model contains suggestions for its own extension and generalisation. Also, a model should have a greater implication than merely the sum of its parts. In doing so, it should act as a basis for predictions about the real world, Toulim (1960). The capability for the collection, ordering and defining of data gives models an acquisitive characteristic, Chorley and Haggert (1967). Models have a psychological aspect, in that they enable some group of phenomena to be visualised and comprehended, which could not otherwise be possible because of the magnitude or complexity of the task. They also supply a cognitive function, in that they are a method for the communication of scientific ideas, Chorley and Haggert (1967).

Modelling Paradigms

Meadows and Robinson (1985) identify four different paradigms of model building. Their work is based on the development of geography models for social decision making.

The first paradigm is systems dynamics, developed from the work of Forrester (1968). He developed a set of representation techniques for simulating complex, non-linear systems with multi-loop feedbacks. He laid the foundation, in many cases, for future work on simulation and more latterly on certain aspects of modelling.

The second of Meadows and Robinson's modelling paradigms is econometrics. An econometric model is a set of theoretical relationships that have been statistically quantified with historic data from a particular economic system.

Input-output analysis, is the third paradigm. This is based on sets of data that measure the flows of goods or money among various sectors and industrial groups within an economy.

The final paradigm is optimisation, which is based on the development of linear programming . Optimisation models select, mathematically, from a large number of possible policies or options, a single set that allows maximum achievement of some objective.

External Perception of Models

Meadows and Robinson (1985) also identify how models may be perceived from an external point of view. Stochastic models are those which exhibit some degree of probabilistic behaviour. These contrast to deterministic models that are built on absolute statements. A second grouping of the external perceptions of a model, is the distinction between a continuous model with no sudden jumps, and the discrete model that has individual points and thresholds. The relationships described in a model may be either linear or non-linear. A temporal view of a model may be either from a perspective, that regards the activities within the system as simultaneous with instant action, or one that has a lagged response in that some elements only respond after a time delay.

Processes within Models

Harvey (1969) gives a clear view as to the constitution of a process within a model. A process is not just a list of events but is a sequence of events that are directly related, by some mechanism, and can therefore form the basis of some explanation. A process in the form of a law depends on the specification of a number of criteria. The closed system must be clearly defined, with the relevant states in the system identified. The principal variable elements in the system and their association must also be stated. The parameters that govern the interaction amongst the variables within the system are then defined, which is then followed by identifying the effect of the events external to the system.

A strict specification of the concept of a process has the advantage that it provides a model framework for formulating process type theory in geography. In some cases, models may yield valuable short term forecasts and may also lead to the identification of a theory. The second advantage is that the strict specification allows the setting up of a norm against which the explanation of temporally sequenced theories may be made.

PART TWO - THE REPRESENTATION OF LEARNING MATERIAL

Introduction

The use of the computer to facilitate learning stems from the capabilities of the machine to perform three functions. First, the facility to represent the data, information and knowledge of a subject area in a coherent form. The second capability is the inference of valid conclusions within that subject domain. The final function is to make available to the user a coherent form of the subject base. The development of computer based modelling has focused on the establishment of some basic techniques, that have then formed the foundations for a wide variety of representation methods. These enhanced methods have then been applied to the structure of learning systems on the computer. This part of the chapter introduces the basic representational techniques and then considers how they have been applied to computer based learning systems, especially the use of the computer for modelling subject areas for learning purposes.

One of the principal reasons for studying representation methods is to identify the steps that must be taken to match the subject knowledge with structures that can be represented on the computer. These structures being some form of computer language. The mapping of the subject areas to a computer language will often take place through some intermediary form of representation. This will often be diagrammatic in form. Many of the representation techniques discussed below are of the intermediary form and act as alternative skeletal structures for portraying subject knowledge. The principal reason for these intermediary representational forms is that computer processing is essentially sequential. The knowledge domain may be a combination of sequential and declarative forms. Therefore a mapping needs to be facilitated between the knowledge domain and the computer processing structures.

The Foundations of Representation and Inference Methods

The representation of the problem domain may be divided into two forms. First, the relationships between the various aspects of data. The two principal techniques used are semantic nets and productions rules. And secondly, the representation of inference methods that are used within the subject domain. There are four principal inference methods that can be used and these are described below. The techniques are mathematical reasoning, logical reasoning, methods based upon procedural steps, and the use of qualitative reasoning.

Semantic Nets

The semantic net is a set of nodes that represent objects, concepts or situations within the problem domain, with the links between the nodes representing relationships. The idea was developed by Quillian (1968), as an explicit psychological model of human associative memory. The semantic net may be represented diagrammatically with nodes as dots, boxes or circles, and the links being drawn as arrows. Both nodes and arcs have labels that represent the entities within the problem domain. A principal advantage of the semantic net is the important associations within the problem domain that can be represented both explicitly and succinctly. Carbonnel (1970) used a semantic net to represent the geography of South America in the program SCHOLAR, which was a system developed to illustrate human computer dialogue. The program interacted with the user to answer and to pose questions about the factual geography of South America.

Production Rules

Production rules are a different method for representing a problem area and were first used in conjunction with computers by Newell and Simon (1963). They based their work on the building of models for human cognition which followed from the original work of Post (1943). A database representing the problem domain is constructed in the form of rules, called productions, which are condition - action pairs. These frequently take the form of :

IF <condition> THEN <action>

This allows for each of the conditions, that could apply in the problem domain, to be shown explicitly. The working of the production systems can be viewed in three parts. First, the set of rules that comprise the rule base. Second, a mechanism that permits the selection of the rule that is to be enacted or 'fired' and finally a method that controls what the system does after firing a rule.

There are various advantages that have been identified with production systems. As each rule is shown separately, the problem domain can be represented in a modular form. The uniformity and simplicity of the rule structure allows for linking ideas in a wide range of problem domains. The fundamental condition-action structure is compliant with a natural way of describing issues in a problem domain. The establishment of the rules allows the issues of control, that is the 'firing' of the rules, to be dealt with separately.

Following the work of Newell and Simon (1972), production rules became one of the more popular methods for representing problem domains. Shortcliffe (1976) produced MYCIN, which represented the medical problem domain of blood infections. It added statistical inference to the condition-action effect of the rules. A rule based approach to the analysis of geological core samples was demonstrated in PROSPECTOR, Duda et al (1976). Davis and King (1977) identified where production rules could be most appropriately applied to a problem area. Rules were suited to domains where there are many facts, with a large amount of diffuse knowledge. They differentiated between those domains, in which there could be formed a set of sub-processes, and those areas where there were groups of mainly independent actions. The latter is the most suitable for rule representation. The third criterion they identified were the domains where the knowledge could be separated from the way in which that knowledge was used. That is, in an area where classificatory groupings were important, as opposed to a domain, that was composed of a series of interrelated steps.

Rule based representations have been adopted in many of the currently available expert systems, with the firing and context of the rules being dealt with implicitly and the rules for the problem domain being represented explicitly

Procedural Methods

The first of the inference representations is the procedural method. This contains knowledge about the problem domain in procedures, that is, small step by step instructions that know how to do specific tasks. They then proceed to perform the task in clearly specified situations. Raphael (1968) and Woods (1968) identified the properties of procedural models and utilised them in question and answer programs. More recent developments, that have been based on this style of procedural model, focus on the environment for learning programming.

Programming using such languages as PASCAL is essentially procedural in nature. Soloway (1981) developed a general representation based on Pascal called MENO, that has the inference mechanism based on programming procedures. Miller (1982) developed SPADE which helped Logo programming and Genersereth (1982) developed MACSYMA, where the general representation was MACSYMA commands and the inference was the programming procedures.

Mathematical

The differentiation between mathematical and procedural reasoning is clearly demonstrated by Brown and Burton (1978A), in BUGGY, that has a general representation based on mathematical tables with the inference methods for subtraction being based on procedural methods.

Logical

With rule based systems the inference methods used are often based on logical methods. Colmeraur (1982) and Kowalski (1979) developed Robinson's (1965) resolution principle into a logical inference language, Prolog. The language Prolog allows the two parts of the problem, identified by McCarthy and Hayes (1969) to be dealt with separately. The first part they defined as the epistemological part, that is, the 'facts' and 'rules' within the problem domain. These can be represented explicitly in Prolog. The second part, being the application of the rules at the appropriate point, in order to draw conclusions. The inference mechanism within Prolog allows this second part to be implemented implicitly.

The Development Of Foundations

The Procedural - Declarative Distinction

During the 1970's a distinction was established, between the declarative and procedural aspects of the problem domain. The declarative aspects give a description of WHAT is present in the domain, emphasising the static aspects of knowledge. These are the facts about objects, events and their relationships, including the various temporal states that are possible in the domain. The procedural representation then identifies the series of steps that can be used to solve problems by the linking of the facts. It identifies how to use the knowledge by finding the appropriate facts. Minsky (1975) and Schank and Abelson (1977) developed the distinction in the form of declarative frames, that represented complex data structures. A script is defined as the inference mechanism linking the frames into a coherent representation of the system. The script can derive results and conclusions. PLANNER, Hewitt (1972), identified the specification of control by the way in which the facts are represented. CONNIVER, Sussman and McDermott (1972), encoded a language at a lower level, so that the user has access to a set of mechanisms for specifying the reasoning process. Prolog, based on predicate logic, represents a further form of distinction between static and control representations.

Simulation

A further enhancement of the basic foundations came with the drawing of results by simulating the problem domain. SOPHIE, was developed by Brown, Burton and Bell (1973) and showed the domain knowledge, using a semantic net, but added a simulator to allow the showing of results. STEAMER, Forbus and Stevens (1981) explains the qualitative processes behind a steam engine simulation. The description is based on a procedural network, which when combined with other representational and inference methods allows simulation, Hollan, Hutchins and Weitzman (1984).

Games

A particular form of simulation is the game. Burton and Brown (1979) developed WEST, which is a rule based system that uses a game playing inference structure. WUSOR, Goldstein (1982), developed the game playing strategy by mixing various representation methods. He used a genetic graph combined with various rules that included probabilistic aspects.

Error Handling

Sleeman and Brown (1982) developed a system called LMS for handling errors made by the user. The system combined the normal rules for algebra and, mal-rules, that is rules that model the errors made by users.

Quantitative - Qualitative Distinction

One particular form of modelling and its relevance to instruction is illustrated by Clancey (1988). He identifies the role of qualitative methods. Qualitative models are non-numeric models that describe objects and processes in terms of spatial, temporal and causal relationships. The description is normally given in the form of generally used words. Qualitative models, according to Clancey (1988) may be of three types. They may be written down, de Kleer and Brown (1984), Sowa (1984). Secondly, they may be believed, that is they form some type of mental model, or thirdly they may be a computational model realised as a computer program.

Clancey (1988) extended the idea of qualitative representation to model descriptions. He identifies a situation specific model, which is a description of some situation in the world. It gives an explanation of how a situation came about or a plan of action. In general, the process of solving a specific problem can be described in terms of a situation specific model. A general model is related to a new situation by applying an inference procedure. He goes on to identify three kinds of model in instructional programs. First, subject material, which is a general model with inference procedures, representing the problem domain to be studied. The second model is the student model, that represents the knowledge and inference procedures of the student. The third model being the teaching procedures model of the communications processes, and the links between the problem domain and the student model. He strongly emphasises the distinction between the programming language, the inference procedure and the general problem domain model.

Application Of Representation And Inference Methods To Computer Based Education

Barr and Feigenbaum (1982) identify three general approaches that have been taken in the representation of knowledge for educational systems. The three approaches are environmental, computer aided learning, and games and simulations.

A principal proponent of the environmental approach is Papert (1980). The approach adopts a free style of learning with the student involved in various aspects of programming. The programming tools are designed to give good problem solving strategies to students. Dwyer (1974) advocated that students become 'solo' operators of computers and thus the computer environment is designed to provide the tools for this to take place. The principles, advocated for this approach, are very similar to those that allow students to use modelling systems in the learning environment. Papert created an educational environment, based on Logo, to help children explore mathematical problem solving techniques. The environment gave opportunities for children to explore their own ideas in a given situation. Papert considered that the learner should have complete autonomy. However, Howe and Ross (1981), advocated the structured use of Logo rather than the full discovery approach.

The environmental approach has developed into the idea of a microworld, Sloman (1984). The use of mathematical microworlds is illustrated by Thompson (1987). The design of these mathematical microworlds is based on the conceptual development for mathematical problem solving. There are four components of the program design, first the construction of the cognitive objectives of instruction. Second, the analysis of the mathematical content and structure. Third, the investigation of the cognitive processes of mathematical comprehension and problem solving. The fourth point is the construction of the computerised environment for teaching the mathematical concepts. Microworlds have a goal in that they serve to provide the students with opportunities to create mental models. The students reflect the structure and composition of the mental models within the microworld. Thus, a mathematical microworld comprises of a system of relationships between composed objects. The student then invokes various operations that transform the objects and their relationships.

Barr and Feigenbaum's (1982) second approach to the representation of knowledge for educational systems focuses on Computer Aided Learning (CAL). The goal of CAL is to build instructional programs that incorporate well-prepared course material in lessons. These are optimised for each student. The late 1960's saw the rise of a number of ideas that were to underpin the many future developments in the field of Computer Aided Learning. Much of the work followed on from that of Skinner (1965) and his development of teaching machines. Suppes (1968), added drill and practice, with two major collaborative projects, laying the foundations for the widely used programs TICCIT and PLATO. Uttal et al (1969) developed the idea of the generation of new problems from a database of possibilities. The method is called generative CAL. Following the generation of new questions the system then moves to a drill and practice mode.

The differences between microworlds and general computer aided instruction (CAI) programs are, first, the information does not come from the computer but from the student. Second, the focus in the microworld is on meanings and relationships, whereas in CAI the focus is generally on facts and skills. Third, microworlds simulate axiomatic systems, which transform attributes of one object to the attributes of another object, whereas CAI simulates applications. The microworld adopts a layered approach to the structure of the problem, with the microworld's assumed role, to be that of a facilitator rather than the teacher substitute role of CAI. In many traditional CAI programs, the program and the curriculum are inextricably linked, whilst the curriculum in the microworld is adaptable because it is built on axiomatic principles.

One branch of the development of CAI programs in the 1970's led to Intelligent Computer Aided Instruction (ICAI). In these programs the course material was represented separately from the teaching and learning procedures. One significant clarification of the structure of ICAI systems was made by Clancey, Barnet and Cohen (1982). They identified that such systems comprise of three parts, the problem solving or expertise model, the student model and the tutoring model. A different view of the paradigms of ICAI was taken by Kearsley (1987), who considered them in terms of the representation and inference methods. The first type is based on the style of interaction between the user and the machine and this is called the mixed initiative dialogue. The second type follows from the first, and are those systems that attempt to coach the user. A further step involves systems that attempt to diagnose the user processes, both for a strategy of learning perspective, and for error correction. The fourth part of Kearsley's classification is the microworld, with the final one being the articulate expert system. Park, Perez and Seidal (1987) consider the different methods of representation of the expertise model and itemise semantic nets, production systems, procedural representations and frame scripts. They also include other types of Artificial Intelligence (AI) representation methods, such as logical inference, a kind of calculus of the process of making inferences from facts, and the analogical representation of certain aspects of knowledge such as maps, models and diagrams.

A complete computer based learning system will have the functionality of all three of the instruction components outlined by Clancey (1988). The representation of knowledge, the model of learning behaviour, and the means of providing instruction will all be present.

However, the relative extent of the development and the explicitness of these components will tend to vary with the different systems.

Woolf (1987) develops the idea of the representation of domain knowledge for a tutoring system, by requiring an investigation into an expert's understanding of the problem. The problem domain may be classified according to concepts, procedures or rules. Conceptual knowledge is the data or facts, the relationships between the concepts, and the various attributes of each of the concepts. Procedural knowledge is the reasoning in the system that solves the problems within the domain. In addition there are the meta-rules that control the way in which the concepts, procedures or rules are used. They represent the action taken by experts to perform transformations in the domain. Some of the rules and meta-rules maybe heuristic, in that they are qualitative rules of thumb. These types of rules, it is argued by Kuhn (1970), are best acquired through the experience of working with examples that illustrate the concepts of the phenomena.

Barr and Feigenbaum's (1982) third approach to the representation of knowledge for educational systems, is the utilisation of simulations and games. In both of these, the driver algorithm for the program is embedded within the program and is not visible to the user. The user manipulates inputs and the program calculates, using the algorithm, the appropriate outputs. Games have the additional aspect of a competitive element added to the simulation, the purpose of which, is to heighten the level of interaction.

PART THREE - THE CURRENT ASPECTS OF EDUCATIONAL MODELLING

Introduction

This part of the chapter commences with the consideration of the most appropriate methods for representing the structure and content of a problem domain. This is followed by a brief review of the interaction between the user and the computer, paying particular reference to the use of models on the computer. The third part of this section then offers different views on the classification of models. The section has a final part, that addresses the teaching of modelling as a learning activity.

Model Identification And Structure

This section commences with a view of how the contents of models may be identified. It draws together the salient points considered previously, and places them in a systematic review of the current situation concerning model building. It further addresses the implications involved in identifying the most appropriate representation of the contents of a domain. One of the principal issues addressed, furthers the view of Bliss and Ogborn (1989), that there is a clear link between model building and programming. This is followed by a brief review of the diagraming methods that are available and which can be used, as an intermediate stage, in the effective building of geographical models on a computer system.

The Identification, Delimitation and Description of a Problem Domain

The first task in the building of a model of a particular domain is to identify the boundaries of that domain. The second task is to decide on the method or methods of description which are to be used for the model. The delimitation of the boundaries of complex systems has been identified as a major area of difficulty. Booch (1991), in describing a methodology for software construction, considers that currently, humans have neither the intellectual capacity nor the tools to model the complete behaviour of large discrete systems. He suggests therefore, we must be content with acceptable levels of confidence regarding correctness. Wilson (1981), in taking a mathematical perspective on building geographical models, identifies the problems of combinatorial explosion. This gives too many possible results to calculate and therefore he develops the more pragmatic approach of a generalised model. This is calibrated from analysis, and can more readily represent the real domain under scrutiny.

Booch argues, that by identifying the general features of complexity within systems, it is then possible to use such features as a basis for the abstractions and decomposition of the system. Courtois (1985) indicates that there are common patterns of complexity within a variety of natural and human systems. Complexity frequently takes the form of a hierarchy, whereby the system is composed of interrelated subsystems. Each of which have their own sub-systems, until some lowest level of elementary component is reached. Each of the sub-systems will have a high degree of internal inter-connection between components. The number of connections between sub-systems will be much smaller. Therefore he argued, that by selecting the most appropriate identification of sub-systems, the inter-connection between them can be considerably reduced, and the model building made easier.

The initial stages of model building are being realised to be of increasing significance. They can hold a key to the eventual success of the model, both in terms of its relationship to the real world, and in the ability to comprehend the main issues within that model. Huggett (1980) calls the initial stage, of identifying the basic components and defining the measurable properties, the lexical phase. He argues the "lexical phase is of enormous importance but has not always been given the attention it should warrant". Ogborn (1990) illustrates the traditional method of developing computational models. First, the detailed functional relationships are considered, and he illustrates this with the example of Ohm's Law. He argues that the full model is then built by moving through complex mathematics until a "full view of the unity of the domain is achieved". As an alternative approach he proposes, that initial attention should focus on the 'form' of the domain. This should be addressed loosely and in a semi-quantitative manner. The purpose of this approach is to understand, such critical issues as the feedback mechanisms, that are present in the domain. This broad overview model can then be successively refined using the more rigourous methods of mathematics. Neidederer (1991) follows a similar line, he argues that certain aspects of

Physics can be more readily achieved by taking a qualitative conceptual formulation of the domain in the first instance.

The process of moving from a complex real domain to the establishment of a model involves the ideas of abstraction, decomposition and hierarchy. Abstraction is the translation of the 'real' features, within the system, into an abstract logical description. Decomposition is the ability to sub-divide the high level ideas, concepts and processes into their component parts. They may then, in turn, be further subdivided. Hierarchy is the creation of a tree-like structure of the relationships between the various levels of detail within the system. De Marco (1981), in developing a methodology for building complex computer based applications, described, quite appropriately, the original real domain as the 'physical' model with the abstract description being the 'logical' model. The extension of this idea to general problem solving and the linking with 'intelligent' based systems is described by Goble (1989), Figure 2.9

General Problem Solving	Project Life Cycle	Knowledge Bases	Model
Identify area where problem has occurred	Feasibility Study Project Inception	Identify area appropriate for knowledge base	Examine physical model of how activities operate
Identify WHAT is to be done	Analysis of situation System definition	Elicit knowledge from appropriate sources and represent in a suitable form	Oevelop logical model for relationships of activities within domain
Agree this with anyone else involved in the problem			
Oecide HOW the agreement is to be implemented	System Oesign	Oesign interface between knowledge base and user	Revise logical model to reflect proposed solution
Produce the solution	System Production System Implementation	Implement the knowledge base and interface	Implement new physical model that is to be used

Obtain acceptance of solution by final users

Maintain the solution and monitor for new problems

Evaluate the solution

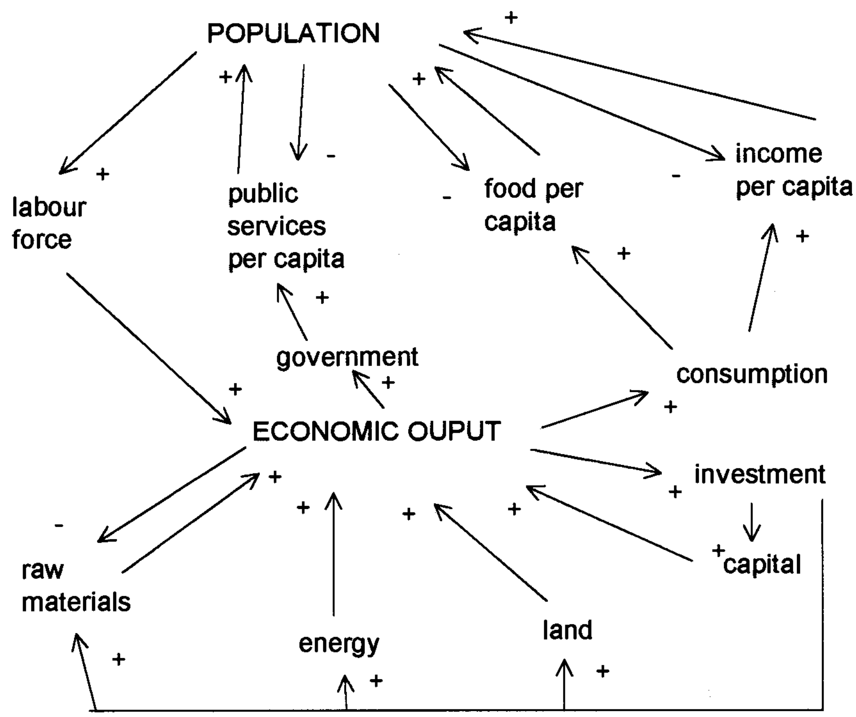
Stages in Problem Solving **Figure 2.9** **(Goble, 1989)**

The logical model can, therefore, be described through the abstraction, decomposition and hierarchy of a problem domain. Holt-Jensen (1988) points out that systems analysis modelling is applicable to many of the different themes that have been present in the development of geography.

The selection of the form of abstraction can vary between analysts viewing the same problem domain. Banbury (1987) states that modelling can be reasonably regarded as a means of simplifying what aspects are significant to the modeller, who must have some prior general understanding of the situation. Waddington (1977) sees this as a philosophy, which gives the model a set of assumptions. Checkland (1981) describes this philosophy as broad non-specific guide-lines for action and suggests that such a philosophy embodies a particular value position. Therefore, the different approaches to the geographical analysis of a domain are influenced by the values brought to the abstraction of the model by the analyst.

The decomposition of the system into its component elements has two perspectives. First, those aspects of the real world that are to be included in the model, that is the endogenous factors, and those that influence the model but are outside of it, the exogenous factors, Meadows and Robinson (1985). The second perspective is the methodology that is to be adopted in decomposing the system so as to arrive at a logical model. There have been identified, by various writers, two principal methods by which a system may be decomposed. They are the functional approach and the structural approach. Each has particular variants and are often ascribed different names. Aktas (1987), working in the area of computer systems analysis, refers to the two principal methods as functional decomposition and data oriented decomposition. Huggett (1980) argues that all geographical systems have a functional or process facet and a structural form facet. Lendaris (1980) differentiates between functional and structural modelling. Structural modelling embodies a geometric form, rather than the algebraic form of the functional model. He adds that a key aspect that differentiates the approaches is one of emphasis. In structural modelling, the emphasis is placed on the qualitative issues, such as topology, rather than the exact statistical properties of the functional approach. The views of Lendaris (1980) and Ogborn (1990) converge with their perception of the structural model, which is a holistic process, through which the users can gain an overall view of a system.

The analysis of a complex business organisation, from both a functional and a data oriented perspective, has given rise to an approach called the Structured Systems Methodology, Gane and Sarson (1979), Yourdon and Constantine (1979), De Marco (1981). More recently, a third perspective has been added to represent systems that have critical time related aspects. Such systems pass through various states. These states, and the transitions between the states, can be represented as part of the abstraction of the domain. There have been two broad methods by which state abstraction can be represented. First, as a variant of the Structured Systems Methodology, and this has been developed by Ward and Mellor (1985) and Hatley and Pirbai (1988). The second method is by adopting an object view of the domain whereby each object or entity has its own state parameters. This approach has been developed by Shlaer and Mellor (1988) and Coad and Yourdon (1990), and is called Object Oriented Analysis.



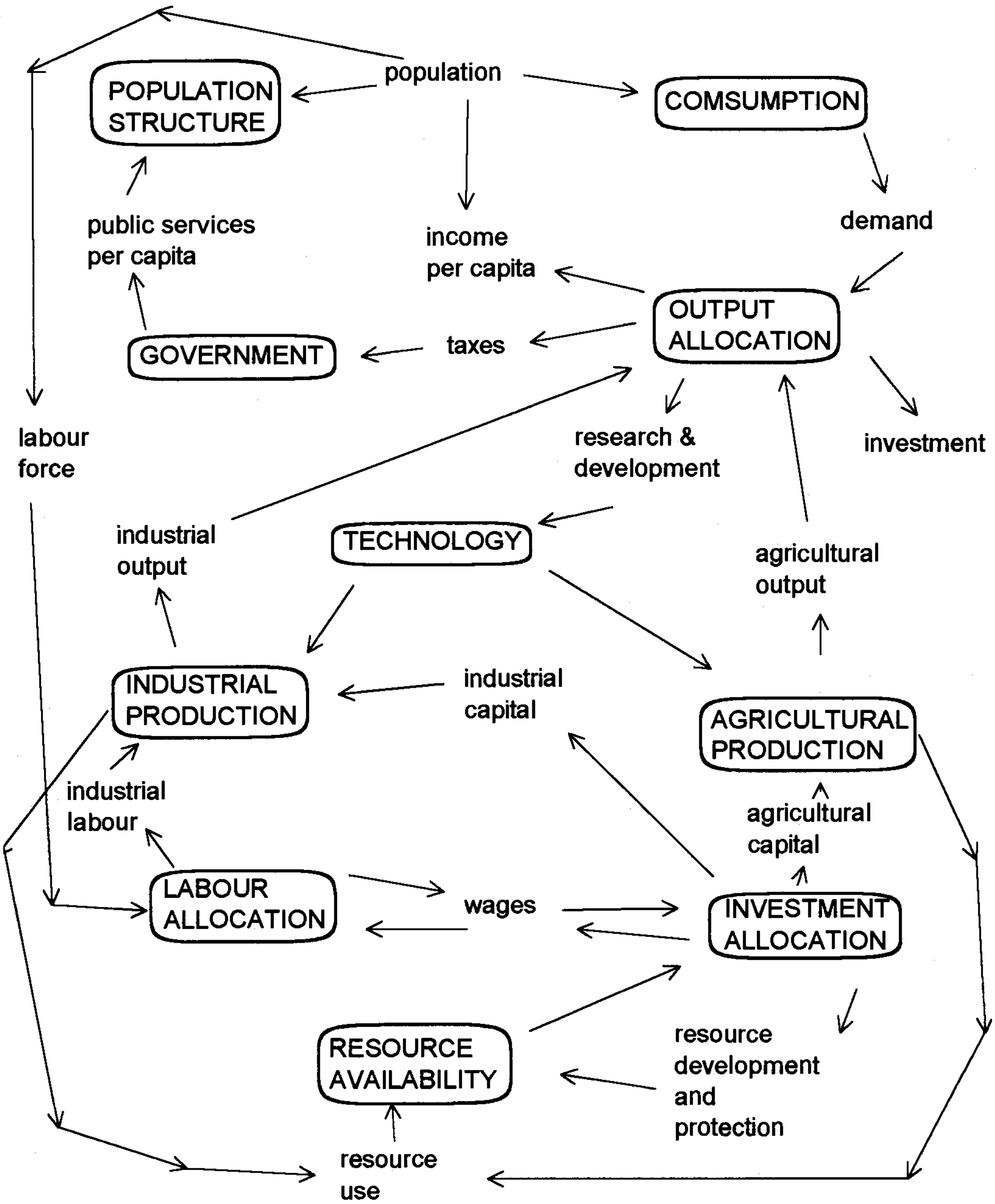
Causal Diagram of Common Elements and Relationships in Economic-Demographic Models (Meadows and Ribinson, 1988) **Figure 2.10**

The geographical applications of model building have led Meadows and Robinson to utilise two of the three perspectives. First, they describe the causal model, which is the equivalent of the state model. Second, they describe the reference model, which is the equivalent of the data oriented or structural perspective.

The causal diagram, Figure 2.10, implies aspects of time and states. Each of the entities, within the diagram would have its own state record that would contribute to the overall status of the domain. The structural model approach, Figure 2.11, has been developed to represent the relationships. It is based on a set of autonomous agents in a system, which collaborate, to perform some high level behaviour.

Booch (1991) argues that the identification of the structure and hierarchy of the objects within a system is the initial step in building a logical model to represent the real domain. Ogborn (1990) adds, that by starting with the 'form' of the model, the approach has the same fundamental idea as the discrete event modelling facilities used by professionals for planning and scheduling. He writes "'objects are defined, which move along paths passing through various events".

van Joolingen and De Jong (1991) identify the model state as one of the three perspectives of a problem domain. Their other two perspectives are, the form of the representation of the model, and secondly the relationships between the model state and the form of representation. They give two forms of representation of models, and these follow the quantitative - qualitative distinction. They then subdivide the quantitative form of models into several component parts. The first of which are the variables, which they define as "an input or output quantity or a quantity that is attributed to the modelled system". The second component of the quantitative representational form is the parameter. "Parameters are quantities that are dependent on external circumstances and are not influenced by variables". Parameters can be static or dynamic. Static parameters are constant throughout the time span of the model. Dynamic parameters are, explicitly or implicitly, a function of the model time. Dynamic parameters can be deterministic or stochastic. A third component of the



Reference Structure for Economic-Demographic Model Figure 2.11 (Meadows and Robinson, 1988)

quantitative representation is the distinction between the discrete and continuous models. The second form of representation of models is the qualitative method. These van Joolingen and de Jong see as "extremely important because they are closer to the mental model the student is to acquire". They go on to argue, that there is no sharp distinction between quantitative and qualitative modelling and simulations. Some modelling methods have both qualitative and quantitative aspects. They state that there are two types of qualitative models. The first is a description in general terms of the quantitative aspects of the system. The second type is where the non-quantitative aspects of the system are modelled. This form, they argue, often leads to building a discrete event model.

Bliss and Ogborn (1989) also identify the importance of the qualitative-quantitative distinction. However, they argue that a three fold description yields a clearer interpretation. The three types being, quantitative, semi-quantitative, and qualitative. Their semi-quantitative models may be closely aligned to the first type of qualitative model identified by van Joolingen and de Jong (1991).

Diagraming Methods

Diagrams are a way of accurately and succinctly representing a system. They form an intermediate link between the original description and the final computational model. They act as a translation mechanism between the actual domain and the final implementation of the model. The first form of diagram that may be constructed is the context diagram. This delineates the boundaries of the system under consideration.

Although the symbols on the diagram vary according to the particular methodology being adopted, there is a commonality of form between all diagrams. Generally systems are represented by using block diagrams with boxes to indicate entities and processes. The interaction between these components being indicated by arrowed lines. Such diagrams can then be developed or expanded to give a detailed description of the components of the system. The most fundamental level, with the components at their most detailed, is called the canonical structure.

There have been many different forms of diagrams that have utilised different symbols. Many of which have been developed to represent a particular view of a problem domain. Martin and Leben (1989) illustrate eight ways of diagraming for describing systems. They may be grouped according to the three perspectives of a domain, namely the functional, the structural and the state views.

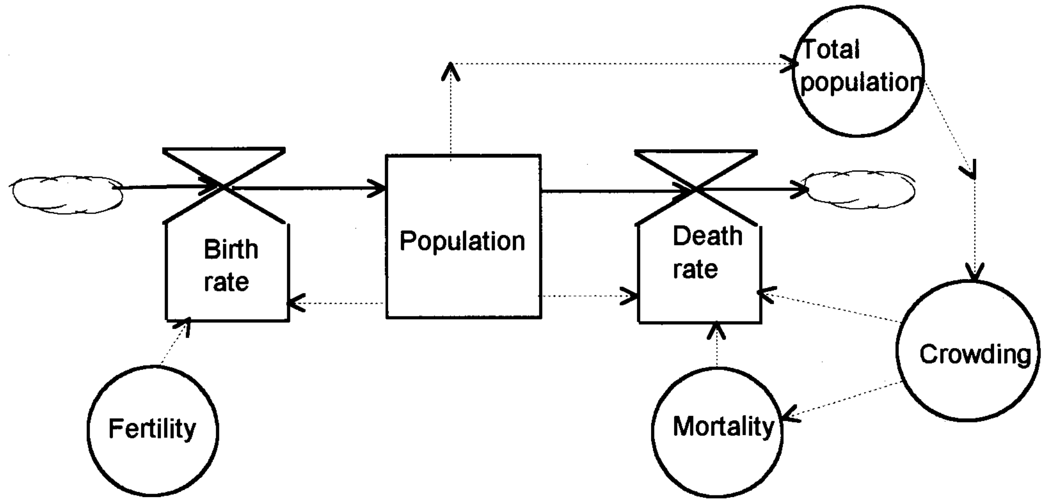
Decomposition, is where high level details are decomposed, to show a greater degree of detail at a subsequent level. This form of diagram is principally used to address the functional decomposition of domains. A data flow diagram shows the flows of data between the various functional procedures that are represented by circles.

Dependency diagrams have blocks that represent objects, with arrows showing the dependencies or relationships between one block and another. This form of diagram is principally used to represent the structural aspects of the domain. A data navigation diagram, which illustrates the interlinking of the data attributes, represents the structural form of the domain.

Time dependent issues, and the sequence of items, can be shown on state transition diagrams. Action diagrams permit the clear representation of high and low level activities on the same diagram and focus on the transitions between the different states of the system. The diagrammatic representation of input and output, both of which are forms of state transition, can be shown in a dialogue design diagram.

In addition, Martin and Leben (1989), identify two ways in which decision processes, which are embedded in systems, may be represented. The two complementary methods are decision tables and decision trees.

Martin and Leben (1989) identified diagraming methods that were general purpose. However, various analysts and system designers have devised special purpose diagraming methods that show in a particular manner, certain emphasised features of a domain. Forrester (1968) developed a symbolic language, Figure 2.12, to form an intermediary stage in the production of a computer simulation. The main modules are state variables, that are shown by valves, with auxiliary variables, which influence the rates of processes, being shown as circles. The flows of objects, people, goods or money are detailed with solid arrows. Causal relationships are shown with broken arrows and clouds depict sources and sinks of energy or mass flows.



Basic Modules of Forrester's(1961) Simulation Language Figure 2.12

Some modelling tools, such as STELLA, have been based on a composite diagraming method. The use of such diagrams as an interface to the modelling environment is seen to be a distinct advantage.

The Interaction Between the User and the Computer Based Model

Instruction with Computer Based Simulations

Teaching and learning may be addressed through the use of computer based simulations. de Jon (1991) shows that the instructional use of computer simulations has four characteristics. The first is the presence of a formalised and manipulable model, that may be defined as the phenomena that are being captured. It is then formalised and implemented as a computer program. The model may be qualitative, quantitative or a mixture of the two. For a quantitative simulation, independent variables, dependent variables, and parameters are combined into a numerical model. For qualitative simulations, the components of the model and the relations between them, will be represented symbolically or structurally. He argues that it is essential that the output of the program is calculated or inferred from the implemented model, in response to input from the learner. The second characteristic of instruction with computer based simulations, is the presence of learning goals. The goals may be of three different types. First, conceptual knowledge, which is the learner's acquisition of knowledge about the underlying model, which acts as the basis for the simulation. The second type of learning goal is the attainment by the learner of operational knowledge, such as the cognitive skills required to solve problems within the subject domain. The final type of learning goal, defined by de Jong (1991) is in the form of meta-knowledge, which he calls " knowledge acquisition knowledge ". This is the learning about the processes that take place, while learning the simulation. The third characteristic of instruction with computer based simulations, focuses on the elicitation of specific learning processes. This aspect he views as having 'cardinal importance'. The simulation must be used to invoke specific learning processes, such as hypothesis generation and testing. These specific learning processes form the path that leads to the learning goals. The simulation environment permits an exploratory style of learning, in that the learners, can generate their own hypotheses and can test them. de Jong argues that this constructive approach is generally accepted as an efficient way to acquire knowledge. He also identifies other learning processes, such as planning and monitoring, that can help the learner to reach the learning goal. The final characteristic of instruction with computer based simulations, is the presence of learner activities. The learner plays an active role, by manipulating parts of the simulation, such as the setting of input variables or parameters and the choosing of output variables that will provide the information from the simulations.

de Jong, (1991) extends his discussion beyond the four characteristics by considering the circumstance when the learners have direct access to the underlying model. In this case the learner may add, delete or modify variables or parameters, and may even adjust the relations between the principal elements within the system.

The benefits of using simulations in instruction are strongly argued by de Jong (1991). He gives, as the most important reason, the learner's active exploration of the domain. Such an approach, he argues, is consistent with modern instructional and learning theories. His second benefit is the hypothetical realities, with learner adjusted time scales, that may be implemented and which permit experimentation and the development of learning. de Jon's final benefit, gained by using simulations in instruction, is the motivational effect they have on the learner who is working with an interactive system.

de Jong (1991), follows Hijne and van Berkum (1991), by adding one module to the structure of three modules, that comprise an Intelligent Tutoring System, Clancey, Barnet and Cohen (1982). The additional module is the learner interface. This four fold approach, is coupled with the characteristics of using simulation instruction, and leads to a proposal for a table of design components, Figure 2.13

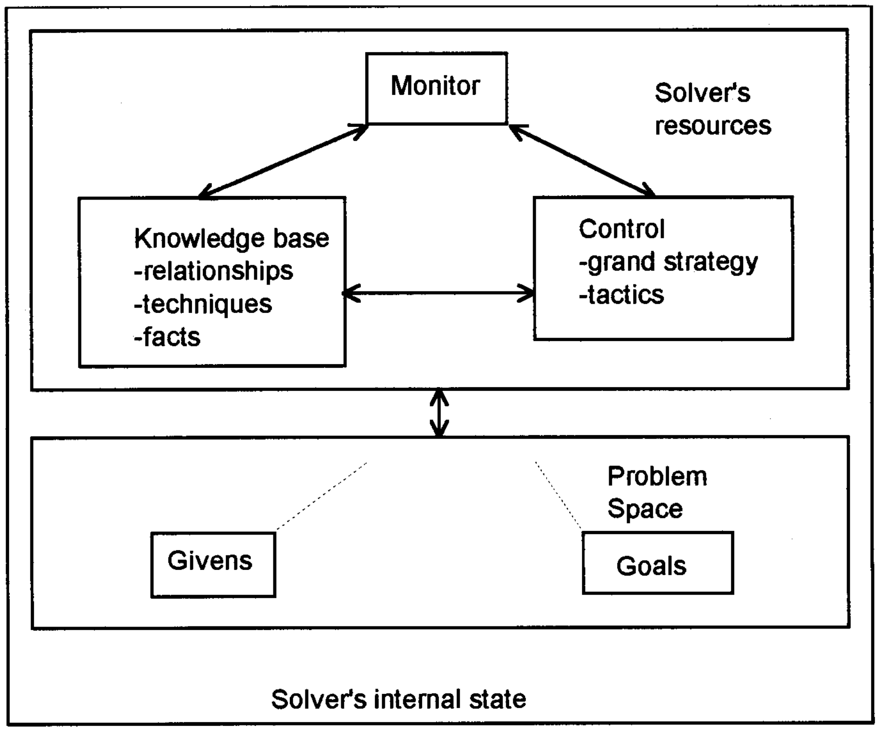
THEMES	Domain	Learner Characteristics	Instructional Strategy	Learner Interface
Models	Domain Models	Mental models Misconceptions	Progressive Implementation	Visualisers Multiple Views Transparency
Learning Goals	Scenarios Experimental frame	Prior knowledge Related skill levels	Immediate feedback for learning	Goal decomposition tools
Learning Processes	Complexity of domain	Scientific skills Self regulation Self confidence	Hints Suggestions Explanation	Learner instruments
Learner Activity	Handles on the model	Knowledge of exploratory learning environments	Giving constraints on input	Input transparency

Figure 2.13 Design Components (de Jong, 1991)

Aspects Of Learning

Ridgeway (1988) indicates that the user brings to a problem solving exercise two principal features, their knowledge base, and the control method for solving the problem, Figure 2.14. The knowledge base comprises of the facts, skills and knowledge of relationships, which the user can bring to bear on the problem domain. The user's control is the manner in which these resources are deployed.

Problem solvers have a range of ways of tackling novel problems. First, at a heuristic level, by trying simple cases and by associating current problems with familiar situations. A second approach, is to work systematically through the details of a decomposed problem domain. These first two approaches can be classified as the bottom up approach and may be equated to the serialist learners identified by Pask (1976). A third approach is to take a more strategic view of the problem domain and



Minimum Resources for Model of Human Problem Solving
Ridgeway (1988) **Figure 2.14**

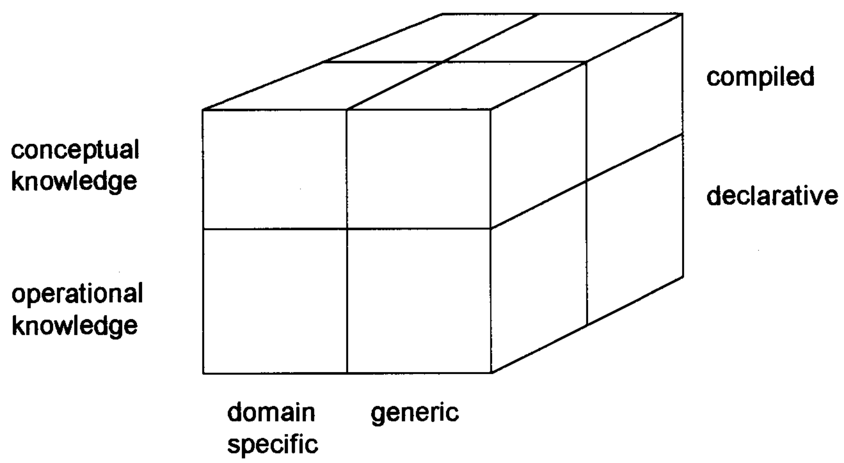
to identify the most appropriate method of finding a solution path. Therefore, familiar problems permit the recall of specific strategies and the allocation of the resources to solve them. This broad overview, encompasses the holist view of Pask (1976) and corresponds with the identification of the structural aspects of the problem domain.

Ridgway's (1988) second feature of problem solving is the control of the solution. The user monitors the progress in finding a solution, to perceive whether progress is being made, or whether a wrong path has been started. If the latter is evident then the user will adjust the solution strategy.

Learning Goals

van Berkum and de Jong (1991) identify learning goals for simulations. They argue for a taxonomy of learning goals based on a cognitive approach. The goals are classified according to the dimensions of the knowledge involved, rather than the behavioural performance. The taxonomy only deals with terminal learning goals and not intermediate goals. The goals do not specify who adopts these gaols and consequently they may be ascribed to either the learner or the instructional process.

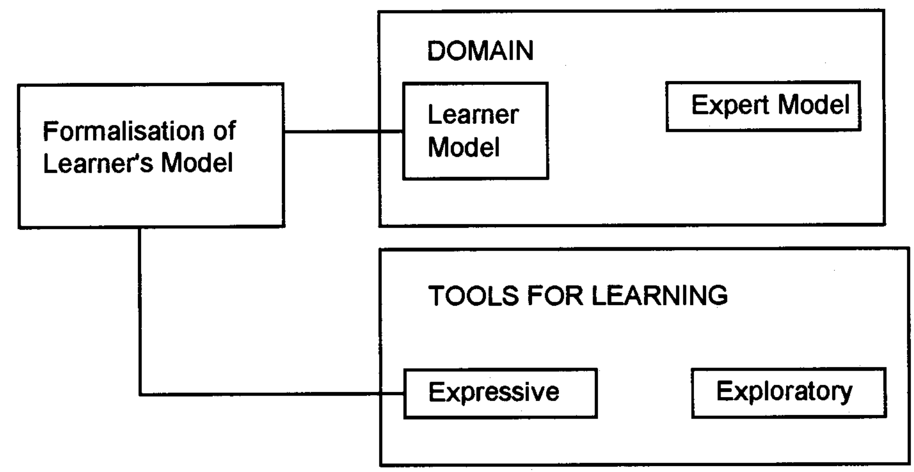
Each specific learning goal can be classified along three dimensions. First, the kind of knowledge to be learned may be determined to be conceptual or operational. Conceptual knowledge is about the principles , concepts and facts, related to the class of system being simulated. Operational knowledge is knowledge about the sequences of cognitive and / or non-cognitive procedures related to the domain. The second dimension is that the knowledge may be coded in a declarative or compiled representational form. The declarative knowledge in this context, is the open knowledge that is in a clear format, and is relatively easy to acquire. Compiled knowledge is represented in a format, that is only obtained after using the knowledge in the problem solving context. The third dimension, is the scope of the target knowledge. Domain specific knowledge is targeted at specific knowledge. Generic knowledge is not specific to the simulation domain, but extends to other domains as well. They structure the learning goals as a three dimensional matrix, Figure 2.15



Classification of Simulation Learning Goals (van Berkum et al, 1991)
Figure 2.15

The Tools For Learning

Bliss and Ogborn (1989) pose two main questions about tools for learning. First, in which ways can the interaction with tools, containing representations of a domain facilitate the learning of that domain. Second, are learners helped by representing and exploring the consequences of their own mental models of a domain. They categorise the tools for learning, in terms of the relationship with the external expertise model of the domain, and the private subjective mental model of the domain, Figure 2.16. The diagram identifies the two types of tools for learning as exploratory and expressive.



The Elements of the Learner's Model (Bliss and Ogborn, 1989) Figure 2.16

Exploratory tools allow learners to investigate models in a given domain. These models may be different from their own and so they can examine any consequences or conflicts. Expressive tools give the learners the opportunity to run their own models of reality and so learn through representing, exploring and reflecting.

Exploratory tools are such learning environments as microworlds, Lewis (1988). Children can explore the consequences of the underlying logic rules or relationships of a domain supplied by the designer of the environment. It requires a well defined and yet open ended environment, in which experimentation with the manipulation of rules and relationships can take place . Bliss and Ogborn (1989) argue that the use of the exploratory models can be seen to be a necessary pre-condition for using expressive modelling environments. They write, "it is possible that pupils cannot give up their own models of a domain until they have had the opportunity to 'try out' and experiment with others." Expressive tools are those that allow the learner to construct and examine their own model, with tools that are transparent to use.

In order to create a solution path, the user develops a mental model which is a cognitive representation of some particular content domain. Payne (1977) argues that these mental models have two components. The declarative, which is the static knowledge within the domain and secondly, the manner in which the inferences and logical conclusions may be drawn within the domain.

Marr (1982) distinguishes between the individual belief and theories, which form part of the mental model, and the universal properties of the mental model, which are those that are publicly agreed.

Learner Activity

de Jon (1991) points out that learning through exploration puts high cognitive demands on learners. This may then result in inefficient and ineffective learning behaviour, where students do not use the opportunities a simulation environment offers. Therefore, he argues, that support is needed if learning from simulations is to be effective. This support can be given by a human teacher or it can be a computer learning environment.

van Berkum et al (1991) distinguish various kinds of learner activity. These can be grouped according to the part of the simulation that is addressed, when the learner activity comes into play. First, the learner may be able to define experimental settings or environments. During this type of learner activity, the model and its environmental parameters can be affected. Typical examples would be, the setting of variables and parameters that refer to the environmental qualities, the setting of the initial conditions for the simulation, or the building of the simulation from component parts.

The second major type of learner activity is that associated with the interaction process. This type of activity focuses on the adjustment of values or parameters. The third type is concerned with the collecting of variables from the simulation and accessing the outputs of the model. The learner must decide, both how and where, to collect the outputs and thus must identify a measuring instrument for the outputs. The fourth learner activity is based on the decisions regarding the presentation and form of the outputs, for example, the distinction between output in graphical or tabular form. Finally, the learner may have control over the pace and direction of the simulation process. This can be called meta-control and refers to the pace, stopping points, and speed of the simulation.

van Berkum et al (1991) consider that learning with simulations is essentially exploration based learning. They define learning processes as the cognitive transactions of the learner that are meant to transform information into knowledge. They suggest a preliminary inventory of simulation learning processes. They argue, that the scheme is descriptive, and not prescriptive, and does not necessarily prescribe a normative sequence of learning. The scheme has a multi-layered structure of learning phases and processes. The phases represent a combination of learning processes that can be characterised as one class of operations, Figure 2.17

	Level One	Level Two	Level Three
	Orientation	Observation	Encoding
			Retrieving
		Analysis	Encoding
			Retrieving
EXPLORATORY		Model Exploration	
LEARNING	Hypothesis Generation		
	Test	Design	
		Prediction	
		Manipulation	
		Interpretation	
	Evaluation	Observation	
		Generalisation	

Figure 2.17 Inventory of Simulation Learning Processes, (van Berkum et al, 1991)

Learning with a computer simulation is characterised as learning in an exploratory environment, Goodyear et al (1991). The environment can stimulate certain processes such as problem solving, discovery learning and inductive learning. Goodyear et al (1991) identifies the relevant phases in the process of problem solving to be :

- preparation : orientation and planning
- execution : transformation, determination of the solution, evaluation
- control : interpretation of the results

Goodyear et al (1991) stress the significance of guided discovery learning, that encourages active experimentation and exploration. Such guided learning also encourages reflective thinking and self regulation. They argue that the central feature of guided discovery learning is that the content to be learned, must be discovered by the learner. It can then be meaningfully incorporated into the learner's cognitive structure. The processes involved are, for example, to rearrange information and to integrate it with existing cognitive structures. The learner then reorganises or transforms the integrated combination, in such a way, so as to generate a desired end result and discover a means-end relationship. Learning by discovery is a matter of recognising relationships. It occurs when relations are perceived in a new way. Information is extrapolated, inferences are drawn, or experience is re-structured, so that new patterns or relationships occur. The principal component of inductive learning is the formation of hypotheses. Inductive learning involves generalising, transforming, correcting and refining knowledge representations. Inductive learning strategies include a variety of processes, such as creating a classification of a given observation or discovering relationships and laws governing a given system. It may also include the forming of a theory to explain a given phenomenon.

Teaching Using Models

The Classification of Models

The pedagogic issues of modelling may be considered in terms of several factors. First, the classification of models that allow a selection and structuring of teaching material. Second, the problem of knowledge elicitation, that is required to be performed by students who intend modelling from first principles. A third factor, focuses on the sequence of activities that can be followed in the teaching of modelling. With the final factor addressing some perspectives on the selection of modelling tool formats to enhance teaching.

There are four principal ways in which computational models, that are used for learning purposes, have been defined by writers. The first is suggested by Ogborn (1990), and is based on the types of interaction between the entities within the system. The second is described by Barr and Feigenbaum (1982), and focuses on the nature of the knowledge within the domain. The third classification, by Webb and Hassell (1988), has a dual grouping under the behaviour of the model and the method of modelling. Finally, van Berkum (1991) et al, distinguish between the types of model and the interaction with a model by the user.

Ogborn (1990) identifies four types of computational models. Cell automata models are based on the juxtaposition of cells that interact. The model is run by relating rules, within one cell, to actions within adjacent cells. Thus, each cell has a state, which changes according to the cells next to it. Cell automata models are based on the fundamental rules of behaviour that link objects within a system, and thereby give relationships between nearby objects.

Quantitative dynamic models are based on the manipulation of numerical variables within a system. These variables change over a period of time, as a result of the values of other variables. The rules of the evolution of the system are the rules for computing the next values. Ogborn classifies DMS, CMS and STELLA as examples of these dynamic models.

The third of Ogborn's four types of computational model is the qualitative state space model. A specified condition of the domain, may be viewed as a point within a space of states. Many games and logical puzzles can be identified through the number of possible states that are available within the confines of the system. The state space of the domain is determined from the identification of the variables and their specific values. In many cases there will be a finite number of these possible states. The movement from one state to another is under the constraints of rules prevalent within the domain.

The final type of computational model is a network realisation model, where there is a cell for each variable that forms part of the system. Each input is either positive or negative dependent on the output from other cells. The pattern of the activation of the network will relax towards one or more configuration. Through the cells interaction with external variables, the impact of the events from the external environment can be viewed.

Barr and Feigenbaum (1982) consider that there are two principal ways of predicting the behaviour of complex systems, both of which involve the construction and running of computational models. The first is simulation and the second knowledge based programming. The difference between them is that the behaviour of the former is based on mathematical equations and the latter on rules. Simulations predict the future state of a system by propagating values of system variables through time. Knowledge based programming infers facts about the state of the system and shows how to achieve defined states. Simulation is suited to problems that can be modelled analytically whereas knowledge based programming is built on heuristics. They argue that a combination of both is required as complex problems have elements, that can be modelled analytically and others that need to be built with heuristic principles.

Webb and Hassell (1988) have identified various types of models within a classification based on the behaviour of the model and the method of modelling. Dynamic system models have developed from system theory and can be described in relationship diagrams. The levels of the components, that is the variables, change over time. Their characteristic feature is non-linearity and the incorporation of feedback loops. DMS, STELLA and MICROMODELLER are examples of this kind of modelling tool.

Spatial distribution models have entities which are positional or can move in space. Reasoning is often through probability distributions. The existing examples of GEOBASE and QMAP have the ability to display spatial information but have no direct modelling capability.

Probabilistic event models have a series of discrete events that take place dependent on various probabilities. The process of modelling is a combination of, the determination of the events, and ascribing them appropriate probabilities. Webb and Hassell identify that LOGO can be used for this purpose, but it is not sufficiently close to the user domain to allow easy or direct modelling by pupils.

Data analysis models are procedures that are applied to collected data to identify patterns. When many variables are present, within a domain, then multi-variate statistical models result.

The final type of Webb and Hassell's models are based on qualitative logical reasoning. This type allows for the construction of models where there is difficulty in obtaining precise quantitative data. Such qualitative models are suitable for encoding heuristic ideas associated with expert systems.

van Berkum (1991) et al define a model as a representation of a system that has been created in order to be able to experiment with it through simulation. Such a system can be physical, artificial or hypothetical. They base their classification on the qualitative-quantitative distinction in the representation method. They argue that in both forms of representation the model is based on a state mechanism. The state definition for the system, contains information about the current properties of the elements, as well as, the set of rules that determine the movement from one state to another. This movement between states, they argue, gives added significance to the aspects of timing within the system . They indicate that timing may be viewed from the perspective of the relationships between the input variables and the output variables. The sequence of providing input and obtaining output is called the interaction process. This interaction process determines, in which order the model elements may be manipulated. The interaction process can be influenced by certain factors, such as, the internal characteristics of the underlying model, and the instructional strategy used. When the interaction itself is a learning goal it will be called a procedure, operation or skill.

The Problems Associated with Knowledge Elicitation for Modelling a Domain

Cotterell et al (1988) summarise the various problems associated with obtaining a clear knowledge of a system domain that is under scrutiny. First, they point out that there is never complete knowledge of the real world, and that it is only one view of the domain that is taken. Second, in the development of any system, the information available is likely to be incomplete. Any system description should address this incompleteness issue. The third caveat, about the knowledge of systems, focuses on states. The various states of the models must be clearly distinguished from the states in the real world. When a view of the system domain is taken, and translated into a computational model, then such a view has to be encoded within the constraints posed by the computer language representation. A simple example is that many events and actions can take place in the real world in parallel, whilst most computer representations will insist on a sequential approach to the encoding. Cotterell et al., make a final point, that the explanation of how a system works, in terms of the relationships present, should not be confused with the prediction of future values of the system variables. They identify three ways of thinking about problem solving so that a mapping into a computational model is possible.

Logo can be used as a basis for procedural thinking, in which the problem is represented as a series of instructions. The initial advantage of using such a language is the small number of commands that can be used. Logo generally has a simplicity of approach made through a structured design. Papert (1980) argues that it is not a computer language but an aid to thinking.

The use of logic, and the implementation of a logic inference method on the computer, is encapsulated in Prolog. It is a declarative programming language, that is a form of descriptive programming. It is based on the premise of describing the problem that needs to be solved and leaving the inference and the solution generation to the computer. Cotterell et al. argue that the greatest benefit is to be able to view independently the rules and statements within the problem. A high level description of the problem is required for encoding into Prolog.

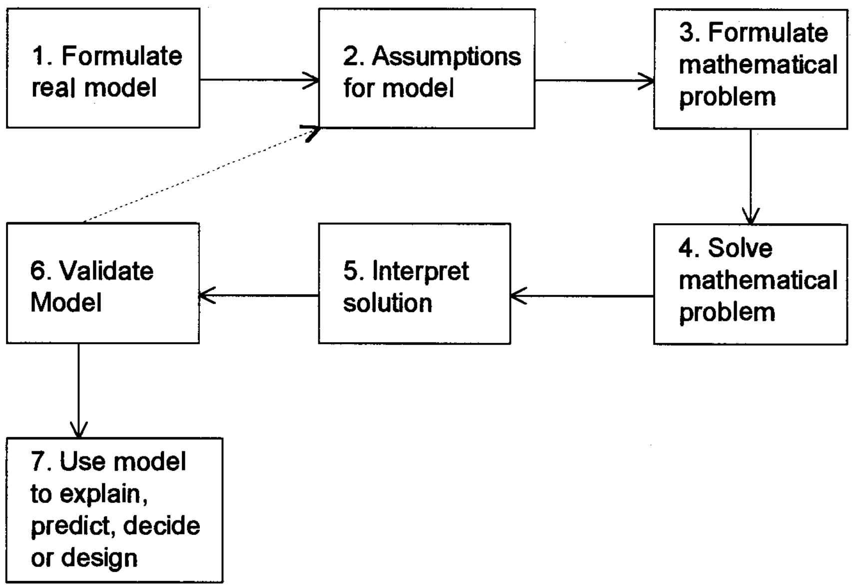
The third type of thinking identified by Cotterell et al is the object oriented approach. The language used for the implementation of the computational models is Smalltalk. The basis of which, is to describe the objects within the domain. Each object is activated at an appropriate point by a signal or message and this triggers the problem solving process.

The Teaching of Modelling

Santos and Ogborn (1992) propose an instructional model for computational modelling. It is based on a methodology commonly described in mathematical modelling. The instructional model is based on the seven stages of mathematical modelling, Figure 2.18. They argue that the instructional model framework should be seen as a scheme to help the teacher design modelling activities for students. It is not a scheme to be followed by students. It is only concerned with dynamic models.

The framework has two levels. One level concerns the construction of particular models. And a second level is concerned with learning about modelling more generally. The outline structure of the instructional model is divided into five areas, Figure 2.19.

Area A	Choice of system to be modelled
Area B	Mechanisms of causation and identification of variables
Area C	Type of model required
Area D	Generation of output from model
Area E	Interpretation, checking, validation and use



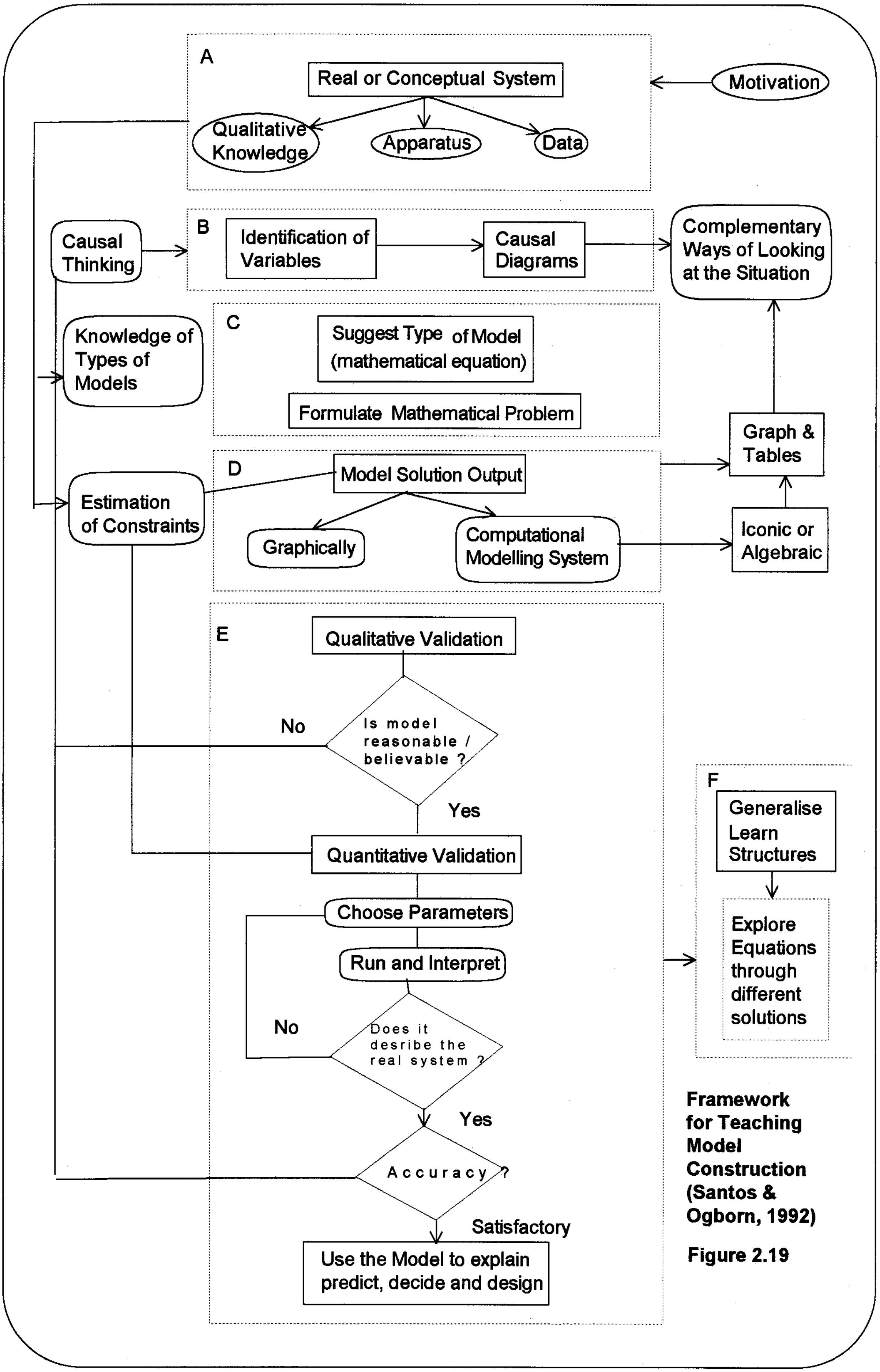
The Mathematical Modelling Process - The Seven Stages (Santos and Ogborn, 1992) **Figure 2.18**

Area F Generalise, learn structures

The Areas A - D correspond to the first four stages of the Seven Stage Mathematical Model while Area E covers the Stages 5 - 7. Area F is an extension of the Seven Stage Model.

Area A determines the choice of the system, that they argue should be firmly based on observed phenomena. Much of the empirical knowledge will, however, at this stage, be in qualitative form. Quantification will develop in the later stages. They suggest that simple experimental work is conducted, which is aimed at a qualitative understanding of the system, that is, what happens and what is affected.

Area B begins with the qualitative understanding of the system and attempts to establish an analysis of causation in the system, so that variables and relationships can be isolated. There is a requirement for a simple representation of variables and the causal and other relationships between them. They argue that there is no need at this



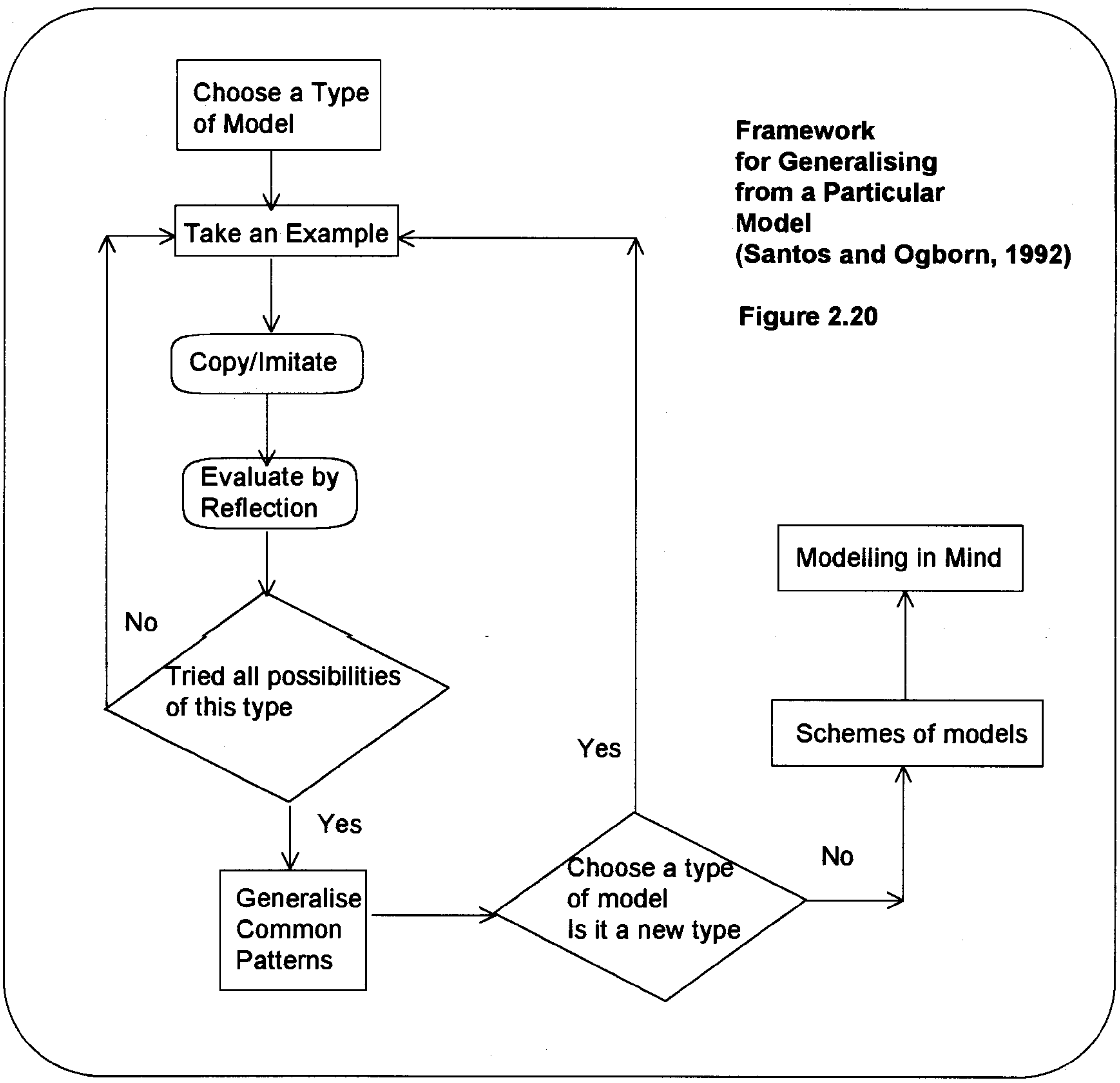
Framework for Teaching Model Construction (Santos & Ogborn, 1992)

Figure 2.19

stage for a detailed specification of the relationships. They suggest the construction of causal diagrams at this stage.

Area C takes the output of Area B and decides the type of model required. In mathematical terms, the equations are now constructed. They argue that students are unlikely to know what type of model is required and so will require guidance on this aspect.

Area D focuses on the production of outputs. The model would be entered into the computer and the output produced by the modelling environment.



Framework for Generalising from a Particular Model (Santos and Ogborn, 1992)

Figure 2.20

Area E then addresses the validation of the output. The authors suggest that this takes both qualitative and quantitative forms. Qualitative validation is the general direction and scale of the results, whereas the quantitative validation is the establishment of the correct numerical outputs.

The additional Area F, addresses the issue of generalising from particular models, Figure 2.20.

Modelling Toolkits

Fung (1993) introduces the idea of a toolkit approach to the building of a modelling environment for use with Intelligent Tutoring Systems (ITS). She emphasises the importance of abstracting and representing knowledge about teaching, learning and the domain. The traditional CAL approaches have knowledge implicitly stored, whereas an ITS attempts to make that knowledge explicit. She argues that the construction of a fully generic system is too premature and that an ITS may be constructed from a 'toolkit'. Simple combinations of the appropriate tools may be directly available to the student, but specific applications could be quickly constructed by a programmer.

The toolkit approach described by Fung (1993) is based on the structure of the underlying representation. The toolkit comprises of two forms of representation. The first is the network form, which is a collection of nodes, each of which, has a number of attributes and links. This type of network is based on semantic nets. The semantic network form of representation is for the declarative aspects of the information that are to be modelled. The second form of representation, for the procedural model, is the production rule.

In addition to the representation methods, the toolkit approach then uses two modelling approaches, that can be applied to both forms of representation. The first is subset modelling, which assumes the learner will act like an expert, but will have some knowledge missing. Subset modelling, with both representational forms, makes assumptions about the initial state of the learner. Subset, also known as overlay modelling, assumes that the learner starts from a position of ignorance and gradually acquires knowledge. The second type of modelling is perturbation modelling, where the representation holds faulty knowledge and skills, that the student may possess but the expert will not.

The building of a modelling system for an ITS is also addressed by Mitchell and Grogorno (1993), who indicate that the "student's map (model) is similar to the expert's map but simpler ". They suggest that the interaction between the two forms of model is based on Conversation Theory, Pask (1976). They consider that learning involves conceiving, analysing and evaluating, and that the learning process does not take place in isolation in one person, but is the interaction between two subjects, the 'teacher' and the 'learner'.

Nwana (1993) offers criticisms of the expert overlay model as suggested by Fung (1993) and Mitchell and Grogorno (1993). First, the overlay approach offers only one principal way to solve a problem. He argues that there may be many different and equally acceptable ways to solve a problem. The second criticism focuses on the strategies adopted in solving the problem. The overlay, method it is argued, may be too restrictive. A third criticism is that the overlay approach does not provide feedback nor does it allow for the individualisation of learning.

Nydahl (1992) addresses the problem of the selection of modelling tools, from a slightly different perspective. He argues that the transfer of knowledge to the student can be characterised, as a process that has three parts. The first, consists of a transformation of the teacher's (expert) personal knowledge into information, in the form of definitions, formulations and explanations etc. The second phase, involves the transmission of this information to the student. The third phase, deals with the transformation of this information into the personal knowledge of the student. Nydahl (1992) goes on to argue, that there is a firm distinction between information and knowledge. Information can be transferred, whilst personal knowledge can only be developed by the student. Powerful pedagogical benefits may be gained, if the computer is used to stimulate the student's activity in phase three, or if the student plays the teacher's (expert) role in phase one. Thus, students could benefit by attempting to build their own expert system for a limited domain.

Conclusion

This chapter has drawn together several themes that underlie the development of a computer based geographical modelling system. The first principal theme has been the systems approach to geographical knowledge, and the associated description of the building of geographical models, from the systems approach. The various approaches, that have been identified, in the development of geography, have also been discussed. This has allowed a clear basis to be established for the development of a wide range of geographical models. A second theme, has focused on the types and styles of models and their component parts that have been utilised within geography and the related areas. The third theme has demonstrated the range of methods and techniques that have been used to represent such ideas as modelling and simulations on the computer. The focus was to identify the principal underlying representation and inference methods, so that a firm basis could be established for the development of geographical models. The final theme, has addressed the current status of modelling, with particular reference to the development of models, both within geography and in wider fields. It has investigated the relationships between modelling and simulation, in the instructional setting. The final part of the status theme has focused on the teaching of modelling.

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CHAPTER THREE - THE RESEARCH METHODOLOGY

PART ONE - THE RESEARCH AND DEVELOPMENT METHODOLOGY

Introduction

The purpose of this research is to produce a specification for a new product that can be used in the classroom. The methodology for the development of a new product can be selected from a range of alternatives. There are three possible research methodologies that could be considered and they are the :

1. Experimental or Quasi-experimental Methodology
2. Action Research Methodology
3. Research and Development Methodology

Borg and Gall (1979), and Cohen and Mannion (1985) consider that the design of most of the Experimental Methodologies, that have been used in education, have been adapted from the physical and biological sciences. The typical experimental design, in education, involves a selection of samples, that are randomly assigned to experimental and control groups. Each of the groups is treated differently on one controlling variable, called the dependent variable, and the results from the two groups are compared.

The random assignment of subjects to the control and experimental groups is of considerable significance in experimental design. In classroom based field work this type of assignment is not always practical, so a Quasi-experimental approach was developed by Campbell and Stanley (1966). The most common form of evaluation, for the experimental design, is the post test, on which the basis for a comparison may be made. In the Quasi-experimental approach the post test is given to the experimental group, but there is no specifically identified control group. For the comparison, the post test is given to a group, that was not the experimental group, but one that can be identified to be a group against which comparisons can be made. The weakness of the Experimental and Quasi-experimental methodologies, for the evaluation of the development of the product, is the difficulty in isolating the variables. A product that has been fully developed could possibly be used, but one that is under development would have too many variables to be able to give either internal or external validity.

Action Research is the small-scale intervention in the functioning of the real-world and the close examination of the effects of that intervention, Cohen and Mannion (1985). They add that there are certain features that characterise Action Research. It is situational, in that, it is concerned with diagnosing a problem in a specific context and attempts to solve that problem in that context. It is participatory, in that the research team members are often actively involved in implementing the research. It is self-evaluative in that modifications are continuously evaluated within the on-going situation. The normal objective of the Action Research is the improvement of performance in some way.

Cohen and Mannion (1985) identify the diagnostic and the therapeutic as the two stages in Action Research. The former analyses the problem and develops the hypothesis, whilst the latter tests the hypothesis by a directed experiment, normally in a working situation. Borg and Gall (1979) identify Action Research, as involving the application of the steps of scientific methods to classroom problems. They argue that it is similar in some respects to regular educational research, but differs principally in the extent to which the findings can be generalised beyond a local school situation. It involves establishing as much control as possible, consistent with the research goals, over such variables as teaching ability. Action Research projects can be carried out in a single classroom by a single teacher. As Action Research projects become more extensive they become similar to other types of research. The emphasis in Action Research is not on obtaining generalised scientific knowledge about educational problems, but on obtaining knowledge concerning a specific local problem.

The results of an Action Research project by a single teacher have important implications for the teacher. However, because of the few cases, the lack of control, and the absence of sampling techniques, the generalisation of the results to a wider field must be treated with the utmost caution. The principal advantage of Action

Research is that it provides the teacher with an objective systematic technique of problem solving that is far superior to personal experience.

Providing sufficient account is taken of the internal and external validity of the conclusion of an Action Research project, the methodology can be very suitable for the evaluation of a completed educational product in the classroom. Action Research may be able to circumvent the difficulties that the experimental approach has in controlling the number of variables. However, the information that is collected, during the research is for implementing change within that educational setting, and is not for generalisation across a range of educational circumstances. The development of a product requires evaluation to be directed towards decision making. Decisions are made about the attributes of the product, as it passes through the different stages of building and development. Thus Action Research is best suited to the summative evaluation of a completed product, and not the formative evaluation of the development process.

The Research and Development Methodology originates from industry where the process involves the building of a prototype of a product. This is based on the best theoretical evidence available. The prototype is then tested and various kinds of feedback are obtained, so that modifications can be made to improve the next stage of the product. The cycle of evaluation and revisions continues until the product meets the specifications that have been established for it.

Borg and Gall (1979) identify the way in which the Research and Development Methodology can be applied to education. The process begins with a careful review of previous research, in order to build a foundation on which to develop the educational product. The building of the prototype begins, and is tested, evaluated and revised until it meets its objectives. That is, until the product brings about the outcomes that it was designed to do.

The critical difference between the Educational Research and Development Methodology and the other methodologies for educational research is the sequence of activities that are followed. In other forms of educational research the researcher typically begins by developing an hypothesis or problem to be studied. Previous research is examined, then a sample of subjects is selected and the relevant data is collected. This data is then analysed using statistical tools and subsequent conclusions are reached about the hypothesis or research problem.

In the Educational Research and Development Methodology a quite different sequence is followed. The formulation of the sequence itself is considered to be a major contribution to the field of educational research. The typical steps in the sequence are :

1. develop a set of objectives or specifications that the eventual product should achieve
2. conduct research or review previous research to :
   a. establish a need for the product
   b. discover the deficiencies of current products
   c. identify approaches that are likely to overcome these deficiencies
3. develop a new product to the point where it may be reasonably expected that it will accomplish its objectives
4. test the product in the setting where it will be eventually used and evaluate its effectiveness in meeting the objectives in this setting
5. revise the product on the basis of the field-test results
6. repeat steps 4 and 5 until the product's objectives have been achieved or until it has been established the approach will not achieve them
7. if successful put the product into operational use

The use of the Research and Development methodology for the development of an educational product has been justified in a number of ways. Borg and Gall (1979) argue that it is the "most promising strategy for improving education". They go on to argue "although making important contributions to education, basic and applied research methodologies are generally poor for developing new products that can be used in schools". They add that with the more traditional methodologies, the results are only positive in a statistical sense and have no direct practical or immediate significance in the classroom. This is because the objective of most research is for new knowledge. The outcomes of most research methodologies are usually a report that appears in a scholarly journal. In contrast, the objective of Educational Research and Development is a finished product that can be effectively used in education. The product is typically in the form of textbooks, audio-visual materials, training manuals and possibly equipment of some sort. Educational Research and Development effectively bridges the gap between research and classroom practice. Moreover, because of its emphasis on development, Educational Research and Development provides schools with products of demonstrated effectiveness.

Many educators have advocated a systematic approach to the designing of a curriculum for any, content, audience or medium. The principles, for which, stem from Tyler (1949) who argued that in any curriculum project there should be clearly defined goals, that provide environments, that evoke students learning experiences. Tyler emphasised the cyclical curriculum development process, so that "as materials and procedures are developed, they are tried out, their results appraised, their inadequacies identified, suggested improvements indicated, and there is re-planning, redevelopment and then reappraisal ". He argued that in this way more effective educational programs and products may be developed, rather than depending on hit and miss judgements as a basis for curriculum development.

Andrews and Goodson (1980) have identified that since Tyler's work over 400 models of systematic instructional design have evolved with varying levels of specificity. Despite the proliferation of models, the general tasks that constitute instructional design development are generic, in that they may be applied to many different purposes. Mielke (1985), in developing educational television programmes, states that much can be learned from target audiences, by evaluating their reactions to existing programmes that feature relevant subject matter or format. Flagg (1990) states that interactive programs may benefit from pre-production testing of possible hardware -

software interfaces, types of interactivity, levels of user control, and feedback procedures.

A second principal justification for using the Research and Development methodology for the building of a product, focuses on the views that can be taken at the different stages of product development. Evaluation of previous research and initial testing of the product in the early stages of development allows information to be collected. This can be used to inform decisions on the strategic content and direction of the product, Mielke (1985). Strategic information can help guide the creativity of designers and reduce the uncertainty of some of the critical decisions. As the project moves into production, attention turns to gathering tactical information about specific aspects of the product.

Callison and Haycock (1988) suggest that teachers are not necessarily good predictors of students' responses to materials. They point out that students and teachers agreed more often about programs that were rated extremely low, than they did about programs rated high. They state, there was a weak correlation between programs rated highly by teachers and the programs rated highly by students. The testing of critical aspects of products with students, during the development, can therefore be argued to be further justification for using the Research and Development Methodology.

Evaluation in the Research And Development Methodology

<u>Evaluation Research</u>

Evaluation is an essential part of every educational research project. Borg and Gall (1979) suggest that in recent years, educators have become increasingly aware of the need for better evaluation data to help in the decision making processes. Research and Development specialists have developed new approaches to meet these needs. In response to this new emphasis on evaluation, a discipline called evaluation research has emerged. Evaluation research involves the systematic collection of evidence on the worth of educational programs, products and techniques. Its main purpose is to help educators to make decisions. There are several kinds of evaluation research, including needs assessment, evaluation of completed educational programs, and the evaluation of new programs during the development process. Evaluation research has two major purposes. Formative evaluation is carried out while the product is being developed and is designed to gather evidence that can be used to modify the product or make it more effective. Formative evaluation is, therefore, the systematic collection of information, which can be used to inform decisions about the design and improvement of the product. The term formative indicates that information is collected during the formation of the product so as to make revisions that might make the product more effective. Formative evaluation may be applied to classroom teaching, Bloom, Hastings and Madau (1971). Curriculum evaluation is defined as "the collection and provision of evidence to aid decision making for the feasibility, effectiveness and value of curricula", Unwin and McAleese (1978). The purpose of evaluation is to delineate, obtain, and provide information for making educational decisions. This information is highly particularistic and specific to a decision situation, and therefore, cannot be generalised to all situations. Thus, the evaluation methodology is not necessarily designed to produce universally valid information, but information that is valid and useful within the decision making context (Stufflebeam et al, 1971).

The second aspect of evaluation research is summative evaluation, which is carried out with finished products and is designed to determine the effectiveness of the product. In summative evaluation studies, competing products or programs are compared in order to measure their relative effectiveness. This comparison often uses either, the Experimental or the Action Research Methodology. Evaluation is based on the measured replies to a series of questions.

<u>The Formative Evaluation Plan</u>

The term formative evaluation was introduced by Scriven (1967) and originally referred to "the outcome evaluation of an intermediate stage in the development of a teaching instrument." However, Flagg (1990) indicates that its use has been broadened to cover any kind of feedback from target students or experts, that is intended to improve the product during the design, production and initial implementation.

The first aspects of the formative evaluation plan are to identify the purposes of the evaluation, and to identify the target recipients for the information, that is gathered in response to the evaluation questions. Stufflebeam and Webster (1980) reviewed thirteen approaches to educational evaluations in projects, that had differing purposes and objectives. They grouped the formative evaluation studies into four categories :

1. connoisseur based
2. decision oriented
3. objective based
4. public relations inspired

Connoisseur based evaluation studies are where experts in the discipline critically appraise and illuminate the particular merits of an educational product.

Decision oriented evaluation studies gather information from the target users, who could be either learners or teachers, so as to improve the design of a curriculum product. The usual recipients of such information are the design and production team members. The evaluation should help educators make decisions that are in the best interests of meeting students needs. The purpose of the decision oriented studies is to help in the making of strategic design decisions that cover the following issues :

1. the development and implementation of the product planning
2. the content of the product
3. the format of the final product
4. the degree of interactivity involved in the product
5 the pedagogy used in relation to the product.

Schuable (1990) and his researchers used prototypes with the children, who would eventually use the product in its final form. They explored in the evaluation, the comprehensibility and accessibility of the product.

The main advantage of decision oriented studies is that programme design and subsequent revisions in design, can be in part, empirically based. The observation of the users of the prototype product, and the interviews conducted with the users, can provide insights into why a program is working or not working. Evaluators can then map out the program's strengths and weaknesses. Such data aids the decision making process during the design, production and implementation stages. Its purpose is to improve the program and maximise its potential effectiveness.

Objective based evaluation studies, define a set of objectives to be attained by the target students. Formative evaluators carry out objective based studies on pilot programmes, in the appropriate educational settings, they measure student performance on pre-tests and post tests. The objectives are normally behaviourally based. The purpose of such studies is to provide developers with an estimate of how well the final implementation of the programme will achieve its goals. It is also to provide project managers and sponsors with a quantitative assessment of progress. The main difficulties are, the problems associated with the experimental methodology, and the drawing of valid conclusions from a partially completed product. Stufflebeam and Webster (1980) argue that because of these difficulties, if objective based studies are to be of use for programme development, they should be employed with decision oriented studies that provide interpretative information to support revisions in the pilot programmes. The main advantage of the objective based study, is that it can estimate whether the program can really achieve its goals. When carried out with a pilot program, the performance data can help determine whether further revisions are necessary.

The fourth of Stufflebeam and Webster's (1980) evaluation study groupings, are those that are public relations inspired. The purpose of which is to collect data to obtain financial support for a project.

The Structure of Questions for Formative Evaluation

Weiss (1972) gives the traditional form of the summative evaluation question, " To what extent is the curriculum product or curriculum programme succeeding in reaching its goals." Flagg (1990) argues that this question needs to be recast in terms of formative evaluation. As there are different phases in the programme, summative questions for all of the gaols cannot be formed for a pilot. During the development, information is required about specific aspects of the final product, and these may be strategic aspects, which may be transparent in the product. A third aspect of the recasting of the evaluation questions, concerns the target audience and the extent to which valid results can be broadly obtained through working with partially completed products.

Weiss in discussing the problems of evaluation, identifies an issue that is more likely to occur during the development stages than in the final evaluation. This issue focuses on the nature of any unintended outcomes3YThat is, information that can be collected which was not within the initial specific realms of evaluation targets. He considers such outcomes may be grouped into three categories. First, usability, which are the factors that influence the capability of the students to use the product. Second, practicality, which is the time and practical constraints, that might well appear in the application of a product to a normal working environment. The final unintended outcome may the changing nature of the importance of various parts of the product. Different attributes may be identified, which are a key to the successful application of the product. To the list of three unintended outcomes, Flagg (1990) adds uncertainty, and argues that some issues may be uncertain, and if the design is to continue in a structured and planned manner, then evaluation questions need to be formed. These will investigate and derive conclusions so that decisions can be made to remove the uncertainty.

In the devising of a scheme of evaluation questions, the quality of measures associated with the answers to the questions, must be formulated. Flagg (1990) suggests consideration is given to what measures will be used, and under what conditions will the measures be applied. There should also be the identification of which methods of enquiry are most suited to obtaining the information from the evaluation questions.

Anderson, Ball and Murphy (1976) give two parameters for the quality of measures. Validity is the extent to which "the measures adequately reflect and present the domain of interests and that it is not equally or more likely to be a measure of something else". The second measure is reliability, that refers to the extent to which a measure, repeatedly applied to the same person, yields the same results.

Planning Evaluation Activities

The structure and content of evaluation activities require careful planning so that they return the information that is needed at each stage of the project. Walker (1985) and Flagg (1990) both identify a base structure for evaluation questions. Walker's first grouping of questions, addresses the pre-conditions required of a product.

1. what is needed ?
2. who needs it ?
3. how much is needed e.g. the scope of the product ?
4. why is the product needed ?
5. what is the value of product if it could do all it is intended to do ?

The second grouping of questions, focus on the indicators of evaluation. These address the ways in which the information can be established, so as to give a clear indication of the relevant results.

1 what indicators of the intended outcomes are there ?
2. what are the characteristics of the indicators ?
   e.g. diagnosing strengths & weaknesses
3. what are the quality aspects of the outcomes ?
   e.g. validity, reliability, credibility
4. what is the method for searching for side effects ?
5. to what extent are the results generalisable to establish external validity ?

Walker then addresses the need for the evaluation scheme itself, citing the following questions :

1. who wants the evaluation ?
2. for what purposes is the evaluation to be conducted ?
3. what relevant audiences have been identified ?
4. have various influences been identified ?

   e.g. perspectives, resources, potential payoff , potential hazards

The final grouping of Walker's evaluation questions, considers the intended effects of the evaluation.

1. what is the nature of the intended effects ?

   e.g. decision making, improved understanding, conflict resolution, complacency reduction
2. what are the evaluator's judgements ?

   e.g. the implications that can be drawn for the necessary conditions for success of the crucial items in the development
3. what are the side effects, both positive and negative ?

   e.g. what additional knowledge was gained and what further enquiry has been stimulated

Flagg (1990) has drawn together, from the study of a number of educational product developments, a seven point plan for the formative evaluation, that takes place during the development of a product.

1. the purposes of the evaluation activities
   - the type of evaluation questions e.g. decision oriented
   - the overall purpose of the evaluation
2. the recipients of the evaluation
3. the grouping of evaluation questions in terms of :
   - usability
   - practicality

importance

uncertainty

4. the nature and scope of the inquiry in terms of :

    validity

    credibility

    reliability

5. the methods used to collect the information
6. the selection criteria for the audience
7. the setting and the procedures in terms of :

    the activities to be undertaken

    the information collection

The Stages in the Research And Development Methodology

The Research and Development Methodology was originally applied to educational products by the staff of the Teacher Education Programme at the Far West Laboratory for Educational Research and Development. The formalisation of the methodology is given by Borg and Gall (1979). The methodology was used at the Far West Laboratory to develop, and validate, educational products such as textbooks, films, methods of teaching, and ways of organising learning. The Far West Laboratory was one of ten regional laboratories funded by the US Office of Education, to bring about educational improvements.

Variations of the Research and Development Methodology have been applied by many other workers, particularly in the development of educational products based on either television or computers. The Childrens' Television Workshop, Palmer (1983), Young (1983) and TV Ontario Nickerson and Gillis (1979), used the methodology for producing educational television programs. Educational software design companies also applied a variant of the methodology, MECC (1984). The procedures were also used by the interactive videodisc developers, Campbell , Tuttle, Gibbons (1982) and Hofmeister, Engelman, Carnine (1986).

Borg and Gall (1979) and Flagg (1990) have identified from numerous studies, the principal steps in the sequence of activities that make up the methodology. These writers also have identified the evaluation activities that take place at the different stages. Borg and Gall classify ten stages in the methodology that can be mapped into the four main phases identified by Flagg, Figure 3.1.

Borg & Gall	***Borg & Gall***	***Flagg et al***	***Flagg et al***
Stage		*Phase*	
1	Research & Information Collection	1	Planning
2	Planning		
3	Development Preliminary Product	2	Design
4	Preliminary Field Test		
5	Main Product Revision	3	Product Development
6	Main Field Test		
7	Operational Product Revision	4	Implementation
8	Open Field Test		
9	Final Product Revision		
10	Dissemination & Distribution		

Figure 3.1 Stages of the Research and Development Methodology (Borg and Gall 1979)

PHASE ONE (Flagg) - PLANNING

Stage One (Borg and Gall) - Research and Information Collection

This stage commences with the identification of a suitable topic of study. Borg and Gall identify the current state-of-the-art in the identified field of investigation. This includes a background review of literature. Some brief classroom observations may be necessary to fill any identifiable gaps. A state-of-the-art report may be prepared.

Flagg explains that the outcome of the initial planning phases is to form a proposal for the product in general terms. The proposal is in the form of a position paper or pre-design document that typically establishes the feasibility of the product.

Stage Two (Borg and Gall) - Planning

The second stage focuses on the planning of the future activities. It initially concentrates on two activities, defining the skills set, and stating the behavioural objectives for the product. The latter, it is argued, may be initially broad so that they may be reviewed as the project progresses. Flagg takes a largely consistent approach and identifies the further contents of a proposal document, that would include, the outline, the contents of the product, a definition of the target audience, the broad goals for the product, the media of presentation, and the proposed usage.

The evaluation for Stage One, given by Borg and Gall, focuses on any small scale feasibility issues, that are not covered by existing research, or are not available in current literature. Borg and Gall's Stage Two is seen as a development stage based on the information gathered in Stage One.

Flagg bases the Planning Phase evaluation on the facilitation of strategic decision making and calls the evaluation process, needs assessment. Harless (1973) states that, the overall purpose of this evaluation is to obtain data relevant to such questions as :

1. is there a need for the programme ?
2. who needs what content ?
3. what delivery system is feasible to address the need & in what context ?

This type of evaluation has been viewed as the first aspects of formative evaluation, Sanders and Cunningham (1973), Stufflebeam, (1983).

PHASE TWO (Flagg) - DESIGN

Stage Three (Borg and Gall) - Develop Preliminary Product

Stage Three addresses the development of a preliminary form of the product. Sufficient development must be performed so that the product can be put into trials. This may include preparation of instructions, lessons and handbooks. Flagg identifies the first part of this phase as being concerned with planning decisions. Judgements are made as to the specific content and objectives. This part of the phase also includes any specific instructional strategies, such as, the format of presentation and the type of interactivity. This period of the development, builds on the conceptualisation of the planning phase and ends with documents that can be used to guide production.

Stage Four (Borg and Gall) - Preliminary Field Testing

Borg and Gall consider the product is ready for field testing at this stage. A small scale trial of 1 to 3 schools, using 6 to 12 subjects is recommended. The methods of data collection can range from interview and observation to questionnaires. Flagg identifies the data collected during this phase, is part of the formative evaluation, and is used to inform the decision making in the latter parts of the design stage.

PHASE THREE (Flagg) - Production

Stage Five (Borg and Gall) - Main Product Revision

This stage is when the results of the trials from the preliminary field testing are considered and the design of the product is developed. The main core of the product is built. Flagg indicates that the end of the design phase and the beginning point of the production phase is indefinite. She explains that typical design outcomes for educational television, might be preliminary scripts or a writer's notebook. A writers notebook details in practical language, the content, audience characteristics, the programme objectives, and its gives example treatments of objectives. Given such a base, writers can generate complete scripts. For computer based instruction, usually a script or story board is developed with a flow chart, that defines the interactivity of the program. The flowchart at this time may only give general directions without much detail.

Stage Six (Borg and Gall) - Main Field Testing

The main field testing is likely to take place in 5 to 15 schools with between 30 and 100 subjects. Quantitative data on the subjects' pre-course and post course performance are collected. Results are evaluated, with respect to course objectives and are compared with control group data where appropriate. At this stage the evaluation moves towards the more summative evaluation forms, associated with the Experimental or Quasi-experimental methodology. Flagg indicates that the principal point of this phase is to help assure the effectiveness of the program. Formative evaluators gather data to guide revisions using, experimental pieces of the program, scripts, story boards, flowcharts or close approximations to the whole program. The final versions are tested with the target groups and experts for, user friendliness, appeal, comprehensibility, persuasiveness and learning. Such information is considered by the designers, along with other data such as time and money, in order to make decisions about the final design of the program.

PHASE FOUR (Flagg) - Implementation

Stage Seven - Operational Product Revision

Borg and Gall identify that the main work of this stage is to revise the product in respect of the field trials. Provided no major unexpected points arise, the decisions at this stage are of a tactical rather than of a strategic nature.

Stage Eight - Operational Field Testing

The purpose of which is to give a final test to the revised and completed product. The tests will normally take place in the target settings, under a normal operational environment. Data is likely to be collected from between 10 and 30 schools, involving 40 to 200 subjects. Methods of collection will include interviews, observations and questionnaires.

Stage Nine - Final Product Revision

This stage implements the changes that results from the data collected during the Operational field testing.

Stage Ten - Dissemination and Distribution

Borg and Gall's final stage is the production of a report on the product, for professional meetings and journals. It is also to work with the publishers, who will assume commercial distribution responsibilities, so that the dissemination can be provided with quality control.

Flagg considers the principal points of the Phase Four are to, fine tune the material for its educational setting, and to pin-point programme management problems. Within the production of the final revision, it is also necessary to develop any supplemental programme materials such as teachers notes.

Flagg differentiates, at this stage, between formative and summative evaluation. The formative evaluation of the implementation stage, helps to make final decisions about the product and might even contribute to the development of other products, or a later revision of the current product. The summative evaluation, measures the impact of the product on the users. The Experimental Methodology is often used by comparing learners who have been exposed to the product and those that have not.

Methods Of Data Collection

Throughout the Research and Development cycle there are a number of requirements to collect data to inform subsequent decisions. The kind of information necessary for making the design and production decisions varies according to the specific project. There are four methods that have been recognised by workers in the field of formative evaluation :

1. self report
2. observation
3. interviews
4. tests

Self report is where the subjects report their status with respect to the product under test. This is fed back to the recipients of the evaluation, either by form of questionnaire or interview. The advantage of self report is that it is a means of obtaining the user's own perception of the strengths and weaknesses of the product. The self-report method's evident weakness, as a basis for decision making, is that the data collected from each individual is subjective. However, cross checking with both, other subjects, and with other data collected from the subjects, helps to establish the validity and consistency of the findings. A form of self report may also be used to elicit the opinions of the expert, if a connoisseur study is being undertaken.

Owston and Wideman (1987) argue that observation can contribute valuable information about the interaction between the students and the product that connoisseur studies fail to obtain. They go on to state that observation of students working on the product can bring to light technical and design limitations that are not obvious to subject experts or designers. Observation can also provide a more accurate view of the ease of use of the product. By framing the correct evaluation questions, observation can give a clear indication of the suitability of the product in meeting the students' needs. The last of Owston and Wideman's advantages for observation, centre on the need to trap and identify unexpected outcomes. They argue that observation can suggest unique ways in which the software can be utilised. Flagg (1990) suggests that observation can be classified in different ways. Firstly, the observation may be structured or unstructured. Secondly, the observation may be obtrusive or mediated. Structured observation is when predetermined observational goals are set. These will often take the form of frequency counts of various types of behaviours, that might be present in the observed subject or group. The outcome is often a tally chart of the frequency and duration of the behaviours. The purpose of unstructured observation is to furnish an unselective, detailed, continuous description of the interaction between the user and the product. The advantages of evaluating with it are numerous. The frequency of use of functions and the length of time the system was used can be calculated from the record, just as from the structured observation. Even more, the unstructured record, adds a richness to the evaluation that is missing from the structured approach. From a continuous narrative of unstructured evaluation, conclusions can be drawn about :

1. the sequential relationships about system features
2. the linking of the behaviours with the situation
3. the inference of the user's attitude towards the system's responsiveness and flexibility
4. the changes in attitude throughout
5. the identification of accessibility problems

In addition any unintended effects of the system are best detected through unstructured observation. Rich qualitative observations are able to help the quantitative summary statistics, because the unstructured approach, lets the observer be open to diverse phenomena. The categories that result from this method might be different from those determined a priori.

Obtrusive observation is when the researcher has a direct interaction with the subjects and their relationships with the product. Mediated observation is when there is a method of recording the observation, so that examination may take place at a later period, thus allowing different parameters of the processes to be reviewed. Video recording of the subject interaction with the product is a common method for mediated observation. Where computers are the basis for the product, then it is possible to record the students reactions to the product in the form of a log of activities. "On line monitoring is the process of capturing characteristics of the human computer interaction automatically, in real time, from the operating system" Borgman (1986). Researchers have found on line monitoring useful in determining which parts of the program were being visited most frequently (Hawkins, Bosworth, Chewning, Day and Gustafson (1986). The computer logs produced can be classified into groups of transactional data such as :

1. which segments of the product were accessed and in what sequence
2. which commands were used and what decisions were made in response to which queries
3. what performance was achieved in task and test situations
4. which error messages appeared

The third method for the collection of data for formative evaluation is the interview. Interviews may range in form, from structured to unstructured, with an intermediary semi-structured type. Fully structured interviews comprise of a list of pre-specified questions from which there is no deviation. In an unstructured interview, there is a general plan, but there are no specific questions identified before the interviews starts. In a semi- structured interview, the evaluator begins with closed or open questions and then probes for further explanation, depending on the answers given.

The purpose of interviews as a method of evaluating, is to obtain a clear understanding of user problems with a program and the possible reasons for these problems. The main advantage of the interviews is their adaptability. Initial questions can be followed up with questions that lead to further clarification and more depth of information.

The final method of collecting data is the test. Tests may be formal or informal. The formal test, when used, is specifically targeted and time constrained. The informal test may attempt to collect relevant information, by the questioning of students through such activities as exercises or workable case studies.

Prototypes

Throughout the Research and Development sequence, there are a number of points at which evaluation takes place with a partially completed product. These partially completed products are referred to as prototypes. Wilson and Tally (1990) consider prototypes important because they enable design evaluation. Flagg (1990) states that prototyping tools should be used for increasing the effectiveness of formative evaluation. Testing early prototypes, however, does not obviate the need to evaluate a program in its final environment.

Flagg (1990) suggests that prototypes are not normally sufficiently complete for students to attain the intended outcome objectives. So evaluation, instead of measuring learning achievement, gives a clearer indication of a user's engagement with the materials. Flagg concedes that such a research approach has its weaknesses, but argues, from the commonsense assumption, that engaging material can provide a necessary foundation for the eventual achievement of the cognitive or affective objectives of the product. Engaging materials is defined as that which is appealing, accessible, comprehensible and credible.

Schuable (1990) suggests that prototypes may be fashioned for the express purpose of performing research with children, and for providing the team with a feeling of what it will be like to use the completed program. Research prototypes are quick, dirty, stripped down versions of the product, and they are most typically used to ascertain the user's ability to interact with the product. Schuable adds research prototypes are usually written quickly in a high level language and thus sacrifice some elements of the final program. For example, the ability to portray graphic objects moving swiftly and smoothly on the screen. Because prototypes hardly ever include sophisticated art work or sound, they are better used for exploring the child's ability to comprehend and interact with the activity, rather than exploring the appeal of the final software program. Research prototypes are valuable, not only because they permit field researchers to address specific design questions, but for two other reasons. First, the prototype acts as a focus of communication for members of the design team. And secondly, the prototype is an important stimulus in the design process. It is easier to imagine enhancements, improvements, and additions to the program, when there is some experience in using a primitive version of it.

Rockman (1990) sees two principal reasons for the importance of evaluating the prototype. First, it takes steps towards the product becoming technically perfect and it allows the removal of syntactic and semantic errors. It gives an opportunity to test out different methods of routing through a program. The second direction of evaluation can consider the instructional component. For example, does the prototype meet its instructional objectives in the manner in which it was designed to achieve them.

PART TWO - THE ADAPTATION OF THE RESEARCH AND DEVELOPMENT METHODOLOGY

Introduction

"Although major Research and Development projects are beyond the capabilities and resources of a single researcher, there are useful contributions that can be made. That is, small scale or limited scope projects, may be undertaken by an individual ", Borg and Gall (1979). Each of the projects that have used the Research and Development Methodology have adapted it to fit the nature of the product and the target audiences.

Borg and Gall (1979) used the methodology to development a 'mini-course' for teacher education. Each course involved about 15 hours of teacher training in the pre-service or in-service setting. The project covered a specific number of classroom skills, that were first described, and then illustrated in an instructional film. The trainee would then see the skills demonstrated in a 'model film' with an experienced teacher. The trainee then developed a short lesson to illustrate the skills and then would teach a small group of students. The lesson is recorded on video-tape, for an analysis of the trainee's lesson. Borg and Gall's ten stage cycle was used to develop the teaching materials.

A variant of the methodology was used for the development and formative evaluation of 'Scoop', which was a teletext magazine for High School students, Crane and Callahan (1990). Jolliffe (1990), working with interactive video, used the methodology to formatively evaluate the development of new products. A second project, Palenque, based on interactive video technology, was developed by Wilson and Tally (1990). The primary goals of which, were to create an interactive optical disc prototype for children to use with their families at home.

The methodology was also used by the Agency for Instructional Technology. The project was a cooperative development process, that worked with a consortium of state schools, to create television projects that no single body could afford to finance.

The projects were targeted at elementary and secondary school materials, Rockman (1990).

The Adaptation of the Methodology to this Research

In following the proposal of Borg and Gall (1979), that a single researcher project should be restricted in scope and size, this adaptation is applied to the initial four stages of the Borg and Gall model or the initial two phases of the Flagg model. The end result of this research, is a design proposal, that could be developed into a final version of the product. The steps identified in the adaptation of the Research and Development Methodology are shown in Figure 3.2

Step One Current Review and Information Search

Borg and Gall (1979) identify, that in this part of the methodology, emphasis is placed on identifying the current state-of-the-art, that includes a review of literature and defining the area of investigation. Step One of the adaptation includes

- the purpose of the product
- a review of the classroom use of computers
- the scope and content to be covered by the product
- the critical design issues
- the educational value of the product

Step Two - Identification of Needs

This step establishes a need for the product and considers its possible uses. Step Two includes:

- the target audience
- the relationship between the target audience and the content
- the setting for the use of the product

Step Three - The Identification of the Software Tools

In order to develop a computer based modelling product there is a requirement to review the possible software tools that could contribute to the development of the product. This step considers the tools that are currently available in the classroom and considers other software tools, currently in use in non-educational areas. The structure of Step Three is :

- software tools available in the classroom
- software tools generally available
- possible tools for the product

This Research	This Research	Borg & Gall	Borg & Gall	Flagg et al	Flagg et al
Step One	Current Review & Information Search	Stage One	Research & Information Collection	Phase 1	Planning
Step Two	Identification of Needs				
Step Three	Identification of S/W Tools				
Step Four	Data Collection				
Step Five	Generation of Themes & Geographical Ideas	Stage Two	Planning		
Step Six	Evaluation of Themes & Selection of Prototype				
Step Seven	Data Collection				
Step Eight	Consolidation of Design	Stage Three	Develop Preliminary Product	Phase 2	Design
Step Nine	Prototype Methods and Contents				
Step Ten	Data Collection	Stage Four	Preliminary Field Test		
Step Eleven	Production of Proposal for Final Product				

Adaptation of the Research and Development Methodology Figure 3.2

Step Four - Data Collection : Interviews with Target Audience

Borg and Gall (1979) identify the need to fill the gaps in knowledge that may be evident in the first stage of the methodology. The use of a model tool and the student's comprehension of models, was a gap that was identified. This step is based on interviews following the use of simulation software and an open modelling tool. The transcripts, for which, are in Appendices Three and Four respectively.

Step Five - The Generation of Themes and Ideas

This step follows, what Schuable (1990) was later to describe as, the brain-storming approach. The step shows the development of the themes and ideas for modelling, which then act as a basis for selective evaluation and refinement. The attempt in this step was to produce a host of ideas for consideration and selection. Schuable (1990) succinctly describes this step as " Once the product point of view has been formulated and the needs assessment and content research is complete, then the production team is responsible for generating or finding viable concepts for individual programs. It is routine to pursue more than thirty ideas to find one feasible topic. During the process, formative researchers serve as a content resource for the team , identifying literature, resources and expert consultants. Although field research is not usually a standard part of the brain-storming process, a researcher may try out an existing program or idea with children, if there is a serious question about the promise of an approach, that is under consideration by the group. The brain-storming approach culminates in the selection of a limited number of specific concepts for computer programs." Examples of the four themes that were developed, by the author, are given in Appendices Three to Six.

The final part of Step Five summarises the four main themes and identifies the similarities and differences between the development of modelling ideas.

Step Six - Evaluation of the Themes and Selection of a Prototype

The themes developed in Step Five are reviewed and an area is identified for a classroom trial. The evaluation was based on :

- the viewing of the internal structure of models
- the range of geographical models
- the developmental complexity of a computer system

Step Seven - Data Collection with a Target Audience

The prototype developed in Step Six was tested with a class of students who represented a typical target audience for the product. A two fold method of data collection was employed. A video was made of the lesson so as to evaluate the reactions of the students to modelling. The video is enclosed in Volume Two. The second form of data collection was the modelling work completed by the students on the computer. The latter is presented in Appendix Seven.

Step Eight - Consolidation of the Design

The data collected from the previous steps, together with the design evaluations of the various themes that were brain-stormed, is reviewed and a description of a final prototype is devised.

Step Nine - Prototype Methods and Content

This step describes the outline structure of the final prototype, by illustrating the geographical content that has been defined for a classroom trial. The prototype examples are described in Appendix Eight.

Step Ten - Data Collection : Prototype with Target Audience

This step describes the data collected from a target audience of students using the prototype. The data collected is in the form of a computer log, and is recorded in Appendix Nine. A second form of data collection are the answers to an informal questionnaire, that sought the opinions of the students towards computer based modelling. The questionnaire responses are given in Appendix Ten.

Step Eleven - Production of Proposal For the Final Product

This step draws together the work completed so far and identifies the structure and contents of the proposed product. Schuable (1990) identifies the activities of this step, " The design phase particularises the proposal of the planning phases and ends with a design document which is used to guide the final production. During this period, decisions are made specifying the content, defining the learner outcomes, and delineating presentational strategies. The amount of detail and specification in design documents, depends on the type and size of the project, and the organisation of the team personnel. There are currently few standard formats for computer based design documents and each organisation and project develops what is appropriate for its working needs. "

Wilson and Tally (1990) identify four components associated with the deriving of a specification for the final product. The components are

- accessibility
- responsiveness
- flexibility
- memory

The four components are behavioural qualities. They argue that formative evaluation serves to optimise these features in the user interface and permit students to concentrate on learning content, rather than learning to operate the system.

The Formative Evaluation Model for Data Collection

In several of the steps of this research, data is collected for the purposes of reviewing and informing progress in the development of the new product. A formative evaluation model is adopted, and has been modified from a combination of Walker (1985) and Flagg (1990). The evaluation is based on five sections.

- Evaluation Premises

  The evaluation premises have five components. The purpose, describes the broad reason for conducting the data collection. The evaluation type, describes specific types of evaluation from Stufflebeam and Webster's (1980) fourfold classification. The evaluation indicators, identify the typical types of outcomes expected and further describe the validity and reliability of the indicators. The final two components of the evaluation premises are the manner in which any side effects will be detected and the external validity of the data collected.

- The Need for Evaluation

  This section considers both the target of the evaluation results and gives the specific objectives for requiring the results.

- The Method

  The method indicates the format of the data collection and describes the settings and procedures under which the data was collected.

- Data Collected in Response to Evaluation Questions

  This section gives the data collected from the students and is classified according to the objectives stated in the Method Section.

- Comments about the Collected Data

  This section contains brief comments with regard to the data collection.

CHAPTER FOUR - DATA COLLECTION

STEP ONE - CURRENT REVIEW AND INFORMATION SEARCH

Purpose of the Product

The purpose of the product is to enable students, in upper secondary school geography classes, to create and modify computer based models across a range of geographical areas.

Review of Current Classroom use of Computers

At the commencement of the research the current classroom use of computers, in upper school geography classrooms, is summarised by Kent (1982). Grummit (1983) reviewed the use Computer Assisted Learning (CAL) in the Sixth Form.

Kent (1982) used the work of Shepherd et al (1980) to describe the use of CAL at the time. His description is based on a four fold classification of the students' use of computers. Within the teacher substitute mode, Kent identifies HURKLE as a drill and practice program, with a similarly based tutorial program being PLATO. The second part of the classification is, the data exploration mode, which includes computer mapping, using SYMAP, a spatial analysis program, NEIGH, and an information retrieval program, QUERY. Statistical analysis is also part of this group and is represented by the non-spatial analysis program, CORR. Within the third category, computer simulations, Kent identifies three typical examples in use. First, a descriptive simulation, RUNOFF, secondly a prescriptive simulation, LIMITS, and finally a game based program, POVERTY. The fourth division of the student centred learning classification, suggests that students could write their own programs. Within the smaller teacher centred CAL, the electronic blackboard, DEWDROP, was identified, as were glass box programs.

Kent (1982) further indicates that hardware was becoming more available to schools, with many school geography departments having access to either a RM 380Z or a BBC computer. Kent also suggested that software development was relatively rapid at the time, with a notable development being a group of eight programs that formed a Geography Package from the Computers in the Curriculum Project. There were also other program developments, some from funded projects such as ITMA, with the program TRANSPOTS, and others directly from publishers, for example, CLIMATE.

Grummit (1983) reviews the software development for the Schools Council Computers in the Curriculum Project and the Geography 16-19 Project. He describes four programs that had been developed for use in Sixth Form Geography lessons. GROWTH simulates the growth of an urban settlement, based on a small market town, from 1901-1981, for which future development patterns can be predicted. The program enables rapid processing of statistical data, which is presented in a spatial form, covering a variety of sequences of urban growth. Various input factors may be modified and adjusted to explore different possible projections. WELFARE is a program designed to facilitate the study of urban social deprivation. It encourages the student to identify criteria which could be the indicators that could contribute to a definition of urban deprivation. The processing of the students' selections, from a range of alternatives, is performed using cumulative rank scores, that are then compared against a Department of the Environment set of references. The correlation coefficient, and the graphing of the results, compares the representation from the program with the students' inputs.

MINE is a simulation of the exploration and exploitation of metallic minerals resources in a Third World Country. The program is intended to enable the student to consolidate knowledge of some of the problems with such developments. It is a competitive game with a variety of inputs to manipulate. PUDDLE simulates the movement and storage of rain water on a small area of the ground. Flows of water and changes in storage, are shown by an annotated flow diagram, and the water balance is given as a summary, at the end of the simulation. Students can use PUDDLE to simulate a system, that is difficult to study in the field. They can select the rainfall intensity and other factors, such as season, duration, rate of infiltration, and percolation. They can then observe the dynamic response of the system. Instructions are given for changing the inputs to the model. The model may also be accessed directly through the BASIC program.

The Scope of Content to be Covered in the Product

The scope of the content of the product, that is to be specified in this research, may be defined in two ways. The scope of the geographical content, will be to cover any dynamic or decision making system within the subject. The product will be applicable to all geographical concepts, to which a system or decision making process can be formed. Thus specific geographical objectives will be :

1. to have the facility to create a wide range of geographical examples
2. to have the facility for the student to create and amend dynamic or decision based models of geographical processes

The second aspect of the scope of the content focuses on the pedagogic issues. The modelling environment will have the facility to separate, the way in which a problem is represented, from the manner in which conclusions may be drawn from it. The product will also give clear access to the structure of the model, that is either being created or amended. Both textual and numerical reasoning will be present, thus allowing the student to experiment with 'approximate' descriptive models. For all types of models the ability to 'run' it in simulation mode will be included within the scope of the project.

Thus the pedagogical objectives relating to the content of the product will be to:

1. separate the representation and inference methods
2. use text and numerical reasoning
3. run models in simulation mode

The Critical Design Issues

Critical issues in the design are, all those factors that must be completely met if the product is to be deemed a success, Gilb (1988). Part of the work of the initial stages of this research are to identify and quantify these critical issues. Based on the initial information search and current review, the first draft of the issues that can be identified to be critical to the successful design of the system are :

1. The model whether created, or supplied to the student for amendment, must be visible to them in a form which allows the creation, amendment and adjustment of all aspects of the model.

2. The representation method or methods for the model must be able to be used in a variety of different areas of geography, with the minimum of distraction caused by the student having to manipulate the working environment. That is, the focus of the students' work should be on problem solving in geography and not on programming or computer functioning activities.

3. The method of representation on the computer should be directly aligned to the systems approach, so that the analysis of geographical problems allows the techniques of systems analysis to be employed by the students, in order to be able to construct model structures.

4. The modelling environment must be able to give a sufficiently accurate representation of the real world. That is, if the model is constructed by an 'expert', in the discipline, the structure and simulation of that model should give sufficient insight into the geographical issues to be of value to the student at that level of geography.

5. The modelling environment, as a result of process modelling, should be capable of displaying the results appropriately. This will include, the ability to portray decision making, spatial analysis, and a series of numerical outputs in graph form.

6. The use of the modelling environment by the student should have perceived value to them in assisting them with their studies of geographical phenomena.

The structure and focusing of the above critical issues will be addressed as the design progresses. This will allow the final proposal for the design, the end point of this research, to be stated in closed and specific design objectives which are critical to the success of the project.

Value of the Product

If the product is completed, so that it fulfils the critical issues identified, then the value of the product may be viewed in three principal ways. First, the creating and amendment of the student models, may help both teachers and learners to recognise each others' model and facilitate interaction and discussion of learning outcomes. Second, the development of external models, from the students' mental models of the processes they are investigating, will allow their perception of geographical areas to be expressed and shared. Finally, the modelling environment and particularly the simulation part, will allow the students to test the models, both against their own perception and against any external data. This will permit self-reflection and self-correction in the learning process.

STEP TWO - IDENTIFICATION OF NEEDS

Target Audience

The target audience for this product is the upper school geography classes in the final years of education. Typically the students will be following either, the latter stages of the GCSE level geography courses, or will more likely be following 'A' or 'AS' level geography courses. The modelling system is not restricted to either, one syllabus, or one particular approach to geography.

Relationship between the Target Audience and the Content

The target audience will be all geography students and therefore a geographical knowledge up to the first stages of GCSE level will be assumed. Furthermore, the modelling system will be available to all geography students regardless of their previous experience in computing. The product will be targeted at those who have not necessarily used computers, either within or outside geography lessons.

Setting for the Use of the Product

The product will be designed so that it can be used within the normal classroom setting of geography lessons. It will offer an additional tool to the teacher to facilitate the explanation of geographical concepts. The amendment and creation of models will be possible within the timescales that could reasonably be considered desirable within the teaching of an examination syllabus in a normal school.

STEP THREE - THE IDENTIFICATION OF SOFTWARE TOOLS

Software Tools Available for Use in the Classroom

In addition to the software written for dedicated use in Geography, Kent (1982), indicates that 'content free software' was becoming more widely available. There were three principal types of this style of software, that were being increasingly used in schools. Word processors, such as WORDWISE and VIEW could input, manipulate and print textual information. Spreadsheets such as VIEWSHEET, could input numerical information and manipulate it on a cell by cell basis. The database was the third form of content-free software and allowed the input, storage and selective retrieval of records of information. An example of a database is QUEST.

Educational justifications for the direct use of the computer language LOGO has been advocated by Papert (1980) and was often used in schools especially the turtle graphics subset of LOGO. Ennals (1983) indicated that PROLOG could be directly used in History teaching.

The Dynamic Modelling System (DMS) is a program developed for the use of 'A' level Physics students. A model of a process in Physics is created, using a small subset of the programming language BASIC. The model is then entered in the DMS. The statements that constitute the model are then constantly repeated and produce varying values and graphical outputs.

Software Tools Generally Available

The Japanese Fifth Generation Computing concept ICOT (1980) had identified the development of knowledge bases. These may be defined as " a collection of simple facts and general rules representing some universe of discourse ", Frost (1986). A subset of knowledge bases was identified for development in the UK by the Alvey Report (1982), and these were called Expert Systems. An Expert System may be defined as " a program that is apparently intelligent and provides a lot of high-quality, specific knowledge about some problem domain", Waterman (1986). One common method for encoding the knowledge of the expert is a series of rules.

Rules take the form of :

IF < condition > THEN <perform action>

This style of rule based representation of expert knowledge is therefore independent of the context to which it is applied. This gave rise to several products called Expert Systems Shells, that contained the three components of expert systems, identified by Addis (1987), namely :

1. a subject domain of facts and principles or rules
2. the skill and ability in knowing when to apply the rules
3. a deductive mechanism in the rules

The expert system shells make explicit to the user the facility to enter the facts and rules of the domain. However, parts two and three are built into the system and are therefore transparent to the user.

Possible Tools for Product

The investigation of background information identified the need for a representation that could deal with both procedural and declarative models. The system would also require some form of inference mechanism to draw conclusions, and furthermore, it should be able to represent results in different forms. Therefore, several tools were identified that had differing strengths, in either the declarative or procedural methods, for representing models. Three tools were chosen for initial investigation as they had the suitability for constructing geographical models. The initial judgements were as follows.

Word processing tools could only contain descriptive material and allowed no processing or inference structure and so were eliminated. Databases could hold structured data, but had no internal inference mechanism for drawing conclusions, and therefore were excluded, although their data structuring methods could be useful for parts of certain types of models.

The direct use of either BASIC or LOGO was also excluded, as both mix the representation methods and the inference methods. This would make for a greater complexity of model creation, and could well distract from the geographical analysis. This would cause the focus of students' attention to be placed on the computer manipulation aspects. However, the Dynamic Modelling System, uses as a representation a subset of BASIC. It includes a transparent inference mechanism, based on iteration around the model, and it can display outputs in different forms. Its strength is the manipulation of models that are procedural in form.

A spreadsheet can hold models in a broadly declarative form, and has a numerical inference built into the method of re-calculation of the cells. Outputs would be numerical values, although there were some limited graphing possibilities.

Prolog could offer the database form of structuring facts and could also take rules in the form of conditional statements. The underlying resolution principle also gave a mechanism for reaching conclusions from the facts and rules. The output would be principally textual in form. Prolog offered the advantage over the other two methods in that the input rules and outputs, could be expressed in words rather than the numerical values of both the DMS and spreadsheets. Prolog, whilst designed principally for declarative use, could to a limited extent, run procedural models.

STEP FOUR - DATA COLLECTION : INTERVIEWS WITH TARGET AUDIENCE

Introduction

In addition to the collection of information from documented sources, two areas were identified where the target audience could supply some information that could shape the type of design. First, in regard to the experience of a normal 'A' level class in the use of a systems approach to the simulation of a geographical concept. An 'A' level geography class had used the package PUDDLE in the course of normal lessons. Information was then required as to whether there was broad recollection of the contents, structure and usefulness of the program. The second phase of this initial information collection from the students, focused on the use of the Dynamic Modelling System for the creation of a geography model. In this early stage, the principal information sought being the understanding of the idea of a model within the context of geography.

The two sets of interviews were undertaken with 'A' level Geography students. The first focusing on lessons undertaken three months previously on the software package, PUDDLE. The transcripts for the PUDDLE interviews are given in Appendix One. The second interview based upon work that had just been completed. The transcripts for the DMS interviews are given in Appendix Two.

The interviews took place at the end of a summer term when the students had completed the first year of a two year 'A' level course. They were studying the 16-19 Geography Project syllabus. All the students were aged 17 and had previously passed the 'O' level Geography examination.

The five students attended an 11-18 Comprehensive school in an outer London borough, which retained two single sex grammar schools. The first year of the 'A' level syllabus had been taught for four periods per week each of 70 minutes. The two teachers who ran the course had five and ten years experience of teaching 'A' level Geography.

The students had varying experiences of using computers. Two of them had passed 'O' level Computer Studies, one of whom was studying 'A' level Computer Science. The remainder of the students had limited experience of computers confined to very occasional use of the school computers in lessons.

The same independent interviewer, David Riley, was used in both cases. He was an experienced geography teacher, with a very broad range of expertise in modelling software and a detailed knowledge of the PUDDLE program. The interviews were recorded on cassette and subsequently transcribed in Appendix One.

The PUDDLE Interviews

1. Evaluation Premises

a. purpose : The broad goal of the interviews was to establish if the students had retained a view of the purpose, function and structure of the software package, PUDDLE.

b. type : The evaluation type is decision oriented , that is the information collected would be for the purpose of informing the decision making process in the next phase of the design process.

c. indicators : Typical indicators of the evaluation outcomes would be statements within the interviews that confirmed or refuted the understanding of the materials suggested in the questions.

The characteristics of the indicators would give the strengths and weaknesses of the approach to the software and the possible identification of any critical success or failure issues.

The validity of the indicators would be checked by, the subsequent questioning within the interviews, and by the comparing of the information gained from the interviews with the other students. Cross checking of some items between the interviews for PUDDLE and DMS could also help to establish the validity of the conclusions.

The reliability of the indicators is not a crucial aspect in that the information to be collected is informative in its nature. The students are being asked to consider subjective reflection and therefore the results cannot be regarded as more than informative indicators that could require further investigation. However, the information could highlight significant features that could supply reliable information if the issues were raised across all interviews. An important factor that is being targeted for collection, in this initial phase, is the credibility of the materials for assisting the students to complete their 'A' level geography work. The motivation to use the program, in a serious manner for study, will be a clear reflection of their subjective perception.

d. side effects : As the information collection was to be at a very early stage in the development cycle, semi-structured interviews based on open questions would be used. Several general themes would be followed by the interviewer but specific issues could be pursued dependent on the student's replies.

e. external validity : The formative evaluation at this early stage does not lead to external validity and the results cannot be validly generalised beyond the development context within which they are posed.

2. The Need for Evaluation

a. the target and purpose of the evaluation results : The results are required in order to make decisions about the structure and contents of the initial ideas for the development of the modelling environment.

b. the specific objectives for requiring the results :

1. To determine the students' level of understanding of the geographical concepts inherent in PUDDLE.
2. To determine whether the students perceive any value in using PUDDLE as a part of their 'A' level course.
3. To ascertain the reaction of the students to the interface.
4. To elicit the students' perception of the modelling and simulations.
5. To establish whether the students could foresee the possible transfer of the structure of the software model to other academic areas.

3. Methods

a. format : Each student in the group was individually interviewed. The independent interviewer conducted open interviews with questions structured to elicit information concerning the five objectives.

b setting and procedures : During the Spring Term various computer based packages had been used in Geography 'A' level lessons. The program PUDDLE was used for approximately six hours of lessons in late March, about two months previous to the interviews. There was one BBC computer available in the lessons. Initially the whole group watched a demonstration by the teacher with subsequent work on the computer being completed in pairs. The computer based work was supplemented by other written exercises. The students were initially asked to explore the software, and by experimentation, to attempt to gain an understanding of the workings of the program. Teacher support was available to facilitate this process. Once the teacher established that each pairing had gained an understanding of the operation of the software the students were encouraged to develop hypotheses and to test them.

4. Data Collected in Response to the Evaluation Questions

The transcripts of the interviews are given in Appendix One.

Objective One : To determine the students' level of understanding of the geographical concepts inherent in Puddle.

An informal measure of the understanding of the geographical concepts of PUDDLE is through the recollection of the students as to its purpose and main features. The nature of the aspects the students could remember after two months, could be a contributory factor in assessing the worth of using computer based modelling tools. Helen remembered (H1) the notion of the variable parameters of the system. " I remember that we had a puddle and you could vary the weather conditions. Like you could snow, rain and you could vary the evaporation rate and you let it rain for an hour and let all the weather conditions occur for an hour. And afterwards you'd see how much had gone into the ground, and gone into the puddle, overflowed or was saturated into the ground, and you could read off the levels and read off the water table ".

Andrew also focused on the nature of the parameters, (A1) " The program was mainly about the hydrological cycle, where the water was evaporating, I think after an hour certain measurements were taken, the depth of water after precipitation and we could change certain aspects of it. We could change the amount of rainfall, the amount of sunshine, change the hour, and the evapotranspiration ".

Minesh (MN1-2) remembered, with a little prompting, both the aspects concerning the parameters and also the sequence of activities that had to be followed. " I remember there is rainfall, evapotranspiration rates, and then there are various rates, soil moisture, puddle, vegetation, surface runoff ". For the sequence of activities he recalled " we set various types of area which we used, if it was autumn that would determine how much rainfall like, heavy, light drizzle and so forth. And then you'd get the various rates of flow, water outputs such as high percentage of surface runoff, the vegetation got a lot of water and how much the puddle could hold. And then how much will go from the puddle into the soil moisture and into the ground level, which will subsequently go deep down right into the ground moisture and then runoff into the earth ".

Martin, however, had more difficulty in recollecting the structure of the program and could only recall one particular problem (MA9) " ...you could extend the amount of evaporation but couldn't extend the amount of rainfall ".

Jennifer could remember (J2) " that the rain was infiltrated through various, through the soil, vegetation and how it was output through various things and that you did not know what kind of vegetation you were on ". However, she could not focus on the relationship between the parameters.

Objective Two : To determine whether the students' perceive any value in using PUDDLE as a part of their 'A' level course.

Andrew commented that the computer was 'quite useful' for geography lessons (A4), and that it was worthwhile taking the time to learn how to use a program (A6). He also saw that it could contribute to future examinations by giving (A8) " a better understanding to, the way things, the processes that go on ". He added (A11) "you've got certain things that stick in your mind, little arrows pointing upwards or whatever". With specific reference to PUDDLE, Andrew considered that the program was sufficiently flexible to meet his needs. Minesh's reaction to the program was that it was "a bit of fun".

Objective Three : To ascertain the reaction of the students to the interface.

An important facet in the understanding of a computer simulation, such as PUDDLE, is the ability to correctly interpret the diagrams that appear on the screen. The students were aided in their recall by printed versions of the PUDDLE screens. The interviewer asked the students to explain the screen. Helen (H19) " Well it starts off at the very top where you have the rain and 5% of the rain has gone into the vegetation, but the rest is going into the puddle. Out of the vegetation and the puddle it splits up into various sections, and it shows you how most of its gone into the soil, and the rest of it seeps right down into the ground".

Minesh, (MN23) stated that he would group the screen into " three forms, inputs, the store and then the output. Stores, of course, would be the vegetation and the puddle. Whereas the output would be the runoffs, the various runoffs down the graph and then, of course, the input would be the rain ". The interviewer introduced a diagram with transfers between stores and asked Minesh how the transfer would fit into his classification. Minesh admitted the problem and went on to say, (MN26) " I'd say that would be a transfer, I suppose there'd be another stage really, transferring stage, where it's neither really, it's inputting into there and it's also an output of there..... you could always call it another stage like the transferring stage. From one store to the other store ".

The interviewer asked Martin as to whether he had immediately understood the box diagram, and he replied (MA28). " No, I got mixed up between the soil and ground. I though it was the same thing, so I thought what's it going into the ground for, if it's already there". The interviewer then asked Martin to explain the vegetation box, (MA29). He replied " I'd explain it in terms of a jungle or something, saying the vegetation, you've got all the trees, puddle is a pool on the ground ". Martin later showed that he had also confused base flow and overland flow (MA39-40).

The questioning then began to focus on the numerical values that were on the screen and to ascertain whether Helen has understood their significance. (H22) " Well, first of all I couldn't take in all of the figures, it was a bit much. You just looked at it and thought *'Oh, what's all this'* So you are just looking at the actual movement and then we sort of broke it down into stages. You realised, as you took the figures in, it made more sense to you then. You could see what was going on ". The interviewer, sensing possible 'information overload' with the screen, asked Helen if it could be improved. She replied (H23) " I can't really see how it could be improved. I think it is quite well displayed as it is. Quite readable ".

Minesh was also asked about the layout of the screen, (MN12). " It was great, it was all laid out, so all you has to do was to really look at it. The arrows pointed whether there was any transfer or not from one source to another ".

Minesh was asked about the summary table, within PUDDLE, and what information it conveyed, (MN2). " Well, I thought the last one, right at the end there was a big table of figures and that was very complex. When I saw it , it was very complex and it wasn't, didn't look right but I suppose that it was right and if I figured it out, but it looked a bit complex to read off, straight off. Because I think it said various rate of infiltration and the porosity of the ground. And there was the other thing, of taking everything into account it was, I can't remember, that very vague ".

The representation of many models and simulations over a period of time is displayed through graphs. The interviewer therefore tackled the understanding and interpretation of the complex graphs that are produced as part of the PUDDLE program. Helen was asked to describe the circumstances that produced a particular graph, which showed a storm in spring, (H29). "Well, the first six minutes seems to have flooded all the vegetation, and its all, and it can't take any, well its taken it all, up to about 45 minutes and after that it's the same level and then it's gradually starting to seep into the ground and after that its stopped, it gets a chance to sink in, otherwise it just stays there, it can't do anything ".

Andrew gave a clear indication that he understood the significance of the graph lines, (A22-34).

Minesh interpreted the spring storm graph as (MN44) " the first amount usually goes straight into the grass and other vegetation. It holds it, and after a while because the plants obviously need it , they need the water and they go straight into the roots. A lot of it is held in the plants, in the nooks and crannies, the shape of the plant usually holds it and then after a while it does seep through ". On being asked about the distinctive part of the shape of the curve, Minesh replied (MN45) " The levels are constant they cannot take anymore without losing any and so its reached its maximum store, and then after reaching it's maximum store it just gives up because of some biological event. And it's just lost by the crevices of the ground and all the different types of pressure which force the water out of the plants and into the soil. There is an increase into the storage in the plants and then it level off again into the soil and a certain amount is kept in plants ".

Jennifer had stated that she preferred to work with graphs rather than flow diagrams (J23). She responded to the spring graph in the following manner, (J26). "Vegetation was very low at the start of the storm, must be because of the weather, because it's spring it's very light. When the storm started within about twelve minutes, eighteen minutes or so to rise considerably to maximum store contents and after coming up for almost an hour it dropped, and after then time it started to go down to what it's original level was but only got down to 50% in two hours".

Objective Four : to elicit the students' perception of the modelling and simulation

In response to the questions ' What is a model ? '. Helen replied " It's a way of putting theories that you learnt. You put them into practice and see how they work. It is a way of proving that theories do work. Or whether if you can prove them wrong, and how you could vary them. And you can learn what various inputs can change and what are the outputs ". She confirmed that she conceived models in terms of inputs and outputs, (H6). She was consistent in her view, when at the end of the interview she was again asked the question 'what is a model'. She replied (H73)," it's an example of how a theory can work ".

Objective Five : To establish whether the students could foresee the possible transfer of the structure of the software model to other academic areas.

The interviewer wished to investigate whether, PUDDLE's 'way of looking at things' could be used in other subject areas. Helen answered (H59), " It could be used in Biology .... used as a study of plants and that. It would not be of any use in English ". "(H60) ...blood, how much nutrient it intakes and the waste products from the body and things like that... various organs that they need ".

Andrew, in response to whether the idea could be used in other areas of Geography, replied (A14) " well we do use a similar sort of program. Got some on industry, where we can change environment and change landscapes ". (A55) " probably to marketing where you've got raw materials going from one place and then they have got to go to the market". (A53) The manufacturing model " would have to be other factors involved such as the cost over distance".

Minesh (MN18-19) attempted to identify an oil model for economic geography.

5. Comments about the Collected Data

Objective One : The manipulation of the parameters seemed to be the most significant feature that was remembered by the students. There was a definite weakness, in the students' recall of the overall purpose of the program, and in their recognising the principles of the underlying model.

Issues to be Addressed during Design : Clarity must be established between the idea of the manipulation of the interface parameters and structure, and possible adjustment of the underlying model.

Objective Two : The feedback about the program was positive and that the activities performed with it were deemed worthwhile.

Issues to be Addressed during Design : PUDDLE presents a strongly interactive interface to the student and this level of inter-activity needs to be maintained. The worthwhile nature of the activity focuses on the geographical topic being a principal feature of the geography syllabus that the students were studying.

Objective Three : The flow diagrams, with the boxes, caused a certain amount of difficulty, principally in terms of the meaning of the labels and in the use of the numerical values. However, the students confirmed, that as they worked with the program, the layout became clearer and more significant. The summary statistical table did, however, not facilitate either, ease of use or the recall of principles.

Issues to be Addressed during Design : Unfamiliar diagraming styles need to be introduced and handled with caution. The immediate impact of a screen full of information could cause a drop in motivation.

Objective Four : The students demonstrated only a weak perception of what constitutes a model. There was also a definite confusion between a model and a simulation.

Issues to be Addressed during Design : There is a need to clearly differentiate between model building and simulation manipulation.

Objective Five : The transfer of the simulation to other subjects was weak with one exception. The transfers to other areas of Geography were similarly unconvincing.
Issues to be Addressed during Design : As the product is to be a 'content free' modelling environment, it is very important that the students can recognise the underlying patterns of the models, so that transfer between the various geographical subject areas can take place.

The Dynamic Modelling System (DMS) Interviews

1. Evaluation Premises

a. purpose : The broad goal of the interviews was to elicit whether the students could understand and use the DMS software to construct geographical models.

b. type : The evaluation type is decision oriented, that is, the information collected would be used for informing the decision making process in the next stage of the design.

c. indicators : Typical indicators of the evaluation would be statements that showed the students had both the understanding of the principles of model building and also had the skills to be able to devise and enter the model into the DMS software.

The characteristics of the indicators would be found in the student's planning and sequencing of the activities required to produce and implement a model.

The validity of the principal indicators would be cross-referenced between the replies given by the five students.

The reliability of the indicators is not of prime importance to these set of interviews, as any information that is gathered will be fed back into the product development. It therefore will be available for more systematic analysis at a later stage.

d. side effects : A semi-structured interview with open questions would be used. Issues, raised by the student's answers, would be pursued by the interviewer so that any side effects could be identified.

e. external validity : This formative evaluation is not intended to lead to any form of external generalisation but attempts to elicit information from individuals that will contribute to the design process.

2. The Need for Evaluation

a. the target and purpose of the evaluation results : These results are required in order to make decisions about the structure and contents of the initial ideas especially in terms of the pedagogic issues.

b. the specific objectives :

1. To determine the students' understanding of the idea of a model within the DMS software.
2. To establish possible strategies adopted by students in order to create models

3. To elicit from the students perceived difficulties in using the DMS system.

4. To gain an insight into the manner in which the students use a previously written model.

5. To elicit the students' opinion on using the DMS for building geography models.

3. Methods

a. format : The independent interviewer, David Riley, conducted open interviews with semi-structured questions to elicit information concerning the objectives.

b. setting and procedures : The interviews were based on a geography lesson that used the Dynamic Modelling System (DMS) software. The lesson took place in mid June, at the end of the first year of the students two year 'A' level course. In a previous 70 minute lesson, the students had been introduced to the DMS package and had experimented with a supplied model on the growth of population. The lesson, on which the interview was focused, was approximately two hours in length. The lesson began with an explanation of the economic geography topic, location analysis, based on the Palander method, Smith (1981). The students were then asked to create a model for the topic. The students were also given the opportunity to investigate other previously constructed geographical models so as to see the explicit methods used for a range of models.

4. Data Collected in Response to the Evaluation Questions

The transcripts for the interviews are given in Appendix Two.

Objective One : To determine the students' understanding of the idea of a model.

If students are to successfully use the DMS, then they must have a reasonable mental picture of what is meant by a model. Helen describes it as "(H5) putting theories into practice and seeing how they work". Jennifer describes a model as "(J44) giving you a visual explanation of a certain type of geography or mathematics or something like that, and its an easier way to understand something". Andrew reflected that model building "(A7) was difficult at first but then... all the pieces fitted together and it seemed a lot easier." Andrew also added that "background knowledge helps to understand the graphs (A20)". The latter remark referring to the need to understand the geographical processes before building the model.

Objective Two : To establish possible strategies adopted by students in order to create models.

The creation of a new model requires a strategy which is identified by Jennifer as (J10):

1. work out a basic equation e.g. natural increase that is births - deaths
2. give the population a starting figure
3. build the equation and enter it into the DMS

One focus of questions, put to the students, concerned the time taken to create models. Jennifer identified that in the "first ten minutes you have got to find out what you can change and how (J32)". She also added " if it is difficult you have to go back to the beginning and work through it and it will take a good half hour ".

Objective Three : To elicit from the students' perceived difficulties in using the DMS system.

The difficulties involved in using the DMS, as expressed by the students, focused on the level of detail and the degree of accuracy with which they had to deal. (H19) Helen identified " little differences can make quite a lot of difference on the graph". Minesh suggested that "you have got to know every single variable and what it does. Otherwise you are really stuck, you do not know what to do". Whereas Andrew said "(A5) its understanding what is exactly in the model... the values. The figures are the main problem ".

Objective Four : To gain an insight into the manner in which the students use a previously written model.

The interviews drew the following comments from the students on the amending of existing models. Helen (H13) summed it up as "working out how you can change gradients and things like that". An indication that she had understood the process is shown when she gave a description of the steps involved, (H19):

1. get graph up
2. look up additional information
3. work out what is being shown
4. choose things you want to alter

Jennifer also indicated that she had a strategy for changing the model "(J33) I see what I can change and how it alters the graph... then you go back to the actual equations and change them or add new lines". This refers to the strategy of altering the VALUES first and having established how the model works, then the lines in the MODEL can be addressed.

Objective Five : To elicit the students' opinion on using the DMS for building geography models.

Minesh said in referring to DMS (MN) "in this case you've really got to think more about it.... which is really good. It makes you think a bit". Martin considered "(MA9) once you get going its pretty easy say to write (models)... it is like writing a normal program, it's very easy".

5. Comments about the Collected Data

Objective One : The idea of a model is still not comprehensively or directly defined, however, the students did describe some of the external characteristics of a model.

Issues to be Addressed during Design : The exact nature of a model must be clearly indicated to the students.

Objective Two : The students showed that they had a positive view of the steps that must be followed in order to construct a solution.
Issues to be Addressed during Design : To ensure that the various types of models for the different areas of Geography can be constructed by following a set of similar steps.

Objective Three : The nature of the accuracy required for most aspects of computer work is indicated in the replies. The implications in the statements, were that the students found the necessary focus on the accuracy to be a little tedious, and on some occasions a distraction from solving the geographical problem.
Issues to be Addressed during Design : Wherever possible, mitigate the need for accuracy and allow developments to take place without the need for total accuracy. Where this is not possible, present the information in such a way that enables mistakes to be recognised more quickly.

Objective Four : The amendment of an existing model produced a two stage approach. First, the manipulation of the values or the variables took place in order to see their effects, and to deduce how the model responded. Having established understanding, then the values were addressed from a geographical stand-point.
Issues to be Addressed during Design : Give the opportunity to amend and adjust existing models as a precursor for both developing new instances of the existing model and for the creation of new models.

Objective Five : The students showed a positive view of using the DMS, providing the effort was put into understanding the material.
Issues to be Addressed during Design : Ensure that the interface and initial starting points within the product are not too daunting.

STEP FIVE - THE GENERATION OF THEMES AND GEOGRAPHICAL IDEAS

The Selection of Themes

The first theme arose from the background research into the nature of the structure of software. This indicated the need for the separation of the representation of the domain, from the inference procedures that are used within that domain. The second theme focused on the successful use of the DMS software using procedural models. The third theme was drawn from the content free software, that is widely available in schools. Within the group of content free software products, the spreadsheet was selected as it was the only one that had both a representation and inference mechanism built into the software. The final theme was the direct use of a computer language. Prolog was selected as it had proved successful in school, Ennals (1985), and it had formed the basis for much of the work in the field of expert systems, Waterman (1986). Prolog has the advantage of separating the representation and the inference methods.

Therefore, four bases for modelling were chosen :

1. the representation of a rule based expert system for an area of geography whereby the underlying structure of the system could be viewed and amended, (Appendix Three)
2. the representation of geographical models in a software modelling system originally designed for Physics, (Appendix Four)
3. the representation of geographical models in a widely available piece of content free software, the spreadsheet, (Appendix Five)
4. the representation of a full range of geographical models directly in a computer language, (Appendix Six)

Developments within the Selected Modelling Bases

Theme 1 The representation of a rule based expert system for an area of geography whereby the underlying structure of the system could be viewed and amended, (Appendix Three).

The Objectives for a Simple Rule Based Expert System in Geography

Objective One :	to build a simple expert system for a geographical topic
Objective Two :	to include in the simple expert system an explanation facility
Objective Three :	to base the system on non-numerical inference
Objective Four :	to allow access to the underlying model

The principal aim of this theme is to identify the viability of building a simple geographical expert system for a specified area of geography. The representation of the underlying model, that gives the system its expertise, should be able to be examined and to be amended. The potential classroom purpose of the system would be to describe in words a geographical decision making process. This would then be represented on the computer. The inference mechanism would then draw geographical conclusions. These conclusions would then be compared with real examples. The factors involved in the decision making process could then be altered accordingly.

Objective One can be justified in terms of the value that is being perceived for expert systems in many other areas. Waterman (1986) argues, that expert systems can capture and manipulate knowledge that has not previously been available through normal software development. Waterman continues, that an explanation facility, objective two, is both helpful to the user and useful for the 'expert'. From a learning perspective, software that can attempt to explain its method for deducing the result is of greater benefit than simply producing an answer. The justification for objective three stems from the comments made by the students using DMS modelling. One issue they raised was the detailed numerical aspects that had to be considered and that this could prove a distraction from the main geographical task. In addition, by using words to describe the situations, the use of the computer becomes analogous to the use of the language used in the geography classroom. Self (1985) and later Ridgway (1988), both argue for making the underlying structure of the model or simulation, more accessible to the user, which is objective four.

The Development Tool for the Expert System

Prolog was selected because of its strength in the manipulation of non-numerical data and the separation of the representation and the inference mechanisms. Waterman (1986) argues that symbol manipulation languages, such as Prolog, are the most suitable for expert systems development. The system was developed in a prototype form and hence the user interface is in a simple text entry form. All entry screens are edited in a word processor, stored as files, and then compiled into Prolog.

The Geographical Content of the Expert System

The concepts of industrial location in 'A' level syllabuses present a suitable area for an expert system, Goble (1987). There are three aspects of the industrial location domain that present difficulties for the construction of normal software, but make it more suitable for a simple expert system. First, the scale involved in the concepts. Industrial location considers, national, regional and urban scales, but the delimitation of these and the relationship between them is not always clear. Second, the relationship between the theoretical and the actual. Theoretical models are often weak in their actual realisation of specific examples. Generally the actual location of industries is frequently described using heuristic principles or general 'rules of thumb'. The third aspect is that there are many 'inputs' to industrial location concepts and their relative weightings can present difficulties. This is particularly appropriate, in the balance between optimum and satisficer decisions, Hoare (1983).

The geographical topic chosen for the development was the principles of industrial location in the British Isles between 1860 and 1980. The system would consider the various factors that have influenced decision making concerning the location of industry.

The Structure of the Expert System

The input factors that influence the location may be selected as follows :

1. the nature of the two principal raw materials and their spread of location
2. the year within the range 1860 to 1980
3. the type of target market for the industry

4. the size of the industry

The table, Figure 4.1, shows the questions that are given to the user, the range of the responses that are possible, and an example of the input from a user.

Question	Range of Responses	Example
Name of Industry	any	steel
Year	between 1860 and 1980	1920
Name of first input material	any	iron ore
Weight of first input material	very heavy, heavy, moderate, negligible	very heavy
Source of first input material	any	iron ore field
Is source restricted or everywhere	restricted, everywhere	restricted
Name of second input material	any	coal
Relative weight of second input material	very heavy, heavy, moderate, negligible	heavy
Source of second input material	any	coalfield
Is source restricted or everywhere	restricted, everywhere	restricted
What is the target market	consumer, industry	industry
What is size of market	national, regional, local	national
What is size of industry	very large, large, moderate, small, workshop	large

Figure 4.1 Inputs to the System

Figure 4.2 shows the input information in its Prolog entry form. The "*/" delineate comments and labels in Prolog and are there to assist readability.

```
materials(/* Industrial Location */

/*Enter name of industry..................... */ steel,
/*Enter year................................. */ 1920,
/*Name of first industry input material...... */ iron_ore,
/*Weight of first input material */
/*very_heavy  heavy  moderate  negligible ... */ very_heavy,
/*Source of input material one............... */ iron_ore_field,
/*Is source restricted or everywhere......... */ restricted,

/*Name of second industry input material..... */ coal,
/*Relative weight of second input material */
/*very_heavy  heavy  moderate  negligible... */ heavy,
/*Source of input material two............. */ coalfield,
/*Is source restricted or everywhere........ */ restricted,
/*Is the target market */
/*industry  consumer  both.................. */ industry,
/*Is the size of the market */
/*national   regional   local............. */ national,
/*Is industry_size */
/*very_large large moderate small workshop */ large).
```

Figure 4.2 Materials Entry in Prolog

The table, Figure 4.3, shows four columns. Column 1, shows the characteristics of the industrial location. Column 2 shows the possible answers that could be selected by the system. Column 3 shows the source of the answer and differentiates, between information supplied by the user, and the answers deduced by the system. Column 4 gives the answers supplied in response to the input details previously constructed.

Characteristic	Range of answers	Source of Answer	Example Output
Name of industry	any	user supplied	steel
Year	between 1860-1980	user supplied	1920
Location	specific location, area location, market location	deduced	specific location
Position	input material sources market	deduced	iron ore field
Type	heavy, light	deduced	heavy
Market size	national, regional, local	user supplied	national
Market Target	consumer, industry, both	user supplied	industry
Technological Development	periods of inventions, general mechanisation, automation, small scale automation, computerised automation, mainly hand labour	deduced	general mechanisation
Transport	rail/canal, rail, road	deduced	rail
Industrial Trend	rapid growth, decline, steady growth, fast_growth	deduced	steady growth
Management Style	entrepreneur, individual, individual and family, directors, corporate, multi national, small company status	deduced	individual and family

Figure 4.3 The Outputs of the System

Figure 4.4. shows the output in the form produced by the system.

```
'Industry name is....................   'steel
'The year is.........................   '1920
'The industry is in a................   'specific_location
'The precise location being..........   'iron_ore_field
'Industry type is....................   'heavy
'The market size is..................   'national
'The market target is................   'industry
'Technological development is typified by..'
general_mechanisation
'Transport is........................   'rail
'Industrial trend is.................   'steady_growth
'Management style is.................  'individual_and_family
```

Figure 4.4 The Outputs from Prolog

The Pedagogic Issues of the Expert System

A feature of an expert system is that it deduces an answer and also supplies an explanation of how that answer was determined. The system produces answers according to the characteristics given in Figure 4.3. For each of the answers that have been produced, the user can request, from the system, a demonstration of how that answer was derived. The explanation of 'position' is given in Figure 4.5 and for 'management' in Figure 4.6

```
'The input material.....................
'iron_ore
'has a restricted location'
'and is heavier than .................... 'coal
'therefore the location is at the source '
'of the input material namely...........
'iron_ore_field
```

Figure 4.5 Explanation of Position

```
'The name of the industry is.................. 'steel
'the year is.................................. '1920

'the following factors influence the management '
'the industrial growth trend is ..............
'steady_growth
'the industry size is obtained from the user... 'large
'the industry type is deduced and is.......... 'heavy
'for the period beginning in.................. '1900
'and ending in................................ '1929
'the management style is......................
'individual_and_family
```

Figure 4.6 Explanation of Management

From a pedagogic point of view, it is beneficial to have the system fully interact with the student. In this system the inter-activity has been increased, by a comparison of the results deduced by the system, and the estimated answers suggested by the student. The student replies to the initial prompts and also supplies the estimated answers.

Characteristic	Range of answers	Student Estimated Answer
Name of industry	any	previously given
Year	between 1860-1980	previously given
Location	specific location, area location, market location	area location
Position	input material sources market	coalfield
Type	heavy, light	light
Technological Development	periods of inventions, general mechanisation, automation, small scale automation, computerised automation, mainly hand labour	period of inventions
Transport	rail/canal, rail, road	road
Industrial Trend	rapid growth, decline, steady growth, fast_growth	decline
Management Style	entrepreneur, individual, individual and family, directors, corporate, multi national, small company status	corporate

Figure 4.7 Student Estimated Answers

If the system and student answers do not match, then the system will produce the explanation of its deduction. The student answers may be constructed as shown in Figure 4.7.

These answers can then be entered into the system in a similar manner to the input. The example input screen from the word processor is shown in Figure 4.8. It can clearly be identified by the title, 'answers', in the top left hand corner.

```
answers( /* Name of industry ................................*/
steel,
/* Year ..........................................*/ 1920,
/* Location : specific_location  area_location
            market_location .......................*/
area_location,
/* Position ......................................*/ coalfield,
/* Type : heavy  light ............................*/ light,
/* Technological development   period_of_inventions
general mechanisation   automation
small_scale_automation   computerised automation
mainly_hand_labour.................................*/
general_mechanisation,
/* Transport : rail_canal    rail    road ..........*/ road,
/* Industrial trend :       rapid_growth    decline
steady_growth           fast_growth ..............*/ decline,
/* Management style :   entreprennuer   individual
individual_and_famliy   directors   corporate
multi_national   small_company_status ............ */ corporate).
```

Figure 4.8 Student Answers in Prolog

The system initially produces a comparison screen to illustrate the differences between the student suggested and the system deduced answers. This is shown in Figure 4.9.

```
''Name....'steel'                          'Year.....'1920
'Locat...'specific_location'               'area_location
'Position.'iron_ore_field'                 'coalfield
'Type....'heavy'                           'light
'Tech....'general_mechanisation'           'general_mechanisation
'Trans...'rail'                            'road
'Growth..'steady_growth'                   'decline
'Manage..'individual_and_family'           'corporate
```

Figure 4.9 Differences between Student and System

The explanation of the differences will then be systematically worked through by the system.

The next stage in the use of the system is to be able to understand and explore the internal structure of the model. A diagram for the structural description of the relationships of the different components, will allow the student to gain a clear overview of the system as a whole, in order that attention can then be selectively focussed on particular aspects. The diagram is in the form of a data flow diagram, Figure 4.10. The first stage is to consider the overview structure of the decision making and the interrelationships of the processes involved. Diagrams have the ability to represent the structure of the inter-relationships clearly. The flows of the data, i.e. the inputs from the user, begin as data flows at the top of the diagram. They each enter a box, which is a process or function box. Each of these boxes, determines an output dependent on the inputs. In order to deduce the output it uses the appropriate reference from the reference store (shown as open-ended boxes). The processes represent the working 'rules' of the system and the reference stores show the decision making. Each of the processes can be examined on the diagram, to determine what input information it requires, in order to make a decision. The final results are then passed along data flows to the User at the bottom of the diagram.

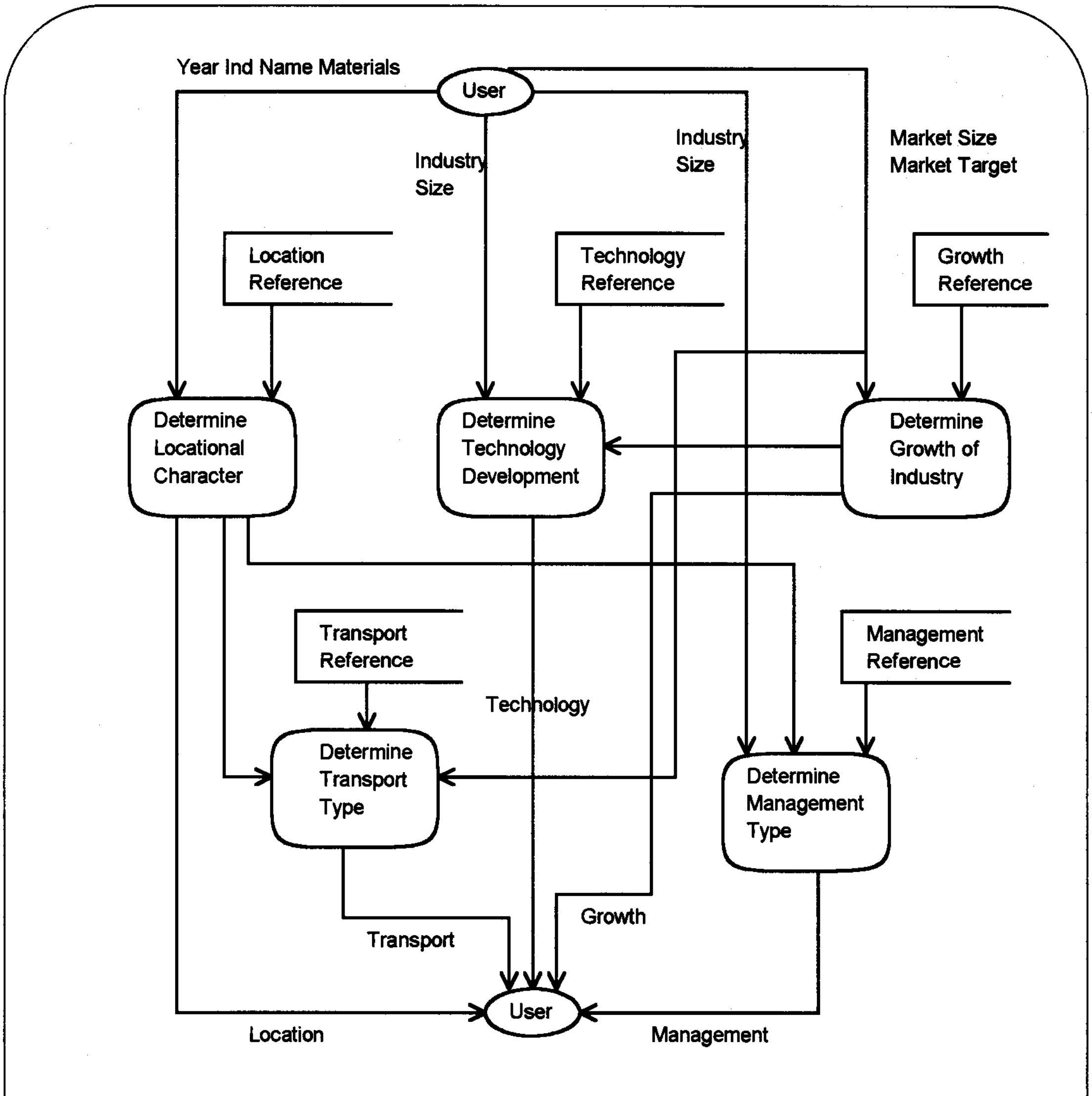


Figure 4.10 Data Flow Diagram of Industrial Location Expert System

The principal decision making structures are in the store references in Figure 4.10. The method by which they are constructed is in the form of decision tables. In this way they can be made more accessible to the user. The style of decision tables, used are a variation on the standard decision tables, Hurley (1983). They are in the form of a look-up table, where the appropriate combination of inputs are searched for in the table, and the output is read from the appropriate column.

Figure 4.11 shows the decision table, in Prolog, for the transport reference on Figure 4.10. Columns 1 to 4 represent the inputs, with column 5 showing the output decision. In the example, previously given, for Steel in 1920. Columns 1 and 2 are used to locate the year 1920. There are several possible selections, rows 3, 4, 5, 6, 9, 10. The process 'Determine

```
TRANSPORT TABLE

/* Columns        1      2      3       4             5 */
ref_transport(  1860,  1899,  heavy,  national,       rail_canal).
ref_transport(  1860,  1899,  heavy,  regional,       rail_canal).
ref_transport(  1900,  1986,  heavy,  national,       rail).
ref_transport(  1900,  1986,  heavy,  regional,       rail).
ref_transport(  1900,  1949,  light,  regional,       rail).
ref_transport(  1900,  1949,  light,  national,       rail).
ref_transport(  1950,  1986,  light,  national,       road).
ref_transport(  1950,  1986,  light,  regional,       road).
ref_transport(  1860,  1986,  heavy,  local,          road).
ref_transport(  1860,  1986,  light,  local,          road).
```

Figure 4.11 Decision Table for Transport

Locational Character' identifies Steel in the 1920's to be a heavy industry. By looking up 'heavy in column 3, then the only rows that have a combination of 1920 and heavy, are 3, 4 and 9. The market size has been entered by the User and is national. Therefore, the one row that satisfies these criteria is row 3. The type of transport for row 3 is given in column 5, namely 'rail'. Each row of the decision table in Figure 4.11 can be considered to be a production rule of the form of an

IF <condition> THEN action

In this case, and with the other decision references, there are multiple conditions, all of which must be true, in order to institute the 'action' part of the rule.

```
1 transport( Name, Year, Transport):-
2       industry_type( Name, Year, Type),
3       materials( Name, Year, Im1name, Im1rw, Im1s, Im1u,
                Im2name, Im2rw, Im2s, Im2u, Target, Msize,
Isize),
4       ref_transport( Start, Finish, Type, Msize,
Transport),
5       Year  >=  Start,
6       Year  =< Finish.
```

Figure 4.12 Prolog Statement for Transport Process

The Prolog statements that corresponds to the process boxes are all of a similar structure, with the example for 'Determine Transport Type' in Figure 4.10, given in Figure 4.12.

Description of Figure 4.12

Line 1 shows the name of the industry with the year, and the answer that is deduced for this process

Line 2 supplies the industry name and year and the type of industry i.e. heavy, light

Line 3 supplies all the details that are input from the user

Im1name : name of input material one

Im1rw : relative weight of input material one

Im1s : source of input material one

Im1u : availability of distribution of input material one

Im2name : name of input material two

Im2rw : relative weight of input material two

Im2s : source of input material one

Im2u : availability of distribution of input material two

Target : target market for the product

Msize : the size of the market

Isize : the size of the industry

Lines 4,5, and 6 then take the information that has been supplied and look it up in the table called ref_transport (line 4).

The Design Evaluation of the Expert System

1. The Strengths of the Geographical Expert System
    - A. allows manipulation and deductions based on typical general descriptive terms used in geography
    - B. gives a relatively easy way of dividing complex problems into manageable units
    - C. allows access to the tables concerning parts of the decision making structure

2. The Weaknesses of the Geographical Expert System
    - A. the building of a model from first principles would require a good knowledge of Prolog

B. the interface is difficult to construct and, as with many languages, prone to syntactical difficulties

C. the addition of useful extra features, such as explanation and comparison, yield a considerable amount of code and additional complexity

Theme 2. The representation of geographical models in a software modelling system originally designed for Physics (Appendix Four).

The Objectives of Utilising the Dynamic Modelling System (DMS) for Geography Models

Objective One :	to identify a range of possible geography models that could be developed in the system
Objective Two :	to investigate whether there is any underlying structure to a range of geographical models

The justification for using the DMS is founded on the success demonstrated in 'A' level Physics, where a wide range of models has been developed, Ogborn (1985). The underlying principles, of Dynamic Systems, on which the DMS is based, were established by Forrester (1968). Meadows and Robinson (1985) identified that dynamic systems could also be used for modelling within the Social Sciences.

The Development Tool - the Dynamic Modelling System

The Dynamic Modelling System comprises of five parts :

1. the model which is written in a subset of BASIC
2. the starting values for the model
3. the setting of the range values for the axes
4. the graphing of the outputs from the model
5. the output of a table of values from the model

In order to construct a model within the DMS, the first three parts must be completed. The last two parts are the output that is produced by the system. In addition the graph axes must be labelled and given a scale.

The model comprises of a series of sequential statements. When the program runs, these statements are continually repeated, until a terminating factor is reached. Within the model, two variables are continually recalculated. These two values represent the outputs on the X and Y axis to the graph.

The Geographical Content of Models for the DMS

A simple example of a complete model within the DMS is population growth, Appendix Four, P144. The model part is given in Figure 4.13. The lines beginning with REM are for information purposes only.

```
1 Rem Natural Inc.
2 NI = BR - DR
3 Rem Add to present
4 Rem population
5 POP = POP + NI
6 Y = Y + 1
7 BR = BR + 20
8 DR = DR -10
```

Figure 4.13 DMS Population Model

The abbreviations are as follows :

NI : natural increase

BR : birth

DR : deaths

Y : year

The model plots the total population against the years. Each repetition of the group of statements represents one year on the graph. Line 2 calculates the natural increase. Line 5 adds the natural increase to the existing population. Line 6 increments the year by one.

Line 7 adds 20 to the number of births and Line 8 takes 10 from the number of deaths. At the end of each repetition the two graph values, i.e. POP and Y are plotted on the graph.

The initial values that are set for the beginning of the model are shown in Figure 4.14

```
NI = 0
Y = 1
BR = 160
DR = 75
POP = 9000
```

Figure 4.14 Initial Values

The geography models listed in Figure 4.15 were all constructed within the DMS, (Appendix Four). They may be described as functional in that the feedback mechanism of Forester's (1968) dynamic systems are not present. However, there are geographical models that can be constructed using the DMS that include feedback mechanisms, Goble and Riley (1988).

POPGRO	- natural increase and population growth
POPINC	- population growth with variable birth / death rates
POPVAR	- population growth with birth / death rate thresholds
TRANS	- comparison of transport costs
DISCOST	- cost for factory location
STEPCST	- stepped costs for market areas
BOFBLK	- break of bulk points and costs of transport
CSTREV	- revenue costs from a central point
CRPYLD	- crop yields
BDRENT	- bid rent graphs for cities
OILEXP	- oil exploration rates of return
OILEXP2	- oil exploration variable rates of return
RADIAT	- amounts of radiation at the edge of the earth's atmosphere
LAPSE	- atmospheric lapse rates
GLACIER	- melting rates of glaciers
PRECIP	- precipitation and evaporation rates
RIVVEL	- calculations of river velocity
VONTHUN	- calculation of Von Thunen circles
QUEUE	- queues of traffic at traffic lights

Figure 4.15 DMS Geography Models

Classroom Use of DMS in Geography

The data collection outlined in Chapter Four, Step Three was based on the models developed in this section. The students were given all of the models listed in Figure 4.15 with the exception of the CSTREV, which modelled the cost revenues from a central point. From the explanation of the geographical concepts of cost revenue areas, the students were then asked to construct a model. The data collection focused on the students' strategy, and understanding of the models.

The Design Evaluation of the Use of DMS for Geography Models

1. The Strengths of the DMS
   A. the graphical and tabular representations
   B. the split screen allowing juxtapositioning of the five different components of the system namely MODEL, VALUES, GRAPH, TABLE and GRAPH PARAMETERS

2. Weaknesses of the DMS
   A. restriction to numerical calculation
   B. limited control structure i.e. repetition around the model

Theme 3. The representation of geographical models in a widely available piece of content free software, the spreadsheet (Appendix Five).

The Objectives of Spreadsheet Modelling

Objective One :	to build a range of geographical models on a spreadsheet
Objective Two :	to investigate standard formats and layouts to achieve models in the different areas of geography
Objective Three :	to investigate the declarative aspects of spreadsheet representation

Objective Four : to assess the value of pre-constructed models that can be either amended or used entirely in simulation mode

The Justification of the Objectives

Geographers have many areas of their subject where numerical manipulation is appropriate. This refers, not only to the quantitative techniques within the subject but also to decision making procedures, that can be founded on a numerical or semi-numerical basis.

Spreadsheets allow the construction of simple models by users new to this form of software. The facility to introduce users, who have little experience of model building, is based on the simple nature of the interface and the declarative representation of the information. The inference mechanism is transparent to the user and basically recalculates the whole of the spreadsheet after each entry. Spreadsheets were originally designed to build financial models. A very important part of financial analysis is 'what-if' calculations. These allow for very rapid re-calculation of the figures so that alternative ideas can be evaluated. In geography, a spreadsheet will be able to produce results that time constraints would not permit if performed manually. The computer can deal with the constant re-calculations, allowing the student time to focus on the geographical significance of the figures.

The spreadsheet is a widely used piece of 'content free' software and students are more likely to become generally familiar with such software and thus will not require special learning sessions for geographical purposes.

The Development Tool

The spreadsheet is a two dimensional matrix of individual cells. Each cell has a reference point e.g. A1, B66. In any cell, there are three possible entries :

1. labels - which are words and letters to give general information and play no direct part in the re-calculation of the spreadsheet

2. numbers - which are the numerical values representing the problem domain
3. formulae - each formula comprises of cell references and numbers, e.g in cell C5 a formula might be A3 * 5 . This would multiply the contents of cell A3 by 5 and place the answer in C5.

The Geographical Content of Spreadsheet Models

The declarative nature of the spreadsheet can be utilised in several ways in order to represent geographical models. Those ways, which are not necessarily mutually exclusive, are:

1. models involving a sequence of activities
2. models involving 'what-if' analysis
3. models that utilise the cells of the spreadsheet as a simple map
4. models that perform statistical or numerical analysis

The models involving a sequence of activities can be illustrated with a spreadsheet showing a simple population growth model, Appendix Five, Page 157. The outputs from the model are determined by the relative rates of birth and death. The difference between birth and deaths rates being the natural increase. The inputs required to drive the model are :

1. The YEAR from which the population projection is to start
2. The POPULATION in the first year
3. The BIRTH RATE for the ten year period
4. The DEATH RATE for the ten year period

The model is shown in Figure 4.16

	A	B	C	D	E	F	G	H	I	J	K
1	POPULATION GROWTH					PLACE:	SOMEWHERE				
2	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	
3	START	START		BIRTH		DEATH					
4	YEAR	POP		RATE		RATE					
5	1971	2000		.038		.020					
6	----------	----------		----------		----------		----------		----------	
7	YEAR	POP		BIRTHS		DEATHS		NAT INCR		TOTAL	
8	1971	2000		76		40		36		2036	
9	1972	2036		77		41		37		2073	
10	1973	2073		79		41		37		2110	
11	1974	2110		80		42		38		2148	
12	1975	2148		82		43		39		2187	
13	1976	2187		83		44		39		2226	
14	1977	2226		85		45		40		2266	
15	1978	2266		86		45		41		2307	
16	1979	2307		88		46		42		2348	
17	1980	2348		89		47		42		2391	
18	==========	==========	==========	==========	==========	==========	==========	==========	==========	==========	
19	TOTAL POP INCREASE BETWEEN					1971 &		1980		391	
20	TOTAL % INCREASE BETWEEN					1971 &		1980		20	

Figure 4.16 Population Growth Model

A model that utilises a 'what-if' analysis is the calibration of gravity model, Appendix Five, Page 165. In the design of an airline network, the gravity model can be used to predict the likely number of people wishing to fly between centres. If some actual figures of those flying are known, the model can predict the remaining. It also predicts, those for which data is known and a comparison between the known and the predicted can give the difference. By adjusting the friction of distance, the model can be calibrated to give the lowest percentage error, Gould (1985). The inputs required to drive the model are :

A. For a network of towns

1. The DISTance between the towns
2. The POPulation of each town

B. For the model

3. The FRICTION OF DISTANCE

C. For at least one of the routes

4. The KNOWN number of people travelling.

The model is shown in Figure 4.17

	A	B	C	D	E	F	G	H	I	J	K	L
1	CALIBRATED GRAVITY											
2	-----------------									Population of Towns		
3	Friction of Distance										--------------	
4	1.90										TOWN	POP
5	--										1	200
6	TOWN	TOWN	DIST	GRAVITY	KNOWN	VALUE	ENTRIES	PREDICT	DIFF	% DIFF	2	100
7	1	2	15	117	1000	8.58	1	421	579	57.91	3	340
8	1	3	20	229	2000	8.72	1	828	1172	58.58	4	50
9	1	4	5	470		0	1	1697	1697		5	90
10	1	5	10	227	2000	8.83	1	818	1182	59.08		
11	2	3	10	428		0	1	1546	1546			
12	2	4	20	17		0	1	61	61			
13	2	5	33	12		0	1	42	42			
14	3	4	18	70	700	9.99	1	253	447	63.85		
15	3	5	30	48		0	1	173	173			
16	4	5	28	8		0	1	29	29			
17						Average				Average		
18						Value				% diff		
19						3.61				23.94		

Figure 4.17 Calibration of Gravity Model

The spreadsheet may be used as a simple map. The location of stations on a rapid service urban railway should be such, that it ensures the overall time for each person, in the area, to reach the station is reasonable, Appendix Five, Page 185. A map depicts, on a grid, the number of people in each area. The stations can be located and then the time taken for each 'grid square' to reach the station can be entered. The total index is the total time for everybody in the area to reach their nearest station. The inputs to the model are :

1. The POPULATION for each grid square on the map
2. The LOCATION of the station
3. The TIME each grid square is away from the station

The model is shown in Figure 4.18.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	STATION																	
2	--------																	
3																		
4		1	34	1	34	1	34	1	34	1	34	1	34	1	34	1		
5		23	34	23	34	23	34	23	34	23	34	23	34	23	34	23		Population by
6		2	45	2	45	2	45	2	45	2	45	2	45	2	45	2		Grid Square
7		16	8	16	8	16	8	16	8	16	8	16	98	16	8	16		
8		19	7	19	7	19	7	19	7	19	7	19	7	19	7	19		
9		34	24	34	24	34	24	34	24	34	24	34	24	34	24	34		
10		17	78	17	78	17	78	17	78	17	78	17	78	17	78	17		
11																		
12																		
13		2	2	2	2	2	3	3	3	3	3	4	4	4	4	4		Total Travelling
14		2	1	1	1	2	2	2	2	2	3	3	3	3	3	3		Index Time
15		2	1	*	1	2	1	1	1	2	3	2	2	2	2	2		-------
16		2	1	1	1	2	1	*	1	2	3	2	1	1	1	2		5750
17		2	2	2	2	2	1	1	1	2	3	2	1	*	1	2		Average
18		3	3	3	3	2	2	2	2	2	3	2	1	1	1	2		Time
19		4	4	4	3	3	3	3	3	3	3	2	2	2	2	2		--------
20																		2.21

Figure 4.18 Station Location

A spreadsheet can also be used for statistical and numerical calculations. An example being the calculation of meteorological lapse rates, Appendix Five, Page 184. When a parcel of air rises, it cools at either, a dry adiabatic lapse, or a saturated adiabatic lapse rate depending on whether the parcel of air is above or below the dew point. The dew point also has a lapse rate on rising. Therefore, the height of the cloud base, and possible rain and / or snow, can be deduced from the intersection of the rates. The stability of the air can also be worked out from the adiabatic lapse rates and the environmental lapse rates. The inputs to this model are :

1. The DRY adiabatic lapse RATE
2. The SATurated adiabatic lapse RATE
3. The DEW point lapse RATE
4. The ENVIRONmental lapse RATE
5. The TEMPerature of the PARCEL of air at ground level
6. The DEW Point TEMPerature at ground level

The model is shown in Figure 4.19

```
        A        B        C        D        E        F        G
1    LAPSE RATES
2    -----------
3      Dry      Sat      Dew    Environ  Parcel   Dew P
4     Rate     Rate     Rate     Rate     Temp     Temp
5     1.00      .60      .20      .95     7.00     3.00
6    ---------------------------------------------------------------
7            Parcel    Dew P    Lapse   Unstable   Rain     Snow
8    Height   Temp     Temp     Rate      Air
9        0    7.00     3.00     1.00
10     100    6.05     2.80     1.00
11     200    5.10     2.60     1.00
12     300    4.15     2.40     1.00
13     400    3.20     2.20     1.00
14     500    2.25     2.00     1.00
15     600    1.30     1.80      .60     ***      ***
16     700     .35     1.60      .60     ***      ***
17     800    -.60     1.40      .60     ***               ***
18     900   -1.55     1.20      .60     ***               ***
19    1000   -2.50     1.00      .60     ***               ***
20   ===============================================================
```

Figure 4.19 Meteorological Lapse Rates

Name	Area
Population Growth	Population
Variable Rate Population Growth	Population
Compound Population Growth	Population
Bidrent Zones	Urban
Farm Production	Agriculture
Infiltration	Hydrology
Manning Coefficient	Hydrology
Gravity Model for Road Building	Transport
Calibrate Gravity Model	Transport
Stepped and Line Cost of Transport	Transport
Least Cost Industrial Location	Industry
Least Cost Location with Terminals	Industry
Profit Areas for Industrial Location	Industry
Longitude and Time	Mapwork
Road Building	Transport
Traffic Flow	Transport
Nearest Neighbour Analysis	Settlement
Journey	Transport
Network Patterns	Transport
Accessibility in Networks	Transport
Oil Exploration	Industry
Meteorological Lapse Rates	Meteorology
Station Location	Transport

Figure 4.20 A Range of Spreadsheet Models

A range of geographical models can be constructed and these may be classified according to the divisions of Systematic Geography. Each model can also be broadly classified by model type. Figure 4.20 shows a typical range of models. The details of which are given in Appendix Five.

The Classroom Use of Spreadsheets in Geography

A spreadsheet model, based on the planning of crops on a farm, has been developed and used with a full class of 15 year olds studying for a GCSE in geography, Goble (1989A). A mixed ability group of 16 pupils also used a spreadsheet to build a simple population model from the initial stages. The principles of the operation of the spreadsheet were explained. The geographical input was a description of the significance of birth and death rates in population growth. The pupils were then asked to construct spreadsheet models, Goble (1989B).

The Design Evaluation of the Use of Spreadsheets for Geography Modelling

1. The Strengths of Spreadsheets
    - A. clear layout and easy break down of simple models
    - B. models easily enhanced and modified

2. The Weaknesses of Spreadsheets
    - A. calculations based on numerical data only
    - B. complexity of formula increases rapidly

Theme 4. The representation of a full range of geographical models directly in a computer language (Appendix Six).

The Objectives for Creating Geography Models using Prolog

Objective One :	to produce a range of models covering different aspects of geography
Objective Two :	to investigate the difference between procedural and declarative models
Objective Three :	to identify format and templates within Prolog for model creation

Objective Four :	to investigate whether a small subset of Prolog could meet the needs of geographical modelling
Objective Five :	to investigate whether simple forms of alternative model structures were possible

The principal task of this theme was to be able to represent a wide range of models in a system that could cope with both declarative and procedural representations. In addition the system had an inference method based on both numbers and text. Also the implications of adding facilities to the system to assist the user were considered.

Justification for the Objectives

Ennals (1983) demonstrated that Prolog could be used for a wide range of historical concepts and therefore Prolog appeared a good tool to investigate for use in geography. Winograd and Flores (1985), argue that students find the approach to models easier through a declarative framework rather than a procedural framework. In terms of student responses and motivation, the time and effort spent using the computer, needs to be oriented firmly towards geographical issues and not programming problems. One other style of model that would be valuable to investigate, are those models that function in a non-deterministic manner.

The Development Tool

Prolog was originally developed within the area of Computer Science. However, in the early 1980's, a school based curriculum project was headed by Kowalski, which investigated using Prolog directly with school pupils. It was used as a means to learning subjects, such as History, Ennals (1983). It is a complete computer language in its own right and has a built in logical inference method.

The Structure of Prolog Models

The initial developments focused on the establishment of a template for procedural models. The population model was again used so that an effective comparison may be made between the different tools, Appendix Six, Page 189. Different sections were identified that would form an overall template and could be used across several procedural models. The purpose of each section is briefly explained and then the population model is explained in more detail. The sections are :

I : the input of information

- the block of statements following 'begin'
- this part of the template is to obtain input details from the program user

II : the heading for the output

- the block of statements following 'heading'
- this part of the template is to print the headings for the output of the results

III : the results of running the model

- the block of statements following 'printout'
- this part of the template is to print the results of the calculations

IV : the model itself

- the block of statements beginning and ending with a label selected by the user
- this part of the template performs the repetition of the model and thereby produces the results for each repetition

V : the conditions for terminating the model

- the single statement beginning with the same user selected label that bounds the model. The contents of the variables are slightly different
- this part of the template provides the stopping point for the repetition of the model

VI : the references

- the block of statements each named after a statement occurring within the model
- this part of the template holds any reference data required by the model statements

Section ' I ' prompts for input and then passes the initial parameters to the process model called growth, Figure 4. 21

```
begin :-
        write('Enter start year .............'),
        read(Year),
        write('Enter start population.........'),
        read(Pop),
        write('Enter end year.................'),
        read(End_year),
        print_headings,
        growth(Year,Pop,End_year).
```

Figure 4.21 Section I - Population Growth

The 'begin' section, before calling 'growth', displays the headings, Section ' II ', for the tabular output of the results, Figure 4.22

```
print_headings :-
        write('Year...'),
        write('Pop....'),
        write('Births.'),
        write('Deaths.'),
        write('Incr...'),
        write('New Pop'),
        nl.
```

Figure 4.22 Section II - Population Growth

Section III prints out the values for each year. The r(7,0) part of the instructions, are to give a tabular output seven characters wide and whole numbers only, Figure 4.23

```
printout(Year, Pop, Births, Deaths,
Natural_increase, New_pop) :-
        write(Year),
        write(Pop,_,r(7,0)),
        write(Births,_,r(7,0)),
        write(Deaths,_,r(7,0)),
        write(Natural_increase,_,r(7,0)),
        write(New_pop,_,r(7,0)),
        nl.
```

Figure 4.23 Section III Population Growth

Section IV, repeatedly increments the value for a year each time. The birth rate and death rates are obtained from reference values. The births and deaths are then calculated. This is followed by the calculation of the natural increase and the new level of the population

(New_pop). The year is then incremented and the results of the calculations passed to the print section.

```
growth (Year,Pop,End_year) :-
        birth_rate(Birth_rate),
        death_rate(Death_rate),
        Births is Pop * Birth_rate,
        Deaths is Pop * Death_rate,
        Natural_increase is Births-Deaths,
        New_pop is Pop + Natural_increase,
        Next_year is Year +1,
        printout(Year,Pop,Births,Deaths,
        Natural_increase,New_pop),
        growth(Next_year,New_pop,End_year).
```

Figure 4.24 Section IV Population Growth

Section ' V ' provides the clause for the end of the recursion, which stops the calling of the process section when the first and third parameters match, Figure 4.25.

```
growth(End_year,Pop,End_year).
```

Figure 4.25 Section V Population Growth

The final part, Section ' VI ' gives the references for the birth rate and death rate, Figure 4.26.

```
birth_rate(0.038).
death_rate(0.020).
```

Figure 4.26 Section IV Population Growth

A full range of geographical examples can be constructed in Prolog, as procedural topics, utilising the 'template' just demonstrated, Figure 4.27, (Appendix Six).

PDGROW	population projection
LIGHTS	the flow of traffic at crossroad traffic lights
LIGHTS2	two flows of traffic at adjacent lights
BIRTH	referencing world regions and then projecting the population in those areas
SHOPLOC	the location of a shop in a neighbourhood for least travelling time
MWAY	the monetary and environmental cost of building a road across an area of land
DRAIN	monitoring the flow of water down a slope to a river channel
TOWNS	the gravity model for the interaction of five towns
LONG	the calculation of the day and time at various places in the world
FARM	the choice of crops to plant to gain most profit with uncertainty about the climate for the growing season
LOCAT	the least cost location for a factory
LANDVAL	the determination of urban zones by amount bid for competing land uses
WATER	the flow of water through a store within the hydrological cycle

Figure 4.27 Range of Procedural Models in Prolog

In a similar theme, the attempt was made to identify a declarative structure that could be widely applied. The focus was on the decision making aspects within geography. The development example chosen was the decision as to whether to locate an industry in a region. The model could be constructed and then used in simulation mode to process the inputs from several other regions. In this way the model could be justified or amended.

The development of the model is similar in style to the Expert System developed earlier, but does not have the sophisticated explanation, and has a focus of establishing a 'template' for several decision making areas of geography.

The first step is a data flow diagram, Figure 4.28, which illustrates the four pairs of inputs. Each of the inputs is structured to give a 'yes' or 'no' answer. The stores contain the decision tables and the process boxes contain the inference rules. The final output is to the User, and gives the decision as to whether the particular region under consideration should be chosen. The model would be 'run' several times to accommodate several regions.

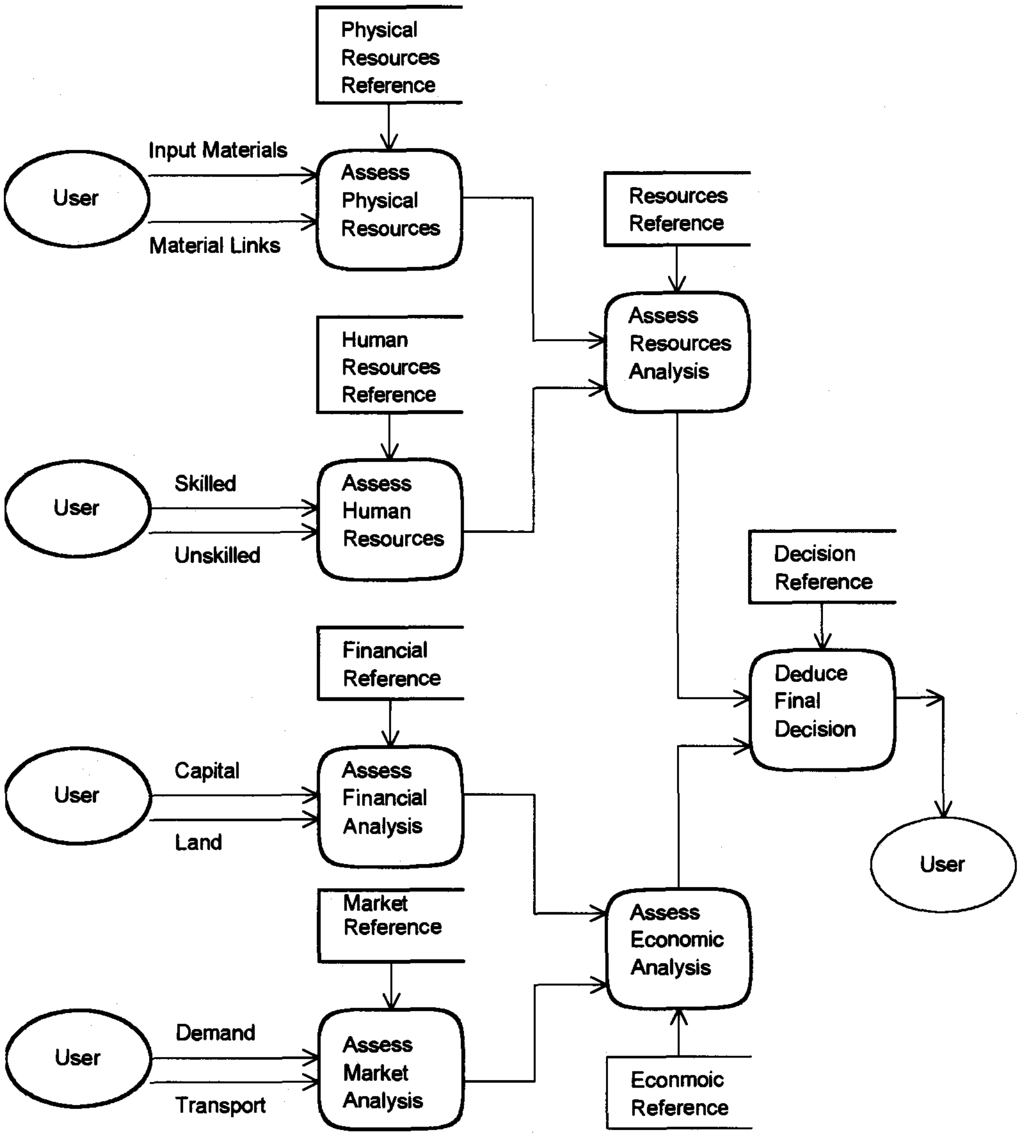


Figure 4.28 Data Flow Diagram for New Industrial Location

Each of the first four processes takes the input from the user. Each store has a decision table that has the combination of four inputs and the one column that represents the outputs. Figure 4.29 shows the initial four stores represented in Prolog.

```
/* Physical References    */
/*          input_materials  material_links  Physical  */
/*                                           good/bad  */
phy_res_ref(       yes,          good,       good).
phy_res_ref(       yes,          bad,        good).
phy_res_ref(       no,           good,       good).
phy_res_ref(       no,           bad,        bad).

/* Human Resource         */
/*          skilled_labour  unskilled_labour Human      */
/*                                           normal/good*/
hum_res_ref(       large,        large,      good).
hum_res_ref(       large,        small,      normal).
hum_res_ref(       small,        large,      normal).
hum_res_ref(       small,        small,      normal).

/* Financial Analysis     */
/*                 capital   land            Financial   */
/*                                           sound/shaky */
financial_ref(     development, plentiful,   sound).
financial_ref(     development, scarce,      sound).
financial_ref(     normal,      plentiful,   shakey).
financial_ref(     normal,      scarce,      shakey).

/* Market Capability      */
/*                market_demand    transport Market     */
/*                                           growth/stable */
market_ref(        high,         network,    growth).
market_ref(        high,         insular,    growth).
market_ref(        low,          network,    stable).

market_ref(        low,          insular,    stable).
```

Figure 4.29 Initial Decision Structures - Industrial Relocation

The Resource Analysis and the Economic Analysis decision tables, Figure 4.30, each take as inputs, the outputs of the two initial processes shown on Figure 4.29.

```
/* Resource Analysis      */
/*              phy_resources    human res  resource_analysis*/
/*                                             good/poor    */
resources_ref(       good,         good,       good).
resources_ref(       good,         normal,     good).
resources_ref(       poor,         good,       good).
resources_ref(       poor,         normal,     poor).

/* Economic Analysis      */
/*               fin analysis    market cap   Econ_analysis */
/*                                             sound / weak  */
economic_ref(        sound,        growth,     sound).
economic_ref(        sound,        stable,     sound).
economic_ref(        shakey,       growth,     sound).

economic_ref(        shakey,       stable,     weak).
```

Figure 4.30 Intermediate Decision Structures - Industrial Relocation

```
/* Decision Analysis      */
/*                  res_analysisres_analysis Decision    */
/*                                           suitable/never */
decision_ref(       good,        sound,      suitable).
decision_ref(       good,        weak,       never).
decision_ref(       poor,        sound,      never).

decision_ref(       poor,        weak,       never).
```

Figure 4.31 Final Decision Structure - Industrial Relocation

The decision structure takes the outputs from the resource and economic analysis, Figure 4.30 and combines then to give a final decision, Figure 4.31

The Prolog statements that enact the process boxes on the data flow diagram are all of the same form. Figure 4.32 shows the examples for Assess Physical Resources and Deduce Final Decision.

```
/* Asses Physical Reesources */

physical_resources(Physical):-
            input_materials(Input),
            material_links(Links),
            phy_res_ref(Input,Links,Physical).

/* Deduce Final Decision */

final_decision(Decision):-
            resource_analysis(Res_analysis),
            economic_analysis(Econ_analysis),
            decision_ref(Res_analysis,Econ_analysis,Decision).
```

Figure 4.32 Prolog Statement for Process Boxes

A third theme, following from the procedural and declarative template development, was that of non-deterministic models. The Prolog system will allow the development of simple non-deterministic models that combine both procedural and declarative aspects. The example is based on the Sahel model, which has been addressed by several writers including Reenberg (1982) and Meadows and Robinson (1985), Appendix Six, Page 207. The domain may be viewed as a set of components that have direct relationships with certain other components within the system. These relationships may be simply modelled by a binary positive or negative influence. There are also some events that are exogenous to the system, which act on particular components in the system, thus causing the overall system to change state. The input events are given in Figure 4.33.

Item	Values	Factor
Medicine	yes/no	Input
Wells	deep/shallow	Input
Drought	yes/no	Input

Figure 4.33 External Events - Sahel Model

The other components within the Sahel domain are :

1. Disease
2. Nomads
3. Water
4. Food
5. Cattle
6. Grasslands

The relationships between the endogenous components and the other components may be represented by a causal diagram, Figure 4.34

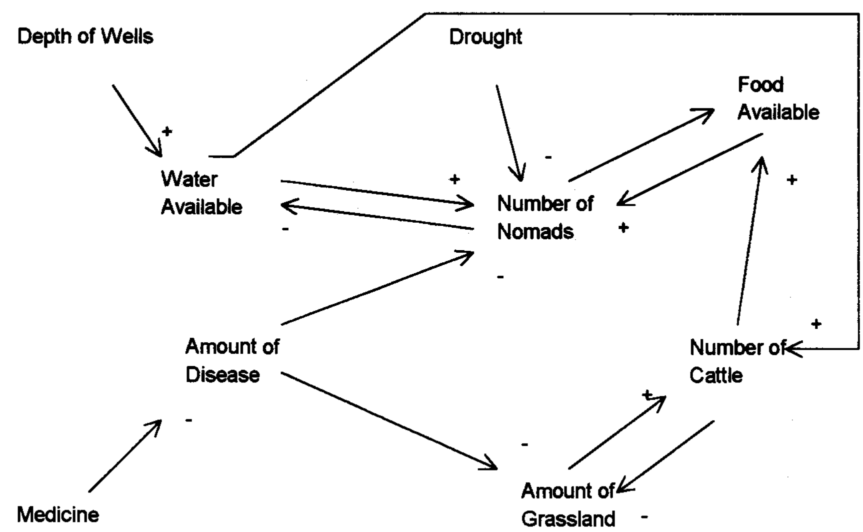


Figure 4.34 Causal Diagram - Sahel Domain (Roberts et al, 1983)

The value for each of the endogenous components and the relationship they have with other components within the domain is summarised in textual form in Figure 4.35.

Items	**Value**	**Factor**
Disease	high/low	Medicine (-)
Nomads	large/small	Disease(-)
		Drought(-)
		Food(+)
		Water(+)
Water	large/small	Nomads(-)
		Wells(+)
Food	large/moderate/small	Cattle(+)
		Nomads(-)
Cattle	high/low	Disease(-)
		Drought(-)
		Nomads(+)
		Water(+)
		Grasslands(+)
Grasslands	large/small	Cattle(-)

Figure 4.35 Endogenous Relationships - Sahel Domain

The overall model can then be represented in Prolog, Figure 4.36. Within the Prolog model, lines 1 to 3 obtain the current 'status' of the factors and print them to the screen. Lines 6 to 8 then obtain the values of the inputs from the user for the year in question. Line 10 looks up the value of Medicine in a simple table, Figure 4.37, and returns the level of disease.

```
1    /* State at beginning of year */
2        status(Year,Disease,Nomads,Water,Food,Cattle,Grass),
3        headings,
4        printout(Year,Disease,Nomads,Water,Food,Cattle,Grass),
5    /* Inputs values      */
6        medicine(Year,Medicine),
7        depth_of_wells(Year,Wells),
8        drought(Year,Drought),
9    /* Determine status for beginning of next year */
10       disease(Medicine,New_disease),
11       nomads(Disease,Drought,Food,Water,New_nomads),
12       water(Nomads,Wells,New_water),
13       food(Cattle,Nomads,New_food),
14       cattle(Disease,Drought,Nomads,Water,Grass,New_cattle),
15       grasslands(Cattle,New_grasslands),
16   /* Increment year and save new status display status */
17       New_year is Year + 1,
18       assert(status(New_year, New_disease, New_nomads, New_water, New_food, New_cattle,
              New_grasslands)),
19       annual_cycle(New_year).
```

Figure 4.36 Prolog Model for Sahel Domain

```
/*                      Medicine        New Disease */
disease(                yes,            low).
disease(                no,             high).
```

Figure 4.37 Decision Structure - Disease

Lines 11 to 15 then look up corresponding values from tables. For example, water is influenced by the number of nomads and the depth of wells. These two inputs, in combination, are looked up in the table, Figure 4.38, to indicate the amount of water now available.

```
/*      Nomads          Wells           New_water  */
water(large,            shallow,        small).
water(large,            deep,           large).
water(small,            shallow,        large).
water(small,            deep,           large).
```

Figure 4.38 Water Decision Structure - Sahel Domain

When the model is 'run', the outputs for the first three years are shown in Figure 4.39.

```
Yr      Disease Nomad           Water           Food            Cattle  Grass
1       low     large           large           large           high    high
Medicine available.... yes/no.........no.
Depth of wells .....shallow/deep......shallow.
Drought ........ yes/no...............yes.

Yr      Disease Nomad           Water           Food            Cattle  Grass
2       high    small           small           moderate        high    small
Medicine available.... yes/no.........no.
Depth of wells .....shallow/deep......shallow.
Drought ........ yes/no...............yes.

Yr      Disease Nomad           Water           Food            Cattle  Grass
3       high    small           large           large           low     small
Medicine available.... yes/no.........no.
Depth of wells .....shallow/deep......shallow.
Drought ........ yes/no...............yes.
```

Figure 4.39 Ouput from Model - Sahel Domain

Pedagogic Issues

One area that was identified as having potential benefit, was the interaction between two models constructed by different people, from the same parameters, Appendix Six, Pages 209-210. For example, a pupil could be given a model to construct and the teacher also constructs a model from the same specification. By following some simple interaction rules, Prolog can compare the two models. Three Prolog statements are made available in the system, so that they can all be used by both the pupil model and the teacher model, Figure 4.40.

```
data_entry(Year, Pop, End_year) :-
          write('Enter start year '), nl,
          read(Year),
          write('Enter start population'), nl,
          read(Pop),
          write('Enter end year'), nl,
          read(End_year),
          asserta(pupil_input(Year,Pop,End_year)).

print_headings :-
          write('Year.....'),
          write('Pop......'),
          write('Births...'),
          write('Deaths...'),
          write('Incr.....'),
          write('New Pop'), nl.

printout(Year, Pop, Births, Deaths, Natural_increase, New_pop) :-
          write(Year),
          write(Pop), write('     '),
          write(Births), write('      '),
          write(Natural_increase), write('      '),
          write(New_pop),  nl.
```

Figure 4.40 Common Statements for Pupil -Teacher Models

The set of statements, Figure 4.41, follow very closely from the previously established Prolog template, except that when the student builds the model, an extra line must be added to pass the results from the 'student' model to the teacher 'model'. The student may create input similar to Figure 4. 41.

```
begin :-
      data_entry(Year,Pop,End_year),
      print_headings,
      pgrowth(Year,Pop,End_year).

pgrowth(End_year,Pop,End_year).

pgrowth(Year,Pop,End_year):-
      pbirth_rate(Birth_rate),
      pdeath_rate(Death_rate),
      Births is Pop * Birth_rate/1000,
      Deaths is Pop * Death_rate/1000,
      Natural_increase is Births + Deaths,
      Next_year is Year +1,
      New_pop is Pop + Natural_increase,
      printout(Year, Pop, Births, Deaths, Natural_increase, New_pop),
      asserta(answer(Year, Pop, Births, Deaths, Natural_increase New_pop)),
      pgrowth(Next_year,New_pop,End_year).

pbirth_rate(38).
pdeath_rate(20).
```

Figure 4.41 Pupil Model

The teacher model has been constructed, so that it can take the same data entry values. Instead of an output section, there is the line which puts the 'results' of the teacher model to the explain section, where the comparison is made, Figure 4.42

```
growth(End_year,Pop,End_year).

growth(Year,Pop,End_year) :-
      birth_rate(Birth_rate),
      death_rate(Death_rate),
      Births is Pop * Birth_rate/1000,
      Deaths is Pop * Death_rate/1000,
      Natural_increase is Births-Deaths,
      Next_year is Year +1,
      New_pop is Pop + Natural_increase,
      explain(Year, Pop, Births, Deaths, Natural_increase,New_pop),
      growth(Next_year,New_pop,End_year).

birth_rate(38).
death_rate(20).
```

Figure 4.42. Teacher Model

The student has constructed their own model in the normal way. When the student is satisfied it is working correctly, instead of typing 'begin' the students enters 'explain'. This then invokes the Prolog statements, that have been constructed from a template by the 'teacher', Figure 4.43.

```
explain :-
        pupil_input(Year,Pop,End_year),
        print_headings,
        growth(Year,Pop,End_year).

explain(Year, Pop, Births, Deaths, Natural_increase, New_pop) :-
        answer(Year, Ppop, Pbirths, Pdeaths, Pnatural_increase, Pnew_pop),
        explain_births(Births, Pbirths, Nbirths),
        explain_deaths(Deaths, Pdeaths, Ndeaths),
        explain_nat_inc(Natural_increase,
Pnatural_increase,Nnatural_increase),
        printout(Year,Pop,Nbirths,Ndeaths,  Nnatural_increase,New_pop), nl,
nl.

explain_births(Births, Births,Births).

explain_births(Births,Pbirths,0) :-
        write('There is a difference in the births'),  nl,
        write('Births are population X birth rate'), nl.

explain_deaths(Deaths, Deaths, Deaths).

explain_deaths(Deaths, Pdeaths, 0) :-
        write('There is a difference in the deaths'), nl,
        write('Deaths are population X death rate'),nl.

explain_nat_inc(Natural_increase, Natural_increase,Natural_increase).

explain_nat_inc(Natural_increase,Pnatural_increase,0) :-
        write('There is a difference in natural increase'),  nl,

        write('Natural increase is births - deaths'),nl.
```

Figure 4.43 Explanation Template

The outputs from the student model that run as a normal Prolog model are shown in Figure 4.44.

```
Enter start year     1970.          Enter start population      1000.
Enter end year     1972.

Year      Pop      Births   Deaths   Incr     Newpop
1970      1000     38       20       58       1058
1971      1058     40       21       61       1119
```

Figure 4.44 Output from Student Model

The output shows that the Prolog has been constructed correctly and that the error lies in the geographical understanding. The request for checking and explanation of errors is invoked by entering the query 'explain'. The program outputs a 0 (zero) if there is a difference in value, between the teacher and the pupil models, Figure 4.45.

```
?- explain.
Year    Pop     Births  Deaths  Incr    Newpop
There is a difference in natural increase
Natural increase is births - deaths
1970    1000    38      20      0       1058
There is a difference in births
Births are population * birth rate
There is a difference in deaths
Deaths are population * death rate
There is a difference in natural increase
Natural increase is births - deaths
1971    1058    40      21      61      1119
```

Figure 4.45 Explanation of Differences

<u>The Design Evaluation of Using Prolog for Modelling</u>

1. The Strengths of Using Prolog Directly
   - A. open ended
   - B. recursion is a powerful tool which can be use implicitly

2. The Weaknesses of Using Prolog Directly
   - A. complex syntax and unfamiliar template structure
   - B. enhancements such as error diagnosis produce very complicated structures to understand

STEP SIX - EVALUATION OF THEMES AND SELECTION OF PROTOTYPE

Introduction

The four design themes, that have been developed, represent the first step in the development of a final system. The initial purpose of expanding the themes into a set of working models, was to appreciate the difficulties in viewing the internal structure of the models. The second purpose was to ensure that a range of geographical examples could be constructed within the modelling system. The third purpose was to gain an appreciation of the complexity of the computer based system, that would be necessary to build suitable and appropriate geographical models.

Viewing the Internal Structure of Models

The expert system in Prolog demonstrated that a decision table structure could give relatively easy access to the model for manipulation and adjustment of internal values. However, the structure of the decision making would require a more direct knowledge of Prolog, particularly its syntactical constructs. The building of a model from first principles in Prolog would require knowledge of Prolog that could reasonably be expected to be beyond the average geography student. The internal structure of the DMS software enabled a clear view of the model. It also facilitated reasonably straightforward methods of building a simple functional geographical model. The construction of the formulae and their methods of display enables simple models, particularly numerical and functional ones, to be built on the spreadsheet. The internal structure of a variety of models in Prolog, showed that the use of a template would have possible benefits over direct Prolog. It could enable students to transfer skills from one model to another and copy the structure of the Prolog.

The Range of Geographical Models

Each of the themes showed that it was possible to produce a full range of geographical models. However, each theme has its strengths and weaknesses. Procedural models fitted easily into the DMS structure as they did into the Prolog template structure. However, DMS was very limited in the use of qualitative and semi - qualitative methods. The spreadsheet, once a template style had been adopted, showed that it could encompass straightforward procedural models. However, it was very restricted in that it could only manipulate numerical data. The use of Prolog showed the benefits of handling textual information but the attempts to extend the modelling resulted in additional complexity.

The Developmental Complexity of a Computer System

In each of the four themes, the movement beyond simple models led to rapidly increasingly complexity. This could partly be attributed to the nature of the very primitive interfaces being used, but also indicated that as the modelling extended across a number of representational and pedagogic issues, then the structures as represented in the development themes became too complex.

Selection of the Prototype

The strengths of DMS can be seen in the tight structure that it gives the student in order to construct a model. The sequence iteration around the model statements allow the student to transfer their basic concepts to another area of geography. The direct use of Prolog was the only tool that could reasonably combine the numerical and textual aspects of reasoning and inference. Therefore, a prototype could be tried with the target audience that would allow both textual and numerical reasoning in Prolog but would supply templates to allow the transferability of skills from one geographical modelling area to another.

STEP SEVEN - DATA COLLECTION : PROTOTYPE WITH TARGET AUDIENCE

Introduction

This prototype system was derived from the ideas discussed in Step Six. The software, which included a word processor and a Prolog compiler was transferred to machines suitable for the use of the target audience. A video recording of the lesson is attached to Volume II. The results produced by the students are given in Appendix Seven.

1. Evaluation Premises

a. purpose : The broad goal of the classroom investigation was to establish whether the students could build a model directly in Prolog. This was to be based on the transference of a model template from a different area of geography.

b. type : The evaluation type is decision oriented, that is, information would be collected that would inform the development of the next design stage.

c. indicators : The typical indicators of the evaluation outcomes would be in two forms. First, the reactions of the students to the problem and the task that is set. These reactions will be identified on the video recording. The second type of indicator will focus on the outputs from the tasks that the students were asked to complete.

The characteristics of the indicators will indicate the strengths and weaknesses of this approach to modelling and may identify possible critical success or failure factors.

The reliability of the indicators is not critical in that the information that is being collected is to inform design decisions, and therefore a more thorough testing may take place at a later phase in the development. However, the students' outputs, to the tasks that are set, can give some tentative cross referencing.

d. side effects : Information from this step will be collected in two ways, the video recording and the output from the student tasks. Both will offer the opportunity to identify any factors not already perceived that may be of special significance.

e. external validity : The formative evaluation at this stage does not lead to external validity and the results cannot be validly generalised beyond the developmental context in which they are posed.

2. The Need for Evaluation

a. the target and purpose of the evaluation results : The results are required to make decisions about the use of a template structure for model building and to deduce the students' capability to directly manipulate Prolog. The results will be used to inform the construction of the next phase of the prototype.

b. the specific objectives for requiring the results:

1. To determine the activities undertaken by the students in the creation of a geographical model using a template.
2. To obtain an indication as to the attitude of the students to the use of the computer for such a task.
3. To establish whether the students could transfer their knowledge of the structure of one geographical model to a different geographical area.

3. Methods

a. format : A 'normal' lesson was taken. The purpose and tasks were explained, and then the students were asked to complete the work. Throughout the lesson a video recording was made. The work completed by the students was collected for analysis at a later stage, and this is shown in Appendix Seven.

b. settings and procedures : This section of data collection focuses on a lesson given to 'A' level Geography students, who were asked to build a model of slope drainage, using a software template based on Prolog. The lesson took place at the end of the summer term when the students had completed the first year of a two year 'A' level course. They were studying the Cambridge 'A' level syllabus. All the students were 17 years old and had previously passed 'O' level Geography. The eight students attended a single sex grammar school in Essex. The group had three Geography lessons per week each of one hour twenty minutes. One teacher had taught the group for one period a week during which they completed the physical geography part of the syllabus. The teacher had been teaching 'A' level geography for eight years. Throughout the course no computers had been used in geography. In addition, virtually no use was made of computers during normal lessons in any subject and therefore the students have had no exposure to using computers.

Each pair of students used a Research Machine Nimbus Personal Computer. Microsoft Word was used to enter and edit the model and a PD-Prolog compiler was used to compile and run the model. None of the students had previously used either the word processor or the compiler.

The author had taken a 90 minute lesson, the previous week, in which the students were introduced to the software and to a population model written in Prolog. The first objective of that lesson was the understanding of the operation of the environment with which they were to work. The second objective was the gaining in familiarity with the structure of a population growth model. The lesson, during which the observation took place, attempted to closely match a 'normal' geography lesson. The group's regular physical geography teacher was in attendance. The aim of the lesson, which was to last about 80 minutes, was given to the students. It was to construct a model that could represent the drainage on a slope. The following were identified as the principal factors that could be included, Figure 4.45

RAINFALL	EVAPORATION
SURFACE WATER	INFILTRATION
OVERLAND FLOW	CHANNEL WATER

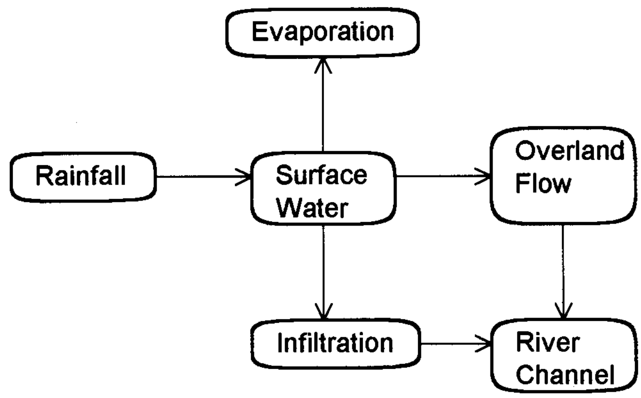


Figure 4.45 Drainage Processes

It was suggested to the students that they should utilise the population growth model structure and representation as the basis for their work . Each pair of students was then allowed to proceed.

4. Data Collected in Response to the Evaluation Objectives

An indirect observation using a video recording was made in order to collect data about the first two objectives. The method of analysis used on the video recording is based on the identification of points in time, throughout the video. These points are determined by the observation of the students, and are either periods of a specific activity, problems encountered, or interpretations of student attitudes. The data collected is itemised by an activity number, a description of the activity, and the reference to the group that was being observed. The elapsed time from the point "Away you go", at which point the students' work begins, is also given

Activity	**Activity Description**	**Time** Min : Secs	**Group**
1	Apprehension of the task that has been set	00.00	A
2	Geographical model building using the diagram	00.30	A
3	Imbalance in contribution from the two members of the group	01.00	A
4	Discussion of relationships within the model e.g. surface water - infiltration	01.10	A
5	Interactive discussion focusing on the use of percentages in the model	01.20	A
6	Review and examination of progress "so what else do we need to know"	01.30	A
7	Checking of the completion of the relations in the model	01.40	A
8	Discussion of problem issues e.g. intensity of rainfall	02.00	A
9	Further review of progress	02.15	A
10	The transfer from the geographical model building to the entry of the model into the modelling system " So how do we enter it ? "	02.24	A
11	Assistance by the teacher in deciding relationships	03.00	B
12	Joint inputs into technicalities of entering the model into the system e.g. positioning of brackets	03.40	B
13	Revision and discussion of entries	04.26	B

14	Identification of syntax issues in the interface to the modelling environment	04.52	A
15	Explanation by one to the other of the capability of the computer to perform the calculations.	05.19	A
16	Examination of what inputs are required to drive the model " Rain and time, is that all ?"	05.25	A
17	Identification of syntax problem, e.g. colon	06.33	A
18	Discussion of relevance of 'Enter'	06.53	A
19	Confusion between the pair in respect of infiltration rate	07.10	A
20	Lack of confidence in establishing relations in the model	07.29	B
21	Students' ideas too simple for the construction of a model, indicated by the teacher	08.17	B
22	Teacher poses issues regarding the order in which the relations are computed	09.25	A
23	Sequence of geographical model represented incorrectly, e.g. location of evaporation in the model	10.10	A
24	Further discussion of relationship between various components of the model	12.24	A
25	Active pair working through discussion of issues	13.23	C
26	The stopping of the progress and reflecting about the nature of one issue i.e infiltration	14.26	C
27	Reference back to the original diagram to check progress	15.27	C
28	Entering model into the computer by following the syntax of the population model	16.50	D

29	Gain in confidence and purpose	18.51	B
30	One student is confident one aspect of the model is correct and the computer will give the appropriate answer	19.02	B
31	Reflection on inputs "only rain and time"	19.21	B
32	Reflection about tasks "we can always come back and do it "	20.02	B
33	Discussion on correction of syntax	20.11	B
34	Understanding of brackets, commas etc from template	20.29	B
35	Reflection on output "got to print something "	22.33	B
36	Progress analysis "let's check we've got everything else right first "	22.43	B
37	Reflection and discussion on model	22.50	B
38	Run through model and check syntax (e.g full stops)	24.52	B
39	Systematic working through of the model following teacher prompting	26.11	D
40	Discussion of relations	26.40	D
41	Confusion about input, calculations and outputs	27.07	D
42	Decision, that a component of model missing e.g. overland flow	27.34	D
43	Discussion about data entries	30.05	D
44	Discussion about syntax	32.50	D
45	Confusion about look-up values	33.47	C
46	Model compiled and printed headings	36.20	D

Objective One 1. To determine the activities undertaken by the students in the creation of a geographical model using a template.

The development of the model was typified by Group A, who started with an attempt to create a model of the geographical aspects from the diagram and information given, (Activity 2). However, the starting point for some, was a difficulty without further assistance from the staff (Activity 11). A initial idea, proposed by a student, was deemed by the teacher to be too simple for the requirement of the question (Activity 21). The subsequent development of the geographical aspects, focus on the clear establishment of the relations (Activities 4, 24, 37, 40). During the development of the model focus was placed on aspects, such as, the range and types of inputs (Activities 16, 31), and the requirements for the outputs (Activity 35).

From the perspective of the organisation of learning, the students demonstrated several methods. These were the identification of stopping points to review progress, either caused by a relevant point in the development, (Activities 6, 7, 9, 13) or the perception of a problem (Activity 26).

Various difficulties arose during the development, either as a result of the students recognising problems, or the teacher pointing out issues. The students then attempted to identify a strategy for resolving the problems (Activities 22, 23, 37, 38, 39, 42). One group referring to the original diagram (Activity 27).

The interface and manipulation of the modelling environment seemed to represent only minor problems for the development and entry of the model (Activities 10, 12, 14, 17, 33, 34)

One group is seen attempting to 'run' the constructed model, (Activity 46).

Objective Two : To obtain an indication as to the attitude of the students to the use of the computer for such a task.

The students demonstrated changing attitudes over the course of the lesson. Initial apprehension, (Activity 1) was typified by the imbalance in contribution between the two members (Activity 3). However, as the work continued so interaction became more positive and more balanced, (Activity 5, 25). Confidence could be seen to grow in the students as they began to focus on the central issues and to identify relevant information. Positive understanding was demonstrated, (Activities 15, 30) . Activity 29 also indicated a clear gain in confidence and purpose

Objective Three : To establish whether the students could transfer their knowledge of the structure of one geographical model to a different geographical area.

Each model produced by the students is compared with the respective part of the population model which had been introduced the previous week. The four models that were produced, are fully shown in Appendix Seven, and are called :

WATER1 WATER2 BANAN LIZALI

The starting point and driving statement in the population model is shown in Figure 4.46

```
begin :-
        data_entry(Year,Pop,End_year),
        print_headings,
        growth(Year,Pop,End_year).
```

Figure 4.46. Initial Statement - Population Model

The groups produced the statements shown in Figure 4.47. The structure and format of the statements given by each group are very similar, with different selections of names for variables.

WATER1
```
begin :-
data_entry(Hour,End_hour),
print_headings,
drainage(Hour,End_hour).
```

BANAN
```
begin :-
data_entry(Rain,Mins,End_mins),
print_headings,
drainage(Rain,Mins,End_mins).
```

WATER2
```
begin :-
data entry(Minute,End_minute),
print_headings,
drainage(Minute,End_minute).
```

LIZALI
```
begin :-
data_entry(Rain,Time),
print_headings,
drainage(Rain,Time).
```

Figure 4.47 Students' Initial Statements

The section on the entry of data from the keyboard was given to them in the population model as shown in Figure 4.48.

```
data_entry(Year,Pop,End_year) :-
        write('Enter start year........ '),
        read(Year),
        write('Enter start population.. '),
        read(Pop),
        write('Enter end year.......... '),
        read(Entry),
        End_year is Entry +1.
```

Figure 4.48 Data Entry - Population Model

The students produced for their models of data entry the details shown in Figure 4.49. The results show a clear similarity, with the exception of LIZALI, which shows an omission of the last line, which concerns implementation details rather than geographical concepts. The section on 'headings' was also produced, in direct accordance with the population example. In the same manner, the section on 'printout', for producing the output details on the screen, shows close resemblance to the original population structure.

BANAN

```
data_entry(Rain,Mins,End_mins) :-
        write('Enter start mins........'),
        read(Mins),
        write('Enter start rain        '),
        read(Rain),
        write('Enter end_mins........'),
        read(Entry),
        End_mins is Entry + 1.
```

LIZALI

```
data_entry(Rain,Time) :-
        write('Enter rainfall intensity            '),
        read(Rain),
        write('Enter period of rain              '),
        read(Time),
```

WATER2

```
data_entry(Minute,End_minute) :-
        write('Enter start minute    '),
        read(Minute),
        write('Enter end minute    '),
        read(Entry),
        End_minute is Entry +1.
```

WATER1

```
data_entry(Hour,End_hour) :-
        write('Enter start hour...... '),
        read(Hour),
        write('Enter end hour      '),
        read(Entry),
        End_hour is Entry +1.
```

Figure 4.49 Students' Data Entry

The main part of the model has three aspects, the first of which is a set of statements where values can be referenced and these are shown in Figure 4.50.

```
birth_rate(38).
death_rate(20).
```

Figure 4.50 - Reference Statements

The students produced the reference statements shown in Figure 4.51. The first three reference statements show a close reflection of the original model. The final one, WATER1 shows an increased level of referencing, with different rainfall, evaporation and infiltration, at different times.

BANAN

```
Evaporation_rate(30),
Infiltration_rate(30).
```

LIZALI

```
infiltration_rate(24).
evaporation_rate(30).
```

WATER2

```
infiltration_rate(40).
evaporation_rate(40).
rain(10).
```

WATER1

```
rainfall(1,20).
rainfall(2,30).
rainfall(3,40).
evaporation(1,10).
evaporation(2,15).
evaporation(3,20).
infiltration(1,5).
infiltration(2,7.5).
infiltration(3,10).
```

Figure 4.51 Students' Reference Statements

The second part of the model contains the fundamental geographical structure that is to drive the model . The population example is given in Figure 4.52

```
growth(Year,Pop,End_year) :-
        birth_rate(Birth_rate),
        death_rate(Death_rate),
        Births is Pop * Birth_rate/1000,
        Deaths is Pop * Death_rate/1000,
        Natural_increase is Births-Deaths,
        Next_year is Year +1,
        New_pop is Pop + Natural_increase,
        printout(Year,Pop,Births,Deaths,
        Natural_increase,New_pop),
        growth(Next_year,New_pop,End_year).
```

Figure 4.52 Population Model

The full models, produced by the students, are shown as follows :

BANAN - Figure 4.53

LIZALI - Figure 4.54

WATER2 - Figure 4.55

WATER1 - Figure 4.56

(they have been tidied in terms of layout, but the contents have not altered from Appendix Seven, line numbers have been added to assist referencing) .

```
BANAN
1 drainage(Rain,Mins,End_mins) :-
2        evaporation_rate(Evaporation_rate).
3        infiltration_rate(Infiltration_rate).
4        Evaporation is Evaporation_rate * Rain / 100,
5        Infiltration is Infiltration_rate*Surface_water / 100,
6        Surface_water is Rain - Evaporation,
7        Overland_flow is Surface_water - Infiltration,
8        Channel_water is Overland_flow + Infiltration,
9        Next mins is Mins+1
10       printout(Mins,Rain,Evaporation,Infiltration, Surface_water,
         Overland_flow, Channel_water),
11       drainage(Rain,Next_mins,End_mins).
```

Figure 4.53 BANAN Drainage Model

In Figure 4.53, Line 2 and 3, reference the evaporation and infiltration rates that have previously been stored. Line 4, calculates the evaporation rate as a percentage of rainfall. In line 5, the amount of infiltration is calculated from the infiltration rate multiplied by the surface water. However, at this point, the surface water has not been calculated. Line 6 should come before line 5. The overland flow and channel water are correctly worked out in lines 7 and 8. The minutes are then incremented and the table of results printed out. The model thus represents a very simple flow of water down a slope, with no inclusion of the delay of the infiltrated water reaching the channel .

```
LIZALI
1 drainage(Rain,Time) :-
2        infiltration_rate(Infiltration_rate),
3        evaporation_rate(Evaporation_rate),
4        evaporation is Rain * Evaporation_rate/1000,
5        Surface_water is Rain-Evaporation,
6        infiltration is surface_water * Infiltration_rate/ 1000,
7        Overland_flow is Surface_water-infiltration,
8        asserta(infiltration(Time,Infiltration)):-
9        Delay is Time-2,
10       infiltration(Delay,Delay_infiltration),
11       Channel_water is Overland_flow+infiltration,
12       printout(Rain,Time,Infiltration_rate,Evaporation_rate,
         Overland_flow, Channel_water),
13       New_time is Time+1,
14       drainage(Rain,New_time).
```

Figure 4.54 LIZALI Drainage Model

In Figure 4.54. Line 1 - 7, follow the same structure as the previous model, except the ordering is correct. Line 8 asserts, that is saves, the amount of infiltration against the time. Line 9, then calculates the delay for the infiltration to be 2 time units. The infiltration for 2 time periods is retrieved in line 10. This model has added a delay in the infiltrated water reaching the river channel.

```
WATER2
1       drainage(Minute,End_minute) :-
2       infiltration_rate(Infiltration_rate),
3       evaporation_rate(Evaporation_rate),
4       rain(Rain),
5       Surface_water is Rain,
6       Infiltration is Infiltration_rate * Surface_water/100,
7       Evaporation is Evaporation_rate * Surface_water/100,
8       Overland_flow is Surface_water-(Evaporation+Infiltration),
9       Channel_water is Overland_flow+Infiltration,
10      Next_minute is Minute +1,
11      New_rain is Rain+10,
12      printout(Minute,Rain,Surface_water,Infiltration,
        Evaporation, Overland_flow, Channel_water),
13      drainage(Next_minute,New_rain,End_minute).
```

Figure 4.55 WATER2 Drainage Model

The model, in Figure 4.55, is similar to BANAN, in that it does not include delays of infiltrated water. However, it does attempt to show a progressive increase in rainfall. Line 4, reads in the starting amount of rain. Line 11 then increments the rain by 10 units. This is then passed out on line 13. However, technically 'New_rain' should also have been included in line 1 if the model is to work.

```
WATER1
1 drainage(Hour,End_hour) :-
2       rainfall(Hour,Rainfall),
3       evaporation(Hour,Evaporation),
4       infiltration(Hour,Infiltration_rate),
5       Surface_water is Rainfall*Evaporation/100,
6       Infiltration is Surface_water-Infiltration_rate/100,
7       Overland_flow is Surface_water-Infiltration,
8       River_channel is Infiltration+Overland_flow,
9       printout(Hour,Rainfall,Evaporation,Surface_water, Infiltration,
        Overland_flow, River_channel),
10      Next_hour is Hour+1,
11      drainage(Next_hour,End_hour).
```

Figure 4.56 WATER1 Drainage Model

The model, in Figure 4.56, shows a slight variation again, in that the rainfall, evaporation and infiltration, are each read from the reference section, so that each hour has different values, lines 2,3,4. The remainder of the model then calculates the channel water without any delay in the infiltrated flow.

The last part of the entry, is the line which stops the model repeating endlessly. It should be of the same structure as the first and last lines of the model, however, within the line, there should a terminating value for the counting variable. The LIZALI entry did not have a terminating value but the remainder did.

5. Comments about the Collected Data

Objective One : The students demonstrated a sequenced and systematic approach to the creation of the model. The video clearly shows active discussion of the issues and the resolution of difficulties. The management of their own learning was also an interesting factor with the identification of revision and progress points.

Issues to be Addressed during Design : The diagram, as well as being a starting point, also acted as a reference during the development of the model. The facility to allow the systematic progress to a particular point is a useful function. One point of confusion focused on the correct sequencing of the activities.

Objective Two : The change in the attitude of the students, throughout the video, was most marked. The students' confidence grew as they explored the ideas, and saw the relevance of the tasks. The discussion, whilst one sided and stilted at the beginning, became more lively and interactive as the understanding fell into place.

Issues to be Addressed during Design : The initial setting of the tasks, and the first steps, require a careful strategy for their introduction so that the students may begin to effectively work with the system, and to gain the confidence required in order to produce a good answer

Objective Three : The outputs from the students showed that they have an overall understanding of the modelling process, and that they could transfer the template from one form of model to another. The work did have minor syntactical errors that would have been frustrating in the long term, as they would have solved the geographical issues, but then would have been unable without, a significant time period, to solve the program issues.

Issues to be Address during Design

Minimalise the syntactical convention as far as possible.

STEP EIGHT - CONSOLIDATION OF DESIGN

Introduction

The consolidation of the design in this step is based on the two inputs of :

- the themes and models that have been developed
- the trials and data collected from the students

Issues for Inclusion in the Final Prototype

1. The final prototype model environment should be able to demonstrate both procedural and declarative modelling. The student should have the facility to use a combination of both forms.

2. The opportunity should be available for the student to initiate their own area for the transfer of a model template

3. The output from the procedural aspects should be able to be presented in tabular and graphical form. This reflects the comments made by the students about the output from DMS. However, recognition should also be taken of complex numerical output that the students in the PUDDLE interview implied led to initial confusion.

4. The interface of the model environment should be such as to improve the accessibility to the students, and to reduce the amount of non-geographical understanding, that is required to run the models.

5. The benefits of group working were indicated in the video recording of the PROLOG trial, and so the final prototype should be capable of being used by groups of students.

6. A method should also be used to elicit the direct opinions of the students, as to both the workings of the software, and the appreciation of modelling in geography

STEP NINE - PROTOTYPE METHODS AND CONTENTS

Introduction

The prototype has been developed with four principal examples, that cover the range of ideas suggested for the specification. The four examples are :

1. Village Population Growth
2. Slope Infiltration
3. Regional Location of Industry
4. General Industrial Location

They are fully illustrated in Appendix Eight.

Village Population Growth

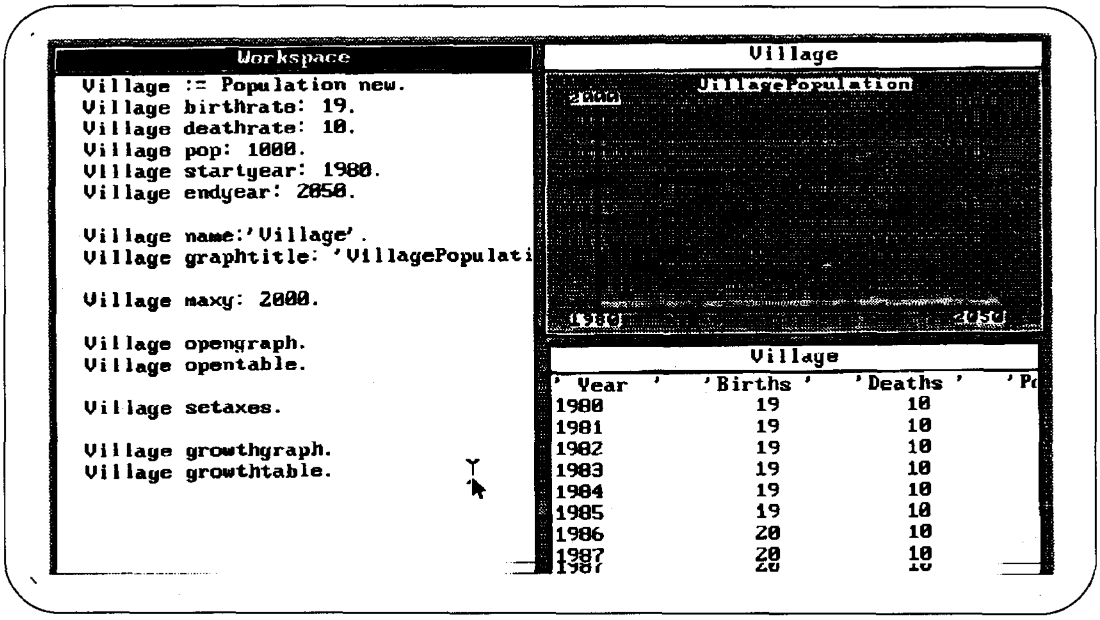


Figure 4.57 - Village Population Growth

The full model for Village Population growth is given in Appendix Eight, Page 219. Figure 4.57 illustrates the growth of a village population. The screen shows three windows, one entitled "workspace", and the other two entitled "Village". One of which contains a graph, which has the title "VillagePopulation", and the second, contains a table of output values. This example is addressed through the manipulation of 'variables' that have already been established in the system. The value of each of the variables can be changed in the "workspace". The variables may be grouped into four sections.

First, the reference for the particular example of population. The line

```
Village := Population new.
```

sets the example to be called "Village", which then precedes each of the variables in the particular example.

Second, those variables that represent the characteristics of the population under consideration. The lines

```
Village birthrate: 19.
Village deathrate: 10.
Village pop: 1000.
Village startyear: 1980.
Village endyear: 2050.
```

set the initial details for the population growth.

Third, the values that are necessary for the drawing of the graph. The line

```
Village name: 'Village'.
```

gives names to the graph and table windows.

The line

```
Village graphtitle: 'VillagePopulation'.
```

gives the title inside the graph window.

The line

```
Village maxy: 2000.
```

gives the maximum value for the top of the vertical axis.

Fourth, there are the statements that open the windows for the graph and table namely:

```
Village opengraph.
Village opentable.
```

The axes and title are drawn in the graph window by the line

```
Village setaxes.
```

The line to draw the graph from the initial values is

```
Village growthgraph.
```

and the line to construct the table is

```
Village growthtable.
```

Several examples many be developed simultaneously. Therefore, if the line

```
Town := Population new.
```

is added, then a town's population growth may be developed in separate windows. All of the values may be changed and the graph and table reconstructed. The lines drawn on any graph, alternate between black and white, and therefore comparisons may be made.

If the lines

```
Village values.
Village graphvalues.
```

are entered in the "Workspace" and evaluated, then all of the variables that may be adjusted are presented in the "Systems Transcript" window.

Slope Infiltration

The full model for Slope Infiltration is given in Appendix Eight, Page 227. Figure 4.58 shows the first of two screens that represent the model for slope run off. This example is addressed through the manipulation of variables that have already been established in the system. The top "Workspace" sets the value for the component parts of the process. The line

```
Runoff := Infiltration new
```

sets the example, in this case called Runoff.

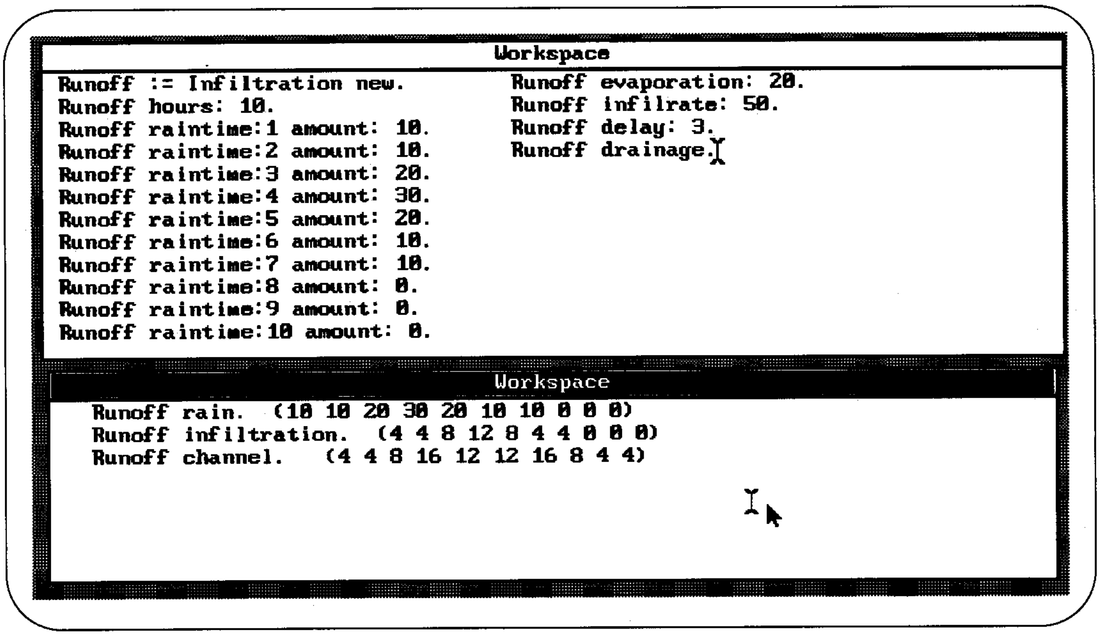


Figure 4.58 Slope Infiltration - Setup

The line

```
Runoff hours: 10.
```

sets the total number of hours for which the process will run.

Each of the next ten statements, the first of which is

```
Runoff raintime: 1  amount: 10.
```

sets the hour and the amount of rain in that hour.

The line

```
Runoff evaporation: 20.
```

sets the rate of evaporation as a percentage of the surface water. Surface water results directly from the rainfall.

The line

```
Runoff infiltrate: 50.
```

sets the rate of infiltration as a percentage of surface water.

The line

```
Runoff delay: 1.
```

sets the delay in hours between the water that is infiltrated and the water that flows overland.

The line

```
Runoff drainage.
```

starts the process working and stores the result, namely the amount of water infiltrated each hour, and the amount of water that reaches the river channel each hour.

The bottom "Workspace" in Figure 4.58 represents a second work space, that has been opened so that the results of the process, can be inspected. If each of the three lines

```
Runoff rain.
Runoff infiltration.

Runoff channel.
```

is evaluated then the ten resultant values of each will be displayed.

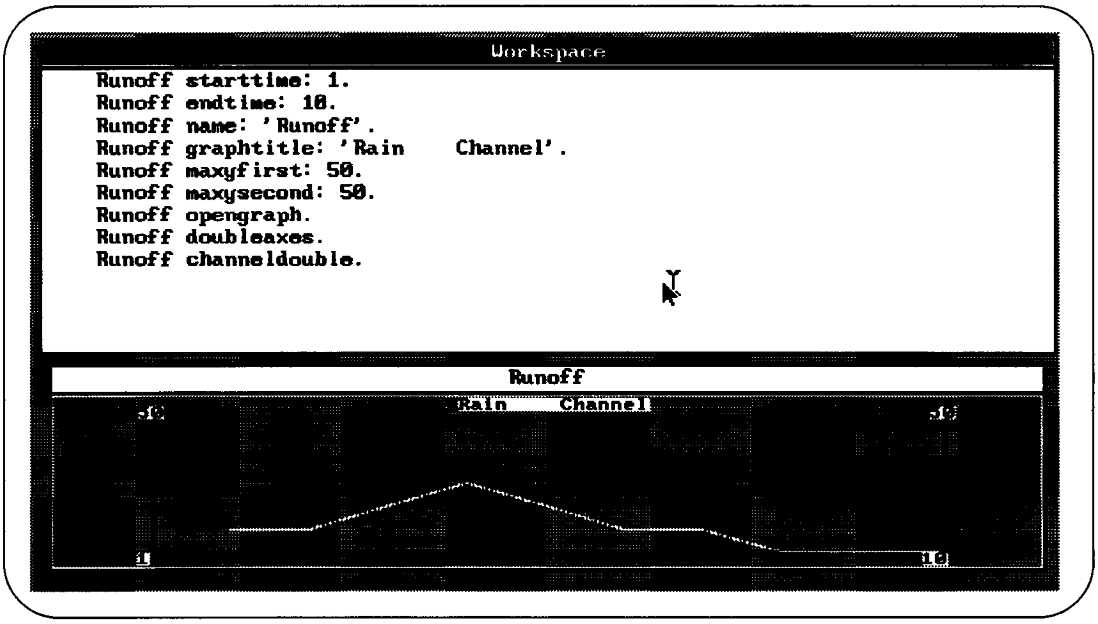


Figure 4.59 Slope Infiltration Output

In Figure 4.59 the "Workspace" at the top of the screen, represents the workspace that contains the initial values that have been scrolled, to give the initial settings for the construction of a double line graph, which will plot both the rainfall and channel water.

The limits for the x-axis are set by the lines

```
Runoff starttime: 1.

Runoff endtime: 10.
```

The line

```
Runoff name: 'Runoff'
```

sets the title of the window that is to contain the graph.

The line

```
Runoff graphtitle: 'Rain   Channel'
```

sets the title of the graph, with Rain referring to the left y-axis, and Channel referring to the right y-axis.

The lines

```
Runoff maxyfirst: 50.

Runoff maxysecond: 50.
```

set the maximum of the two y-axes, respectively the left and the right.

The line

```
Runoff opengraph.
```

opens the window in which the graph will be drawn by prompting the user.

The line

```
Runoff doubleaxes
```

draws the axes and the labels for the graph.

The line

```
Runoff channeldouble
```

draws the graph from the values of the rainfall and the river channel.

A new set of inputs and values may be started following the resetting of the existing results to nil. The line

```
Runoff reset
```

will cause the resetting of the rainfall, infiltration and channel values to nil.

The various initial values may be changed at any time, providing the number of hours is not changed. Thus the following could be changed :

```
Runoff raintime: 6 amount: 50.
Runoff delay: 5.
Runoff evaporation: 2.
```

If the line

```
Runoff drainage.
```

is then evaluated, then the new graph can either be superimposed or redrawn from the start.

Regional Location of Industry

The Regional Location of Industry model is given in Appendix Eight, Page 230. Figure 4.60 is a qualitative model that is concerned with the decisions taken when an industry is deciding in which region to locate. The decision process is initially based on four divisions of input. Those four divisions are:

1. Physical Resources

2. Human Resources
3. Market Capability
4. Financial Analysis

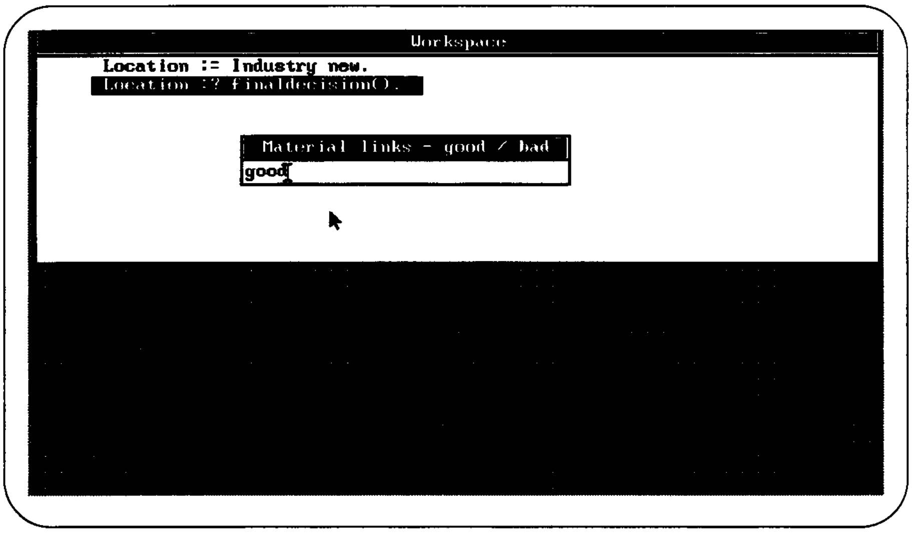


Figure 4.60 Regional Location of Industry

Each of the four, has two questions and each question has two alternative answers. Each question begins with :

" Does the region under consideration have ...."

Physical Resources :

Question	- Input Materials	Answer	- yes / no
Question	- Material Links	Answer	- good / bad

(other similar industries / component suppliers)

Human Resources :

Question	- Skilled Labour	Answer	- large / small
Question	- Unskilled Labour	Answer	- large / small

Market Capability :

Question	- Market Demand	Answer	- high /low
Question	- Transport	Answer	- network / insular

Financial Analysis :

Question	- Capital (available)	Answer	- development / normal
Question	- Land	Answer	- plentiful / scarce

In Figure 4.60, the "Workspace" window at the top of the screen gives the statements that drive the questions, and then there is room to record the answer for each region. The answer is suggested by the system, but the user enters it into the workspace so that a summary for all regions is created.

The line

```
Location := Industry new
```

sets up the example entitled 'Location'.

The line

```
Location :? finaldecision().
```

is required to start the questions appearing on the screen. The questions appear in their own window, with the title of the window, and the alternative answers that are possible appearing in the top frame of the window. The illustration show the question "Material Links" with the alternative replies "good" or "bad". The line below, on which the word "good" appears, is the default answer and can be accepted by pressing return. Having worked through each question in turn, the final decision is then also displayed in its own window.

General Industrial Location

The full model for the Generalised Inudstrial Location is given in Appendix Eight, Page 233. Figure 4.61 shows a qualitative model based on the Expert System, which was Theme One in the developed examples. It is concerned with the characteristics of the location of an industry. Any industry may be selected and a series of details about that industry are required.

The questions posed are :

Question - Name of industry

Answer - Any

Question - Year

Answer - Between 1860 and 1986

Question - Weight One (Weight of input material one)

Answer - heavy / moderate / negligible

Question - Distribution one (Type of distribution of one)

Answer - restricted / everywhere

Question - Source one (Source of input material one)

Answer - Any

The questions weight, distribution, source are repeated for the second input material.

Question - Industry size

Answer - veryLarge / large / moderate / small / workshop

Question - Market size

Answer - national / regional / local

Question - Market Target

Answer - Industry / Consumer / both

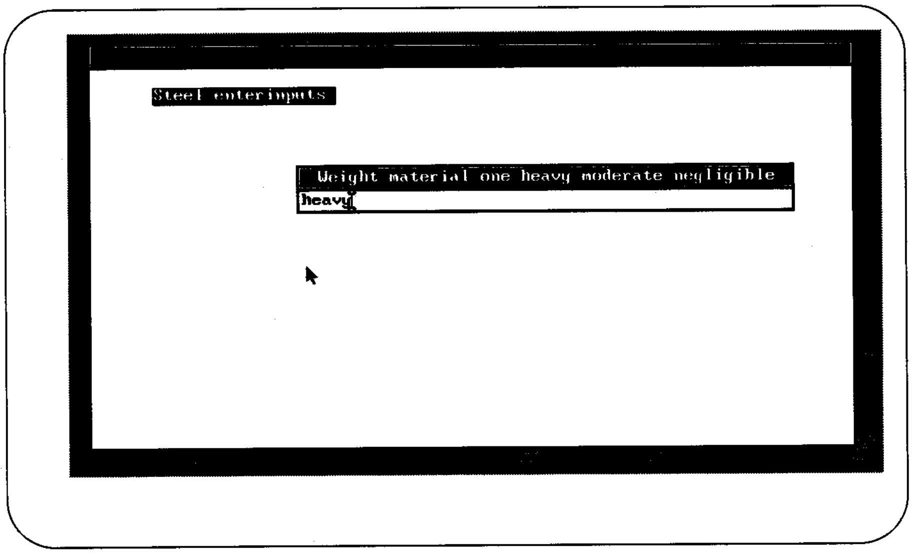


Figure 4.61 Question Prompts for Industrial Location

The question are posed by the system as shown in Figure 4.61. A command line can then be entered that prompts for the opening of a window, which is done at the top of the screen. After the last prompt window. The line :

```
Ind results
```

is evaluated and the initial input values and the conclusions are given in the window, Figure 4.62.

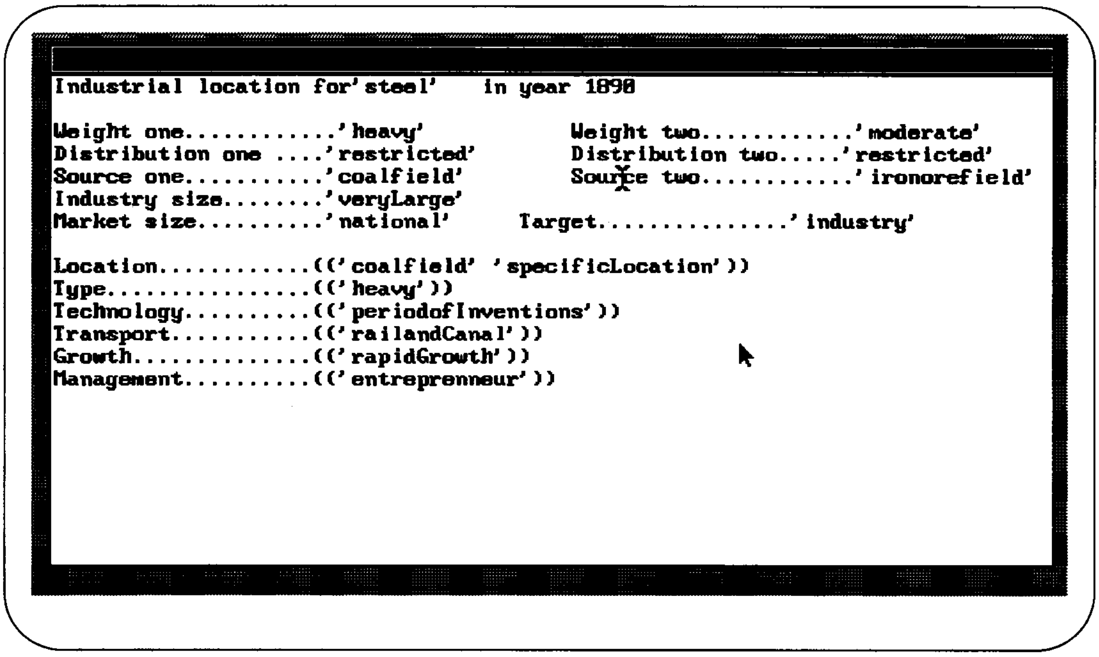


Figure 4.62 Outputs from Industrial Location Model

The changing of individual input values is possible, by invoking a line in the bottom working window. The message that follow the global variables are given and the new values are placed after the colon, Figure 4.63

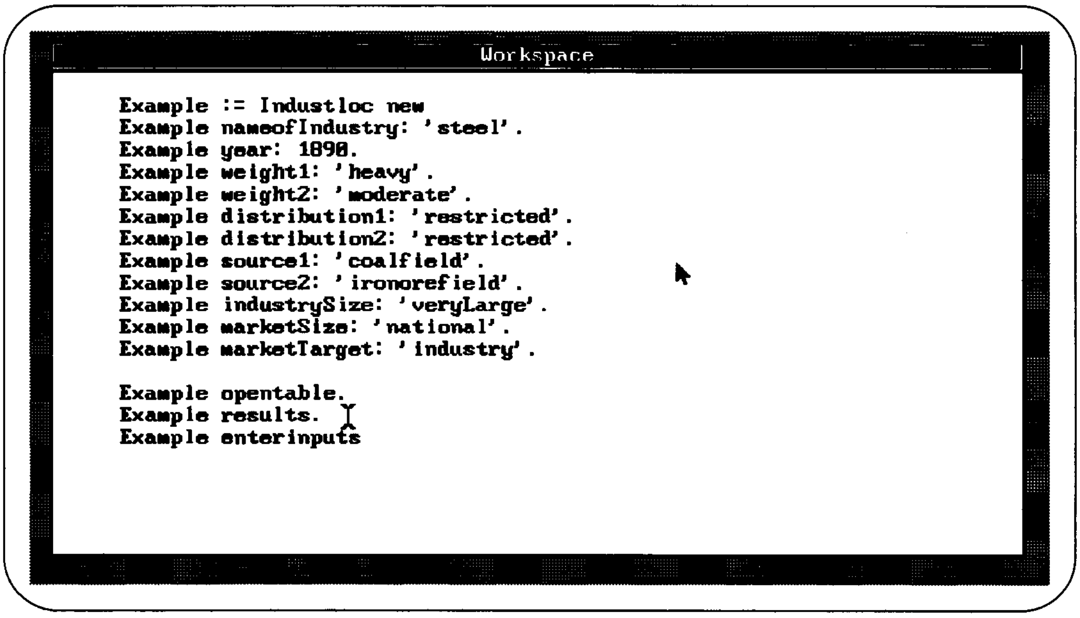
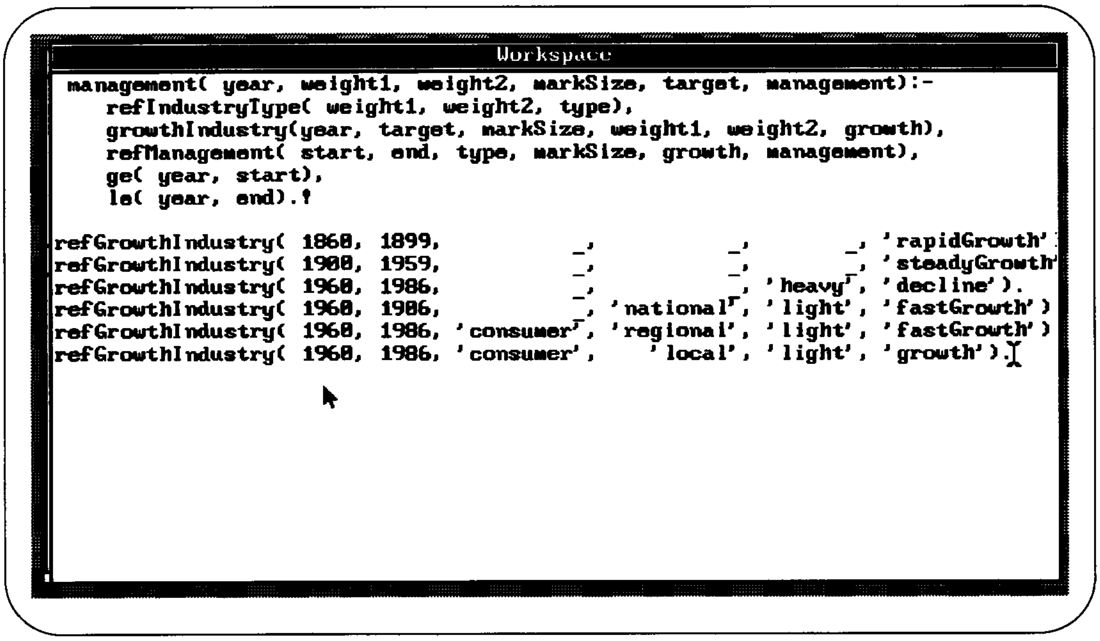


Figure 4.63 Changing Individual Values

The 'rule' and the decision table can be accessed via a browsing function. The layout of the rule and the structure of the decision table is given in Figure 4.64



```
Workspace
management( year, weight1, weight2, markSize, target, management):-
    refIndustryType( weight1, weight2, type),
    growthIndustry(year, target, markSize, weight1, weight2, growth),
    refManagement( start, end, type, markSize, growth, management),
    ge( year, start),
    le( year, end).

refGrowthIndustry( 1860, 1899,           _,          _,        _, 'rapidGrowth'
refGrowthIndustry( 1900, 1959,           _,          _,        _, 'steadyGrowth
refGrowthIndustry( 1960, 1986,           _,          _, 'heavy', 'decline').
refGrowthIndustry( 1960, 1986,           _, 'national', 'light', 'fastGrowth')
refGrowthIndustry( 1960, 1986, 'consumer', 'regional', 'light', 'fastGrowth')
refGrowthIndustry( 1960, 1986, 'consumer',    'local', 'light', 'growth').
```

Figure 4.64 Rule and Decision Table Structure

STEP TEN - DATA COLLECTION : PROTOTYPE WITH TARGET AUDIENCE

Introduction

This section has three parts. The first two parts are two-hour lessons given to 'A' level Geography students. The initial session focused on the manipulation of the existing models and in gaining familiarity with the system. The logs of the students' activities are given in Appendix Nine. The second session invited the students to construct a model of their own choosing. The third aspect of data collection was a questionnaire given to the students. The questionnaire focused on the students' perceptions of the practical sessions and the software tools. The full questionnaire replies are given in Appendix Ten.

Manipulation of Existing Models

1. Evaluation Premises

a. purpose : The broad goal of the activities was to establish whether the students could utilise the software environment for modelling and to gain an insight into their perception of the activities.

b. type : The evaluation type is decision oriented, that is, the information collected will be used to inform the production of the specification for the final product.

c. indicators : Typical indicators of the evaluation would be the successful completion of the exercises and a range of positive points in the use of the software environment.

The characteristics of the indicators would be the production of sound geographical ideas.

The validity of the replies will be established by cross-referencing the work completed by the students.

d. side effects : The students will be taught in a normal lesson. Issues raised by the students in the lesson will be noted A log of the activities produced by the students, can be used to identify any unusual or unplanned aspects that become prominent.

e. external validity : The results from this data collection are not universally generalisable but will produce information that may contribute to the next stage of the development.

2. The Need for the Evaluation

a. the target and purpose of the evaluation results : These results are to be used to make decisions concerning the content and structure of the final product, the contents and style of which will be identified in a specification.

b. the specific objectives

1. To establish that the students could use the software interface by manipulating a population model.
2. To demonstrate the students could interact with a more complex drainage model.

3. Methods

a. format : A two hour geography lesson was delivered in a computer laboratory. Data was collected from the two sessions, in the form of logs, that were automatically created on the computer by the software and which required no direct involvement by the students. The logs allow the re-creation of the exact sequence of events with the display on the screens, and activities undertaken by the students. Whenever a line is evaluated, that is, the User asks the systems to 'perform' that line, such as save the birth rate with the line "Village birthrate: 19.", the system stores that line in the log file.

b. setting and procedures : The sessions took place at the end of the summer term when the students had completed one year of the two year 'A' level course. They were studying the 16-19 Geography Project syllabus. All students were aged 17, and had previously passed GCSE level Geography. The students attended a Sixth Form College in a shire county. The group had four one hour lessons per week equally divided between two teachers, both of whom had more than five years experience in teaching 'A' level Geography. The group had a little experience of using computers in various subjects, but this did not include geography lessons.

The sessions were given by the author at a computer centre in the local college. No other teachers were present. It was the first occasion on which the author had met the students. The students worked in groups at each machine. Each group of students used a IBM PC AT machine which was running the Smalltalk environment with embedded Prolog. The modelling environment developed by the author acted as the interface for the students.

The lesson commenced with a short general explanation, by the author, of the role of models in geography. Descriptive illustrations were taken from work the students had undertaken in 'O' level Geography.

A population model and the associated instructional information was supplied to the students. The students were given access to the machines and a short period of instruction was given with regard to the control of menus and how to create and use the workspaces.

The following activities were then given to the students :

1. Construct a screen that resembles the one shown in the diagrams.
2. Adjust the values to represent a developed country such as the United Kingdom.
3. Adjust the values to represent a typical Third World country.

This initial set of activities focused on becoming familiar with the modelling tool and being able to do some simple adjustments of pre-existing models.

The second example, given to the students, again involved the setting up of the values for the manipulation of an existing model, that represents the slope runoff. The instructions to help in the construction of the screens was given to the students along with a blank screen that is available when starting the modelling environment.

The following activities were given to them :

1. Construct screens that resemble those in the diagrams.
2. Construct a typical runoff profile for a hot summer day, with a heavy period of rain, for about three hours on a granite hillside.
3. Construct a second profile that would represent a day of intermittent drizzle, in winter, on a chalk hillside.

4. Data Collected in Response to the Evaluation Questions

Objective One : To establish the students could use the software interface by manipulating a population model.

In response to the first part of the task, each group produced a close approximation to the initial requirement, which was to duplicate on the computer system, the screen illustrated on the hand-out. The screen on the hand-out corresponded with the Village Population answer given in Step Nine. The edited log scripts for this activity are shown in Figure 4.65 - 4.68, and Appendix Nine.

```
"evaluate" Village := Population new.!
"evaluate" Village birthrate: 19.!
"evaluate" Village deathrate: 10.!
"evaluate" Village pop: 1000.!
"evaluate" Village startyear: 1980.!
"evaluate" Village endyear: 2050.!
"evaluate" Village name:'Village'!
"evaluate" Village graphtitle:
'Villagepopulation'!
"evaluate" Village maxy: 2000.!
"evaluate" Village setaxes!
"evaluate" Village growthgraph!
```

Figure 4.65 Village Population Group JT

```
"evaluate" Village := Population new.!
"evaluate" Village birthrate: 19.!
"evaluate" Village deathrate: 10.!
"evaluate" Village pop: 1000.!
"evaluate" Village startyear: 1980.!
"evaluate" Village endyear: 2050.!
"evaluate" Village name:'Village'.!
"evaluate" Village maxy: 2000.!
"evaluate" Village setaxes.!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!
```

Figure 4.66 Village Population Group KE

```
"evaluate" Village :=Population new.!
"evaluate" Village birthrate: 19.!
"evaluate" Village deathrate: 10.!
"evaluate" Village pop: 1000!
"evaluate" Village startyear: 1980!
"evaluate" Village endyear: 2050.!
"evaluate" Village graphtitle: 'Village
population'!
"evaluate" Village maxy: 2000.!
"evaluate" Village setaxes.!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!
```

Figure 4.67 Village Population Group RM

```
"evaluate" Village := Population new!
"evaluate" Village birthrate: 19!
"evaluate" Village deathrate: 10!
"evaluate" Village pop: 1000!
"evaluate" Village startyear: 1980!
"evaluate" Village endyear: 2050!
"evaluate" Village name:'Village'!
"evaluate" Village graphtitle: 'Village
population'!
"evaluate" Village maxy: 2000.!
"evaluate" Village setaxes.!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!
```

Figure 4.68 Village Population Group ST

```
JT
"evaluate" Village birthrate: 10.!
"evaluate" Village deathrate: 10.!
"evaluate" Village setaxes.!
"evaluate" Village := Population new.!
"evaluate" Village pop: 1000.!

KE
"evaluate" Village birthrate: 20.!
"evaluate" Village deathrate: 18.!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!

RM
"evaluate" Village birthrate:    10.
Village deathrate:    10.
Village startyear:    1980.
Village endyear:      2000.
Village pop:          900.!
"evaluate" Village growthgraph!

SS
"evaluate" Village setaxes.!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!
"evaluate" Village birthrate: 20.!
"evaluate" Village deathrate: 18.!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!
```

Figure 4.69 Developed Country Model

Figure 4.69 shows the population figures for a developed country . Group SS omitted this first part of the question.

```
KE
"evaluate" Village birthrate: 40.!
"evaluate" Village deathrate: 25.!
"evaluate" Village growthgraph.!

SS
"evaluate" Village birthrate: 40.!
"evaluate" Village deathrate: 25.!
"evaluate" Village growthgraph.!

ST
"evaluate" Village birthrate: 50!
"evaluate" Village deathrate: 38!
"evaluate" Village growthgraph.!
"evaluate" Village growthtable.!
```

Figure 4.70 Developing Country

The final part of the population task was to amend the model inputs, to represent a developing country, Figure 4.70. Two groups did not complete this section. Overall, the outputs show a satisfactory grasp of the idea, with the principal aspects of birth and death rates being amended. However, such items as the titles etc. were not altered.

Objective Two : To demonstrate the students could interact with a more complex drainage model.

The students were asked to produce three variations on the slope drainage theme, the first, a duplicate of the general information given in the notes. The second, for a granite hillside, and the third, for a chalk hillside. Again, the students manipulated the figures but did not adjust the titles of the graphs or tables.

Runoff evaporation: 20.
Runoff infilrate: 50.
Runoff delay: 1.

Runoff evaporation: 40.
Runoff delay: 1.
Runoff infilrate: 5.

Figure 4.71 Slope Drainage KE Group

The initial values set by the KE group are as specified, Figure 4.71. The second set of figures represent the granite landscape, with infiltration set to a relatively low percentage figure, with delay and any underground water reaching the river also set to

Runoff evaporation: 40.
Runoff delay: 1.
Runoff infilrate: 5.

Figure 4.72 Slope Drainage JT Group

a low value. The third circumstance was not attempted by the KE group. The JT group only produced the initial values, Figure 4.72

Runoff evaporation: 20.
Runoff delay: 1.
Runoff infilrate: 50.!

Runoff evaporation: 50.
Runoff delay: 5.
Runoff infilrate: 1.

Runoff evaporation: 10.
Runoff delay: 10.
Runoff infilrate: 60.!

Figure 4.73 Slope Drainage RM Group

The RM group, Figure 4.73, produced the initial values and then produced values for the subsequent sections, which show rapid runoff and high evaporation for the summer granite hillside, and low evaporation and long underground delays for the winter chalk hillside. The SS group, Figure 4.74, produced correct interpretations of the initial values, for granite, but did not complete the chalk hillside runoff.

Runoff evaporation: 20.
Runoff infilrate: 50.
Runoff delay: 1.

Runoff evaporation: 40.
Runoff delay: 1.
Runoff infilrate: 5.

Figure 4.74 Slope Drainage SS Group

The ST group, Figure 4.75, adjusted the values correctly in regards to the evaporation and infiltration rates, but with the chalk hillside did not adjust the delay in the underground water reaching the river channel.

Runoff evaporation: 20.
Runoff delay: 1.!
"evaluate" Runoff infilrate: 50.!

Runoff evaporation:40 .
Runoff delay: 1 .!
"evaluate" Runoff infilrate: 5.!

Runoff evaporation:5 .
Runoff delay:1 .
Runoff infilrate:70.

Figure 4.75 Slope Drainage ST Group

5. Comments about Collected Data

Objective One

Although the groups were obviously new to the modelling tool, the results were a little disappointing. The students were encouraged to experiment with the system, however, the number of evaluations was very low, which indicated the students did not generate many attempts at models. For those students, who did attempt to answer the question, as one would expect with 'A' level students, they knew approximately the right values for the birth and death rates for developed and developing countries. However, they did fail to adjust other values e.g. the graph titles.

Objective Two

The results of the drainage model exercise, showed some aspects that reflected understanding of the basic principles, however, again the experimentation was limited and several of the groups either missed out aspects, or omitted to change specific values in order to make their answers acceptable.

The Application of a Model Template to a New Area of Geography

<u>1. Evaluation Premises</u>

a. purpose : The broad goal of this lesson was to establish whether the students can create a model for a different area of geography using a model template.

b. type : The evaluation type is decision oriented, that is the information collected will be used to identify salient points for the specification of the final product.

c.. indicators : The typical indicators of this evaluation would be the construction of a decision based model that embodies sound geographical principles.

The characteristics of the model would be found in the creative application of the model to a different area of geography.

The validity of data collected can be considered in terms of the variations of the answers produced by the students, based on the underlying template. The consistent use of the template structure should give some basic validity to the overall exercise.

The reliability of the indicators are not of prime importance, the data is for developmental decisions only.

d. side effects : The models produced by the students will offer tangible evidence of the activities in which they have been involved. These can be examined for any factors or aspects that are common between them, but have not been specified as a particular objective.

e. external validity : This formative evaluation is not intended to lead to external generalisation, but attempts to add to the information framework for the decision making that will affect the final specification.

2. The Need for Evaluation

a. the target and purpose of the evaluation results : These results are required to make the final decisions about the structure and content of the specification for the product.

b. the specific objectives

1. To establish that the students can identify a suitable area of geography for the construction of a model using the decision making template.

2. To determine that the students can construct an appropriate model that is geographically sound.

3. Methods

a. format : A two-hour geography lesson, with the students' answers to the problem posed, supplying the data for evaluation.

b. setting and procedures : The students were the same as those identified in the previous classroom trial, although the groupings had changed. The lesson introduced the decision model based on the Regional Location of Industry. The students worked through and investigated this model. They were then asked to construct a model of their own choice, for which the decision making structure was applicable. They were also asked to produce typical examples, so that they could test their model.

4. Data Collected in Response to the Evaluation Questions

Objective One : To establish that the students can identify a suitable area of geography for the construction of a model using the decision making template

The groups of student produced decision based models for the following areas of geography :

- Coastal Land Model - which was to determine, through the decision making process, the suitability of coastal land for development
- Nuclear Waste Dumping Model - this determined the suitability of land for the dumping of nuclear waste

- Effects on Ecosystems Model - the model considered the impact of various factors on local ecosystems.

Objective Two : To determine that the students can construct an appropriate model that is geographically sound.

Coastal Land Model

The model was to determine the suitability of a section of coastal land for development. The students identified eight inputs, which they grouped into four groups of two, which followed the structure of the template, Figure 4.76.

Physical Considerations
- the gradient of the land
- the stability of the land

Economic Considerations
- price of the land
- price of protection

Transport
- accessibility
- efficiency

Local Considerations
- environmental damage
- availability of land

Figure 4.76 Input Factors - Coastal Land Model

They then identified two qualitative descriptions for each of the inputs and constructed four tables to show the 'decisions' that would result from each table, Figure 4.77.

Physical Considerations

GRADIENT DOMAIN	STABILITY OF LAND	PHYSICAL
steep	unstable	no
steep	stable	yes
low	unstable	no
low	stable	yes

Economic Considerations

PRICE OF LAND	PRICE OF PROTECTION	ECONOMIC DECISION
high	high	no
low	low	yes
high	low	yes
low	high	yes

Transport Network

NETWORK	ACCESSIBILITY	EFFICIENCY DECISION
good	good	yes
bad	bad	no
good	bad	no
bad	good	yes

Local Considerations

ENVIRONMENTAL DAMAGE	AVAILABILITY OF LAND	LOCAL DECISION
high	high	no
low	low	yes
high	low	no
low	high	yes

Figure 4.77 Decision Structure for Input Values - Coastal Land Model

The students then grouped the outputs from the initial four tables into two tables, one of which addressed the local considerations for the decisions, and the other the human factors, Figure 4.78

Human Considerations

TRANSPORT DECISION	ECONOMIC DECISION	DECISION
yes	yes	yes
no	no	no
yes	no	no
no	yes	yes

Land Considerations

LOCAL DECISION	PHYSICAL DECISION	DECISION
yes	yes	yes
no	no	no
yes	no	no
no	yes	no

Figure 4.78 Intermediate Decision Structure - Coastal Land Model

The final decision table, Figure 4.79 uses the inputs from the human and land tables and produces the final decision.

Final Decision

HUMAN DECISION	LAND DECISION	DECISION
yes	yes	yes
no	no	no
yes	no	no
no	yes	no

Figure 4.79 Final Decision Coastal Land Model

Having constructed the frameworks for their models, the students were then asked to produce examples from their previous knowledge. The group produced those given, Figure 4.80, with the appropriate decision that they decided should be made at each point.

Example - **BARTON-ON-SEA**		**CLACTON-ON-SEA**		**TORQUAY**	
Physical	no	Physical	yes	Physical	yes
Economic	yes	Economic	yes	Economic	yes
Human	yes	Human	yes	Human	yes
Transport	yes	Transport	no	Transport	yes
Environ	no	Environ	yes	Environ	yes
Local	no	Local	yes	Local	yes
Final	no	Final	yes	Final	yes

Figure 4.80 Examples for Coastal Land Model

Suitability of Land for Dumping Nuclear Waste

This group commenced with an example description of the factors affecting nuclear waste, Figure 4.81

Example - SIZEWELL

GEOLOGICAL	stable	yes
AQUIFER		no
POPULATION	within 50 km	yes
	large	yes
PUBLIC OPINION	opposed	no
	well-informed	yes
FINANCE	capital	development
	land	plenty

Figure 4.81 Example for Dumping nuclear Waste

The various decision making structures, following from the template, were then constructed Figure 4.82. The intermediate decisions are shown in Figure 4.83.

Geology

STABLE	AQUIFER	GEOLOGICAL DECISION
yes	yes	no
yes	no	yes
no	yes	no
no	no	no

Population

WITHIN 50 KM	LARGE	POPULATION DECISION
yes	yes	no
yes	no	no
no	yes	yes
no	no	yes

Public Opinion

OPPOSED	WELL INFORMED	OPINION DECISION
yes	yes	no
yes	no	no
no	yes	yes
no	no	yes

Finance

CAPITAL	LAND	FINANCE DECISION
development	plenty	yes
development	scarce	no
normal	plenty	no
normal	scarce	no

Figure 4.82 Suitability for Nuclear Waste

Land Suitability

GEOLOGICAL DECISION	FINANCE DECISION	LAND SUITABILITY
yes	yes	yes
yes	no	no
no	yes	yes
no	no	no

Social Suitability

POPULATION DECISION	OPINION DECISION	SOCIAL SUITABILITY
yes	yes	yes
yes	no	yes
no	yes	yes
no	no	no

Figure 4.83 Intermediate Decisions

Final Decision

LAND DECISION	SOCIAL DECISION	FINAL DECISION
yes	yes	yes
yes	no	no
no	yes	no
no	no	no

Figure 4.84 Final Decision

The final decision for the dumping of nuclear waste is shown in Figure 4.84.

Effects on Ecosystems

The factors affecting the ecosystem are shown in Figure 4.85

Physical Effects

INDUSTRY	POLLUTION	DECISION ONE
large	small	no
large	large	yes
small	small	no
small	large	yes

Human Effects

TOURISM	POPULATION	DECISION TWO
high	high	yes
high	low	yes
low	high	yes
low	low	no

Ground Effects

GRADIENT	WATER TABLE	DECISION THREE
high	high	yes
high	low	no
low	high	yes
low	low	no

Vegetation

SOIL TYPE	VEGETATION	DECISION FOUR
acidic	non-varied	yes
alkaline	varied	no
acidic	varied	no
alkaline	non-varied	yes

Figure 4.85 Effects on Ecosystems

DECISION ONE	DECISION TWO	DECISION A
yes	yes	yes
yes	no	yes
no	yes	yes
no	no	no

DECISION THREE	DECISION FOUR	DECISION B
yes	yes	yes
yes	no	no
no	yes	yes
no	no	no

Figure 4.86 Intermdeiate Decisions Ecosystems

DECISION A	DECISION B	FINAL DECISION
yes	yes	yes
yes	no	yes
no	yes	yes
no	no	no

Figure 4.87 Final Decision Effects on Ecosystems

Example - RIVER BASIN AT WITHAM IN ESSEX / HARLECH SAND DUNES

RIVER BASIN AT WITHAM IN ESSEX		HARLECH SAND DUNES	
INDUSTRY	large	INDUSTRY	small
TOURISM	low	TOURISM	high
POPULATION	large	POPULATION	small
SOIL TYPE	alkaline	SOIL TYPE	acidic
GRADIENT	low	GRADIENT	low
WATER TABLE	low	WATER TABLE	high
VEGETATION	varied	VEGETATION	varied
POLLUTION	low	POLLUTION	low

Figure 4.88 Examples for Effects on Ecosystems

The intermediate decision for the impact on ecosystems is shown in Figure 4.86, with the final decision given in Figure 4.87. Examples of the impacts on the ecosystems are shown in Figure 4.88

Comments about Findings

The selection of the examples seemed clear and suitable for the purpose. The actual construction of the decision making structures were technically correct, and could be the basis for discussion. For example, the students show that although they consider BARTON to have good transport links, and that economically it would be feasible the overall decision would be no. The tables give many questions that could be followed up by the teacher in pursuing these models, such as how do the students justify the difference in the transport decision between CLACTON and TORQUAY.

SMALLTALK QUESTIONNAIRE

1. Evaluation Premises

a. purpose : To gain the students' views as to the value and significance of using modelling software during their geography work.

b. type : The evaluation type is decision oriented , that is, the information collected will be used in the final specification for the product.

c. indicators : Typical indicators would be positive or negative reactions to the lesson, and the software.
The validity of the indicators could be judged in terms of the consensus of the opinions.

d. side effects : Issues that are raised on comments made in the 'open' parts of the questionnaire.

e. external validity : This questionnaire is not universally generalisable and is intended only to produce information for the specification stage.

2. The Need for Evaluation

a. the target and purpose of the evaluation results : The results are for decision making and could help to identify any crucial issues that have not been adequately considered.

b. the specific objectives

1. To determine the opinion of the students regarding the strengths and weaknesses of the modelling system in helping to learn geography.

2. To establish the attitude the students have towards using the system.

3. Methods

a. format : A questionnaire had been designed and written out with a series of questions which would allow open answers.

b. setting and procedures : Having completed the exercises on the population and slope drainage, followed by the transfer of the model template, the students were asked to complete the questionnaire about the day.

4. Data Collected in Response to the Evaluation Questions

The full replies to the questionnaires are given in Appendix Ten.

WHAT ARE THE STRENGTHS OF THE SYSTEM IN HELPING TO LEARN GEOGRAPHY ?

There was a general consensus that the system could help give a more thorough understanding of geography. Typical comments, along these lines, included Katie "I think that it will help geographers learn how things are related to one another, and also, as it will encourage people to experiment with things, it will probably increase their understanding". Emma perceived the value of the system, through the way its used, when she wrote " It makes you think because you are not only answering the question but are actually making up the questions as well." James also followed the theme of helping to structure thinking when he added " It allows you to manipulate your knowledge and to show results in a clear way." Matthew thought the modelling environment's strengths, centred around its ability to show relationships. Robert looked at the strengths of the package from its ability to allow experimentation and concluded " (it) helps you remember the relationships as you 'discovered' them yourself as opposed to being told." Sauni followed the same theme, as Robert, as she considered the most important point, was the seeing of actions rather than being told about them. Tony took a different viewpoint, to thinking about the subject, and considered its strength to be " as an aid to project work and revision as it helps display data in a clear and easily understandable way." Stephen took an entirely different perspective, the issue of the wider application of the system across geography, when he wrote " It gives a sound base in general ideas of each section of geography e.g. what ecosystems are about, factors affecting location of development etc. "

WHAT ARE THE WEAKNESSES OF THE SYSTEM IN HELPING TO LEARN GEOGRAPHY ?

Stephen's principal weakness focused on decision tables and the restriction of only two states for each input. This is not a system restriction, but reflects Stephen being an inexperienced user. A similar theme was introduced by Sauni, who considered the system lacked the detailed knowledge required in specific situations. Again, the remarks of a new user to the system. James return to the two state value of the decision table. "It is perhaps too confined in the logic program as there are no in-betweens (yes and no are extremes)." Again, this is not a restriction of the system. Emma's weakness, pursued the same line, concerning the values of the table, however, the author finds her remarks a little confusing when she wrote " Its a bit limited as the system does not deal with opinions, everything has to be classed as a value. However, this is not a real weakness just a slight drawback". Matthew's main identification of weakness was the time it took to type in ideas as he was not used to a keyboard. This was echoed by Katie, who has a clear perception of using such a program in class when she added " I think it may take a long time to program some results in, which is unhelpful, as time on computers is very short in schools " . Matthew did, however, comment that the system was " pretty easy to follow ". Tony, although having a computer background, wrote "the operating system was difficult to get to grips with at first". Robert identified the time it would take to set up examples. He also added the problem of lack of computer skills " may leave people behind ".

DO YOU CONSIDER THE SYSTEM WORTH LEARNING TO HELP IN YOUR UNDERSTANDING OF GEOGRAPHY. PLEASE GIVE REASONS.

This question produced the most mixed responses, with some clearly in favour, whilst others did not see it was worth learning for a variety of reasons. Those in favour included Katie who wrote, " Yes, because when people are experimenting they often come across things they otherwise would not have considered. It will help teachers tie the threads of lesson together." Emma followed a similar line of thought when she wrote " The system is worthwhile - it gets you thinking more and is much different to a normal geography lesson". The remembering of principles, through visual experience, was why Sauni considered it was worth learning and using the system. Stephen agreed that it was worth learning, principally so the outcomes of any sets of circumstances may be seen. Matthew thought the whole system too time consuming and considered it too simple and added " You could be told the information quicker than the computer could tell you ". James summed up the same viewpoint very succinctly when he wrote " I am interested in passing exams only and feel that this is possible from reading books etc. The system is not essential for a full grasp of the subject ". The application of the systems to projects seem to sway Robert just in favour, a point supported by Tony.

DID YOU ENJOY THE DAY ?

There was a unanimous agreement that they had all enjoyed the day using the modelling environment.

DID YOU FIND IT INTELLECTUALLY DIFFICULT ?

Generally the answer was 'no' although there were two references to having to think about the table construction.

WOULD YOU RECOMMEND SUCH A DAY TO YOUR FELLOW GEOGRAPHY STUDENTS ?

A further unanimous verdict that they would recommend the day to their fellow students.

STEP ELEVEN - PRODUCTION OF PROPOSAL FOR FINAL PRODUCT

Purpose

Overall Aim

To produce a software based modelling system, that will allow the development and manipulation of a large range of geographical simulations and models.

Specific Objectives

The developed system is required to :

- allow the running of opaque simulations which have been previously designed and entered into the system
- allow the user to access the underlying structure of the models, and to be able to amend these, both in terms of values and by the addition and deletion of parameters and components
- permit the formulation of a number of supplied 'templates' for models, the structure of which can be made visible to the user. These templates may then act in the same way as 'shells', in the various types of content free software
- allow the student to construct from first principles a model, to enter it into the system, and to be able to run it in simulation mode, so that the inputs and outputs can be tested
- permit the inclusion and access to a wide range of geographical models

Design Criteria

The following design criteria represent the functionality that is expected within the developed modelling system. The developed modelling system must be :

- understandable to the student : in that the method of structuring and representing the models must be clear, so that the student may perceive the overall structure, as well as, the details of the model. The enhancement of the structure through diagrammatic representation would be beneficial

- accessible to the student - in that the interface is constructed to minimalise the difficulties it presents in amending and altering models
- facilitate reflection - in that the student should be able to view any progress made, with a view to re-considering the work completed
- capable of reflecting the teaching strategy of a five stage model namely :

1. to be able to use a simulation and manipulate the inputs and view the consequent output, in different representational forms, e.g. tables, graphs and spatial distributions

2. to be able to view the structure of the internal components of the model and their relationships, so that both, values may be altered and parameters added or deleted

3. to transfer the 'template' of an existing model to a new area, so that a new model can be devised and entered. When this 'new' model has been entered it should be able to be used in simulation mode.

4. to be able to offer a range of 'templates' with examples, so that different areas of geography may be modelled.

5. to be able to offer an environment that facilitates the building of new models from first principles. The facility required to support this, is to be able to selectively combine a series of different template structures, to give a new model which has a new form of 'template'

Representation Methods

Within the developed modelling systems there should be the following representation and inference methods.

1. declarative representation - the use of text and words for the structured description of the problem area. Examples of this form of representation include, industrial location, regional location of industry, and the Sahel model

2. procedural representation - the use of text and / or numerical values in a sequential framework. Examples of this form, are the population and slope drainage models

3. quantitative representation - the facility to enter numerical values which will act as a basis for mathematical or statistical calculations

4. semi-qualitative - the ability to represent as a set of values, various textual descriptions. These would then form the basis for amended decision tables as illustrated in the industrial location and regional location models

5. mathematical - the facility to derive answers from numerical inputs by mathematical and statistical inference

6. logical - the facility to automatically deduce logical inference from simple tabular representations

The above methods should be able to be intermixed, so that models may be constructed, that have both procedural and declarative parts, and deduce conclusions both mathematically and from logical inference.

Interface Components

The interface components should address the 'direct manipulation metaphor' for interface design, de Hoog (1991). Schneiderman (1987) defines, the key ideas of this style of interface, as the visibility of objects and actions of interest. The command language syntax is replaced by the direct manipulation of objects. Objects on the screen are a representation of real world objects. Actions, such as navigation, are performed with a pointing device such as a mouse. This reduces the amount of syntax knowledge required by the user. A hypertext style interface could be utilised to allow for the construction of simple data flow diagrams, that would then expand into textual and numerical descriptions, Goble (1987).

Development Examples

The following examples, based on models previously developed, should be included :

Name	Description	Subject Area
Population Growth	A dynamic model demonstrating simple population growth from birth and death rates	*Population*
Variable Population Growth	The dynamic growth of population with the facility to dynamically adjust the birth and death rates	*Population*
Compound Population Growth	The dynamic growth of population with the facility to dynamically adjust the birth and death rates and to include emigration and immigration	*Population*

Sahel	A non-deterministic dynamic model that describes the various relationships between factors that impinge on the region	*Population*
Bid rent Zones	The manipulation and plotting of the bid rent zones for a theoretical city	*Settlement*
Shop Location	The mapping of an area and the identification of the locations for a shopper station within that area	*Settlement*
Farm Production	The calculation of profits and losses from the selection of crop types with specified yields dependent on weather conditions. The various weather conditions are selected at random	*Agriculture*
Infiltration	The modelling of slope run off with various storage units and flows	*Hydrology*
Manning Coefficient	The calculation and manipulation of the inputs to give outputs in accordance with Manning Coefficient calculations	*Hydrology*
Gravity Model	The facility to create and manipulate a gravity model of flow between various cities.	*Transport*
Calibration of Gravity Model	The facility to calibrate the gravity model due to increased data collection on flows between two points	*Transport*
Stepped and Line Costs	The calculation of the cost of transporting raw materials and finished products	*Transport*
Line Costs with Terminals	The calculation of transport cost, using line costs and initial or intermediary location of processing or transhipment terminals	*Transport*
Traffic Flow	The modelling of traffic flow at simple and complex road junctions	*Transport*

Road Building	The modelling of road building, through a mapped area, with inference being made on cost and environmental issues	*Transport*
Least Cost Location	From inputs of transport, fixed and other variable costs, the calculation of optimum and satisficing locations	*Industry*
Exploration	The mapping of an area and the consequent efforts, costs, and environmental issues in developing that area	*Industry*
Industrial Location	Decision making model on the location of industry in a country or region	*Industry*
Industrial Relocation	A decision making model which determines the suitability of a region for the relocation of an industry	*Industry*
Lapse Rates	The calculation of meteorological lapse rates	*Meteorology*

Description of Input Forms

The following types of input are required in order to build models and to enter and manipulate the geographical data that is required of models.

- free form text : this allows text to be entered in various workspaces and evaluated, and does not require the specific and syntactical positioning required of many systems. This is indicated in the SMALLTALK environment and is shown in the trials

- tabular : the development of many models can be completed succinctly and accurately in a tabular form that both helps structure the problem area, and gives a method of cross referencing. This type of input and output, similar to a spreadsheet should be available for the user

- map : in order to be able to satisfactorily represent geographical information, map inputs are specifically needed. This can be in a similar form to the tabular method with the map being represented as a series of 'cells', each of which can be ascribed many characteristics, which can then be modelled together. The station location example, in the spreadsheet models, demonstrates this approach

- structure diagrams : the initial formation of a diagram of a model is important. The facility to enter the diagram in box form and to then invoke lower levels, as in a hypertext system, is a requirement

Output Descriptions

The form of output should be under the control of the user. The various forms of outputs that would be required include :

- textual : the output of words or descriptions which result from the logical inference of some models
- tabular : the output of numerical values, in the form of a tabular representation, for each of the values. The tabular output form is demonstrated in the DMS
- graphical : numerical outputs from dynamic models should be able to be represented in graphical form, with the choice of the axes variables, being determined by the user. The values plotted on the graph should include the facility to do overlays, as the simulation or model progresses through a series of states
- map : where appropriate the output should be able to be represented in a grid system, that emulates a map. The value plotted in each grid cell, should be under the control of the user

CHAPTER FIVE - SUMMARY AND DISCUSSION

Introduction

This chapter presents a summary of the thesis and in particular examines the principal features of the research. It then moves on to the implications and interpretations of the work. Reference is also made to the limitations of the research methodology. The structure of this chapter follows the recommendations of Borg and Gall (1979).

Brief Restatement of the Problem

The overall aim of this research was to produce a specification for a geographical modelling environment based on a computer system. The specific objectives of the research being :

> *Objective One*
>
> - to investigate the underlying structure of geographical problems and to determine how they may be openly represented on the computer
>
> *Objective Two*
>
> - to demonstrate that a range of geographical models can be implemented in a computer based modelling environment
>
> *Objective Three*
>
> - to show that students can utilise a computer based modelling environment in geography lessons
>
> *Objective Four*
>
> - to indicate ways in which access can be given to model construction and model manipulation on a computer based system

Objective Five

- to produce a specification for a computer based modelling system in geography

Description of the Main Features of the Method

The methodology adopted was based on the Research and Development Methodology, Borg and Gall (1979). The original methodology was devised for teams developing educational products. The methodology was adapted for an individual researcher by the selection, and modification of the initial analysis and design stages. The adaptation was formed into eleven steps, that systematically moved from the original identification of needs, through several classroom investigations, to the final specification. A range of data collection techniques were used including interviews, indirect observation, and the outcomes of modelling exercises that had been completed by the students. A variation of Walker's (1985) formative evaluation schema was used to inform the design decision making process at successive stages. The final specification for the product was given in Step Eleven.

Principal Findings

The principal findings may be considered in respect to the objectives of the thesis.

Objective One

During the development of geographical models, across a range of modelling tools, some common underlying structures were identified. These structures could address the requirements for solving geographical problems, as well as, making sufficiently simple the representation of the problem on the computer. This common structure was referred to as a 'template' for a model. The establishment of a template structure, within a modelling environment, allowed the subsequent development of other models. This was not necessarily from the same geographical area as the first model, but was an example that could easily be implemented using the template. Examples of these templates were indicated during the development of the models and during the classroom trial of the PROLOG prototype. The basic population template was modified to produce a model for hydrological flow. A decision making declarative template was also used by students in the classroom trial of the SMALLTALK environment. The students, on this occasion, produced several different decision making situations based on the original industrial location template.

Objective Two

During the development phase, four modelling bases were chosen and a range of geographical models were developed for each of them. The four themes showed a variety of possible models. With the exclusion of the specialist expert system theme, the other three themes, DMS, spreadsheets and Prolog showed that it was possible to construct a large core of models, that could be implemented on all three modelling bases. This was then extended into the final trial and specification, whereby all of the forms of models, that had been indicated, could be developed.

Objective Three

The data that was collected from the students, in all phases of the research, indicated that the students could both, amend existing models, but also had the strategies for the construction of new models. This was indicated in the comments of the students who had used the PUDDLE program and the DMS. The PROLOG trial gave a clear indication of the ability of the students to transfer from one geographical area to another, and the evidence was shown in the models they produced. A further series of models was also produced by the students using the SMALLTALK environment.

The attitude of students towards modelling could be seen to be positive and they indicated in various ways that the majority of them considered it a worthwhile process. Positive indications were given by the students to both, the use of PUDDLE, and the use of the DMS. The motivation and attitude of the students in the PROLOG trial could be seen and evaluated from the indirect observation of the video recording. The personal assessment questionnaire, given to the SMALLTALK trial students, also showed an overall positive view of the process of modelling, in relation to their geographical education.

Objective Four

Models in geography teaching can be used in a variety of ways. The first may be identified to be the manipulation of the parameters and features of simulations. Second, the underlying model of the simulation may then be accessed and altered. Third, a new model may be constructed from a template of a previous model, with the final way being the construction of a completely new model. The research principally addressed the progress through the first three of these stages. The PUDDLE model and the SMALLTALK population models were forms of simulation manipulation.. The initial stages of the DMS and PROLOG trials, investigated the manipulation of existing models, in these cases, a population growth model. The development of models from pre-existing templates was seen in both the DMS, PROLOG and SMALLTALK trials.

Objective Five

The general specifications that were formed during the Eleventh Step of the investigation, were constructed under a number of headings that resulted from developments whilst conducting the research. These particular points, emphasised the design criteria, the representation methods, the interface components, and the examples that illustrate the 'templates' that could be used in classroom applications.

Conclusions about Findings

The conclusions that may be drawn from the research findings may be grouped into three areas. The geographical issues focus on the range and substance of the geographical knowledge that may be included in the development of computer based models. The second area concerns the most appropriate methods for the representation of the models on the computer system. The third and final area addresses the various pedagogic issues that may be considered with reference to the teaching of modelling.

<u>Geographical Issues</u>

Harvey (1969) identified various methods and tools for geographical analysis that were discussed in Chapter two. Each of these methods and tools have been addressed during the research. The Cognitive Description, the simplest form, may be illustrated by reference to the initial declarations of the contents of the decision making models during the trial of the SMALLTALK environment. Harvey's morphometric analysis was demonstrated in the construction of the model during the PROLOG trial. These models, having been completed, could then be used for simulation purposes. Thus a range of different geographical conditions could be simulated. Both Harvey (1969) and Santos and Ogborn (1992), indicate that the identification of cause and effect, within a domain, can enable the manipulation of the principal aspects of the observed phenomena. The cause-effect analysis underlays the development of the slope drainage model during the PROLOG trial. The development of the Sahel model, during the ideas generation phase, focused on the descriptive textual model that could use the idea of temporal states, as the basis for moving between different phases of the model. The functionalist philosophy of scientific explanation in geography, Harvey (1969), was addressed on the simple structured decision making model in the SMALLTALK environment. The final part of Harvey's classification was systems analysis. The breaking down of the geographical domains, into various component parts, and investigating their relationships, has formed a central part of this research. It has passed through the stages of simulation, the manipulation of existing models, and the derivation of new models.

The spectrum of geographical models, that have been developed, have attempted to identify and cover the principal areas of geographical knowledge. Selected spreadsheet models, can encourage the various aspects of spatial literacy and follow from such conceptual issues in geography, as the calibration of the gravity model. The Systematic approach to Geography, has a variety of models, that have been indicated and demonstrated in the development of the research. The regional perspective of Geography, was demonstrated in models, such as, the industrial location expert system and the decision making model, tested in the SMALLTALK trials. The final Ecosystems approach was demonstrated by the use of the Sahel model in the PROLOG ideas generation phase.

Boardman's (1985) three themes in the approach to Geography, are based on the perception of human interaction, and the control of the environment. These were discussed in Chapter Two. Some of the models produced would cover the first of the themes, Humanistic Geography. The work on decision making in the SMALLTALK trial was taken from the Geography 16-19 Project, Naish (1976,1985). One of the aspects of the behavioural geography theme, is the concept of the 'satisficer' economic man, Wopert (1964), Hoare (1983). The declarative and textual descriptive models of both the expert system in industrial location, and the other Prolog declarative models serve to illustrate how this particular view of Geography may be approached.

Types of Model Representation

The procedural-declarative distinction, introduced in Chapter Two, acted as a basis for the types of modelling environments that were used. The development of the modelling ideas, and the use of the models in the trials, indicated that certain areas are more easily represented in one form of model, while others are more easily constructed in a different form. By utilising an underlying inference method, based on logic, it is possible to represent many geographical areas in a textual description, rather than the more detailed quantitative form. The representation of such models closely aligns with the semi-qualitative models of Bliss and Ogborn (1989). The DMS environment allowed the development of functional models, based on the quantitative procedural idea of dynamic systems. The use of templates, coupled with a modelling environment that permits both logical and mathematical inference, indicates that there would be benefits in mixing the two forms of representation. This is in accordance with Barr et al (1989), who indicate that a mixed form of representation is necessary for the successful description of a complex model.

Pedagogical Issues

It was indicated in Chapter Two, that Santos and Ogborn (1992) have proposed a stage model for the teaching of modelling. Their model is particularly addressed at mathematics. However, van Berkum et al (1991), Goodyear et al (1991) and Bliss and Ogborn (1989) all stress that the learning of modelling should include a variety of guided discovery techniques. A broad theme, that may be drawn from the findings of this research, and from the data collection from the students, suggests that it may be possible to combine the stage development of modelling, with aspects of guided discovery learning to form a synthesized scheme. This is possible if the iterative phases of guided discovery learning outlined by van Berkum (1991) are included.

Stage One of this combined scheme would commence with an examination of a simulation and the manipulation of the inputs of that simulation. The opportunity for the students to experiment, with the various inputs and values from a range of examples, could be included. The student interviews, during the PUDDLE and DMS trials, indicated that they found this approach helpful. Bliss and Ogborn (1989) argue that such experimentation may have to take place before students can attempt to commit their own mental models to a modelling system. van Berkum (1991) suggests this to be part of the Orientation phase, that follows an iterative pattern of observation, analysis, exploration and hypothesis generation. The initial stage of the Santos and Ogborn (1991) teaching model, differs from the combined model, in that the area for model building is first identified, and then a broad model is established which is later refined.

The Stage Two of the combined scheme, would examine and manipulate the model itself, which therefore must be available to the students for inspection and amendment. This would correspond to Bliss and Ogborn's (1989) idea of exploratory learning.

Stage Three would involved the identification, by the teacher, of an area of the subject to which the student could transfer their knowledge of the 'template' of the model. This would correspond to the PROLOG trials, when the slope drainage model was developed from the population model, using the same underlying template.

Stage Four would be when the students were asked to transfer the template to an area of geography selected by themselves. This was demonstrated in the decision making model of industrial location in the SMALLTALK trial. The final Stage would involve, further development with a range of model templates, that are then used in an iterative manner, and which could then lead the student to identify a new model from first principles.

General Evaluation

Whilst evaluating against objectives is a very strong form of drawing conclusions, problems may arise, if inappropriate objectives were chosen in the first place. Knapper (1980) gives five criteria for the evaluation of learning :

1. Students are actively involved in the learning process
2. Learning is improved by practice
3. Learning is orientated towards some goal
4. There are considerable individual differences in learning both in quantitative and qualitative terms
5. Learning is affective and contains emotions such as motivation

The application of these criteria to the activities, within the research, is taken in the context of the Research and Development Methodology. That is, the data collection can indicate particular exemplars of activities, but they cannot validly be generalised beyond the developmental context.

1. Students are actively involved in the learning process

Evidence for this criterion was demonstrated in the video recording of the PROLOG trial, when the students' discussion provided the basis for establishing and understanding the model. Initial reactions from the students on the video, showed a lack of confidence, however, as the lesson progressed the students became much more actively involved in the learning process. During the SMALLTALK trial, the task that was set for the transfer of the decision making 'template', required the students to actively discuss and work together in order to produce any form of solution. Indirect evidence is also supplied by the PUDDLE and DMS interviews and the questionnaire at the end of the SMALLTALK trial.

2. Learning is improved by practice

Little evidence is presented in respect of this criterion, with the exception of remarks made during interviews for the PUDDLE and DMS activities, when more than one student indicated that practice would be essential, in order to obtain a firm understanding of model manipulation and building. However, the nature of a modelling manipulation and creation environment, ensures that active learning must take place, as the requirement for success, depends on a very positive approach to learning from the student.

3 Learning is orientated towards some goal

The goal for all of the modelling activities is the understanding of geographical systems. Particularly the identifying of the components and the establishing of the relationships between those components. The video observation showed active discussion of the inputs, relationships and the outputs from the system under consideration. The data collected in response to the questionnaire, at the end of the SMALLTALK trial, did however, indicate that there were mixed goals among the students, with one reporting that modelling tasks are too time consuming with regard to the goal of passing examinations.

4. There are considerable individual differences in learning both in quantitative and qualitative terms

The development of models, in a learning context, is about understanding concepts and principals and is not directed at learning in a quantitative manner. The success of qualitative learning of concepts is a difficult evaluation task. However, the data collection from the interviews and video observation, does suggest that the students were engaged in activities that could well lead to quality learning. However, the tasks of clearly establishing this, in a generalised way, would fall to the Experimental Research that could be completed with the final product.

5. Learning is affective and contains emotions, such as motivation.

No comments can satisfactorily be made as to the success or failure of the methods employed during the trials, due to the manner in which the data collection was performed. The researcher was an active participant in all activities. The use of the systems were new to the groups, and therefore the 'Hawthorne effect' would be expected. However, two replies, from the SMALLTALK questionnaire, indicate a certain amount of encouragement that this criterion could be met. The first was that they unanimously agreed they enjoyed the experience, and secondly that they would recommend it to their friends.

Evaluation can also be considered against criteria that are recommended for the selection of software for use in a geography lesson. Huckle (1988) offers such criteria.

> *1. Relevance - does the package deal with a significant social situation or issue which affects pupils present or future lives*

The proposed product, can include decision making and social situations, that can enable discussion of issues between the students and the teacher. The video observation of the development of a model, showed clear periods of active debate and discussion about the model.

> *2. Knowledge - is the situation packaged in such a way as to ensure the teacher and pupils gain a critical theoretical grasp of what is going on*
> *- does the package explain or merely describe the social world?*
> *- does it help develop appropriate concepts and theories ?*
> *- does it allow teachers and pupils to consider alternatives to the social arrangements at present ?*
> *- does it allow the teacher and pupils to construct and refine their own knowledge ?*

In order to pass the first stage of the Five Stage model, it becomes increasingly important to understand the components of a system and their inter-relationships. Models can be constructed from both subjective and objective points of view and comparisons of them can further discussion. The video observation indicated clear periods of reflection by the students about the models that was being constructed.

> *3 Social change - does the package have explanations of how the situation arose and how it is likely to change*
> *- does it acknowledge conflict over the present and future nature of society and allow pupils to recognise their own role as potential agents of changes*

Models based, on one of the themes in the development, the Expert Systems, allow for the textual description of the development of a particular phenomenon in geography.

The value of parameters could then be altered and a revision of the decision making structure could be made so as to project ideas into the future.

4. Communication Skills - does the package develop intellectual, communication and social skills

- are these merely coping skills or do they allow social criticisms and effective participation in society

The modelling product would encourage group work, which could be directed to the issue raised above by Huckle.

5. Values and Politics - does the package contribute to values and political education

- does it promote values awareness and clarification and analysis

- does it develop the knowledge skills and attitudes which contribute to political literacy

In order to amend or construct a model, it is necessary to analyse and clarify the requirements. The developmental nature of the stage approach, in combination with declarative decision based models, will allow for the promotion of values and the inclusions of factors of political literacy.

Discussion of the Study's Methodological Limitations

The Research and Development Methodology was selected, as it enabled the collection of data, to facilitate formative decision making about design issues for the modelling system. Within the Steps of the adapted methodology, the formative evaluation that took place was based on Walker (1985). The collection of data was specifically targeted at decision making, and therefore the classroom trials were not conducted on the basis of external validity, beyond the development context. The principal aspects that made such validity limited were, firstly the nature of the samples, which were very restricted, and secondly, in respect of Experimental Research, there was no control group. A further limitation on the generalisation of the results, was the nature of the question posed at the interviews. The questions were only semi-structured, so that any side-effects that were identified could be pursued. The PROLOG and SMALLTALK trials also had the active participation of the researcher, thus directly influencing the facility to broadly generalise the results. The observation method, in the video, attempts to focus on critical design issues and therefore, does not gives a systematic and extensible view of the whole lesson. Whilst the data collection was subjective and restricted, the cross-correlation of the interviews, the work produced and the observations did lead to conclusions, that could be drawn for design issues in accordance with Borg and Gall (1979). As they suggest, in defining the methodology, the latter stages of the methodology would conduct the investigation along lines more compatible with Experimental Research. The adaptation for this research, produces as its final step, a specification for a product. It would be this product, that would be put into an Experimental Research investigation.

One of the inherent difficulties, that is incumbent in the Research and Development Methodology, is the nature of prototypes and their validity. All prototype developments are approximations of the final smooth and finished product. A difficulty in the development of prototypes is to ensure that the limitations of the development neither handicap the student in performing the educational tasks, nor distort the results that can be obtained from the trials.

Implications of Research

The implications of this research for the educational environment, can be viewed against the current situation pertaining to upper secondary school geography classrooms, and in particular the use of the computer in those classes. Kent (1992), follows the initial description of Hall (1982) and places the use of computers in the Aeotechnic Era. This is characterised by a realistic view of the capabilities of the computer in geographical education. This follows from the greater enthusiasm of the Neotechnic Era of the 1980s, which in turn succeeded the skepticism of the Paleotechnic Era of the late 1970's. The geography curriculum has also changed during the development of this research. The 'drive to centralisation', Naish (1992), has taken place, with the establishment of Geography in the National Curriculum and Technology in the National Curriculum. Geography and Information Technology have established close links over recent years. This view is typified by Freeman (1992) who suggests that for some years Geography teachers have incorporated information handling into their teaching through resource based learning and enquiry learning.

A modelling product, such as that which would be developed from the specification of this research, could be placed within the classification of software offered by Watson (1989) which identified six main aspects :

- word processing
- desk top publishing
- data handling and interrogation
- viewdata
- spreadsheets
- modelling

Watson (1989) also identified the styles of software that were available for use in the geography classroom. The modelling would fit within the simulation style, although some aspects would be grouped under the problem solving style. The styles identified were :

- quizzes
- role plays
- tutorial
- problem solving
- simulations
- graphics
- educational games
- statistics

The findings from the research have suggested a Five Stage development of modelling and this can now be considered in respect of the specific contents of the National Curriculum. The latter is the outline of the principal contents of the Geography curriculum, up to the compulsory school leaving age, and will form the basis for the development of geography at subsequent levels. The modelling product, proposed in this research is targeted at the latter years of compulsory education and at the two years that succeed it. The differentiation between the two would be in the complexity of the model and the development of the areas of geography that are addressed. The continuity and progression within geographical learning is illustrated by HMI, DES (1986) :

- *carrying out more complex tasks*
- *moving from a familiar problem to an unfamiliar one*
- *applying more advanced skills*
- *becoming more confident and independent in using IT*
- *using more sophisticated software*

The Five Stage development model can be developed using a simple model initially and then can follow the suggestions of the HMI in identifying the progression of the students.

The Non-Statutory Guidance for Technology in the National Curriculum, DES (1990A) suggests that pupils who possess an IT 'capability' will have :

- *knowledge about applications of IT and about IT tools such as word processors, databases, spreadsheets and software for processing sounds and images*
- *the skill to use appropriate IT tools effectively*
- *an understanding of the new opportunities IT provides*

The use of a modelling product, will particularly address the second point, and will encourage the skills to use software for the effective development of geographical learning.

The Non-Statutory Guidance for Technology in the National Curriculum, DES (1990A), also states that the use of Information Technology can enhance and extend teaching by

- *making learning more practical*
- *giving access to new experiences*
- *enabling pupils to focus on skills such as analysis, evaluation, prediction and forming hypotheses*

The modelling product could be principally used to address the third aspect, with each stage of the Five Stage model, having the capability to allow the students to develop the skills illustrated.

The first Stage, the manipulation of simulation would be compatible with section 2.4 in the Non-Statutory Guidance, DES (1990A) :

> *- Using a simulation program can enable teaching to be related to real problems and take account of economic influences*

In addition, modelling is an important part of the progression, when viewed by tracing the five aspects of the IT capability :

> *- developing ideas and communicating information*
> *- handling information*
> *- modelling*
> *- measurement and control*
> *- applications and effects*

The document continues, and discusses the role of modelling, it states "Computer models are representations of the real world, or of abstract situations. Pupils should use, investigate, manipulate and alter designed computer models." Progress is achieved through :-

> *- increasing the complexity of tasks in which pupils are required to manipulate data, speculate about outcomes and examine consequences*
> *- using more complex models*

The proposed use of the Five Stage development, coupled with a broad based modelling environment as indicated in the product specification, can be seen to be attempting to meet these needs.

The Technology in the National Curriculum document, DES (1990B), addresses modelling under Key Stage Four., where it states that :

> " *Pupils will continue to use simulations to support investigations e.g. they might compare data from experiments with those of a computer model and refine the model to match the results from their investigations. More able pupils will consider the mathematical basis and accuracy of such models and extend their skills to*

the design, implementation and testing of complex models "

The example given within the document, for how such work may be achieved, is a geographical one and closely fits with a simplified version of the PUDDLE and slope drainage models used in the PROLOG trial. The document states :

> *Key Stage 4 - Geography Example*
>
> *Topic : River Study*
>
> *Activity : Pupils undertake a field study of a river basin. They study fluvial processes affecting the basin and analyse the hydrological processes within the drainage system*
>
> *Information Technology capability*
>
> *Pupils determine the information required, the purposes for which it is needed and how it will be analysed. They design ways of collecting and organising the information, create a database or spreadsheet and analyse the data. They examine the inputs, outputs and stages of a simple computer model of a drainage basin, and modify the whole to represent different rock types and rainfall conditions*

The five Attainment Targets of the Geography in the National Curriculum, DES (1991), have been introduced in Chapter Two. Within these Attainment Targets, there are various activities identified at different levels. Several of these could be fulfilled using the Five Stage development and the proposed modelling environment.

Within the Attainment Target One, Geographical Skills, L7 the requirements are to " *interpret and identify geographical relationships between variables* " and cites an example of " *the various factors influencing stream flow* ". It further suggests the use of systems diagrams to explain such relationships. A simplified model could be built within the modeling environment to illustrate this point.

L8 suggests that pupils use "*indicators to identify variations in quality of life between places and discuss the suitability of indicators*". The declarative decision making aspects of the modelling environment could be used for such activities, as could the 'template' used in the development of the Sahel model.

L9 "synthesise information from different map sources, to produce a sketch map which identifies important geographical features and reveals spatial patterns and associations within an area ". Within the specification for the new product, is the development of various models, constructed with the use of the spreadsheet. These allow for the comparison of different spatial aspects. so that conclusions may be drawn.

Attainment Target Two, in the Geography in the National Curriculum, DES (1991), focuses on a Knowledge and Understanding of Places. L8a emphasises the importance of a systems approach " *identify geographical patterns relationships and processes in the home regions "*. A simple model for the home region, could be constructed using one of the templates, that have been identified. This could be followed to a greater level of complexity to meet the requirements of L10a " *synthesise patterns, relationships and processes in the home region "*

Attainment Target Three concentrates on Physical Geography. L8b states " *analyse the hydrological processes operating in a drainage basin system in terms of inputs stores flows and outputs "*. It suggests the use of a computer model or a system diagram of a drainage basin, to analyse the variables that affect flows within the system.

A further example, from the Physical Geography section, could be based on the Sahel type model developed during the research, when L10b suggests to " *give a detailed account of how physical and human processes combine to cause desertification*".

The aspects of Human Geography, comprise of Attainment Target 4, L7d suggests " *analyse the changing distribution pattern of the iron and steel industry* ". This is compatible with the use of a 'simulation', in the form of an expert system, as indicated in one of the development themes.

The decision making examples, used in the SMALLTALK trial, could be used as a basis for L8b" *analyse the role of decision makers in processes affecting urban and regional development."* It continues to state " *analyse the respective roles of entrepreneurs , property owners, international organisation, economic and land use planners, community groups, local and central governments* "

Several of the models, developed and suggested in the generation of the range of geographical models, give a general conceptual approach, for example, the calibration of gravity model. This area could then be used to fulfil the requirements of L8d " *apply general concepts to the interpretation of patterns and processes in human geography ; accessibility, distance-decay, urbanisation, core periphery, environmental perception* ".

L9b addresses the issues of transport for which a number of specimen models were developed, and cites as an example " *to analyse the impact of changes in traffic flow on the transport networks* ". The declarative decision making model could act as a basis for fulfilling L10a " *evaluate alternative explanations for international disparities in levels of economic development* ".

The final Attainment Target is Environmental Geography, L8a " *analyse how the growth of both population and economies increase the pressure on natural resources and analyse the impact on regions e.g. pressure on open spaces, demand for water and on specific countries, e.g. the effects of population growth and economic development on the exploitation of, and the attempts to conserve, the natural resources* " These areas can be addressed by a variety of models and model templates, that have been illustrated in the research, ranging from growth models, based on dynamic systems, to decision based models.

The ' Sahel model template' could be used to address the related L8b *"analyse with particular attention to one example why some environmental systems are fragile : review the relationships between human actions and physical processes in tropical rain forest, tundra, semi arid lands and wetlands* ".

The discussions of the application of this research to the various areas of the National Curriculum illustrates that a modelling environment would have the potential for meeting many of the requirements. However, this needs to be tempered with the realities of attempting to use a complex modelling environment in 'normal' lessons. One subjective approach to its potential use in lessons, can be given by consideration of a SWOT analysis. SWOT analysis attempts to identify the strengths, weaknesses, opportunities and threats, offered by a potential situation. The approach is widely used in management issues, Johnson and Scoles (1989) and has its origins in Ansoff (1968). Whilst it is subjective, it can offer insight into possible issues for consideration. Therefore, possible use of the modelling environment in schools, can be considered under the four headings.

- Strengths

  - The proposed modelling product covers a wide range of topics in geography, and therefore, has the potential to save time in learning new software. It allows the students to gain familiarity with the product that can enhance the options available to the student.

  - The concept of model building encourages the students to think and allows for creativity in the development of solutions to geographical problems. The proposed stage model, encourages systematic development of modelling, and the various templates allow various parts of the modelling concepts to be examined.

- Weaknesses

  - The proposed modelling tool is complex, which mitigates against it being taken up by teachers, who have a limited amount of time to pursue new ideas.

  - Some of the ideas present in the modelling environment, for example, decision tables, are not familiar tools to the majority of geography teachers.

- Opportunities

  - The modelling product can offer the opportunity to introduce software, which will allow for a different approach to many of the topics in current syllabuses and in the National Curriculum

  - The modelling tool can complement, and enhance existing methods of teaching, and does not directly challenge or replace them. It can be used, to introduce new topics, as a main medium for conveying the ideas within a topic, or as a reinforcement and revision aid at the end of a topic.

- Threats

  - A principal threat, to its acceptance, is if it is perceived as a technical product and not a geographical one.

  - The concept of modelling environments, and the working structure of the different models, uses terminology and ideas that are not in common usage in the geography classroom.

- Some teachers will be unconvinced that the process of modelling can aid learning in significant ways.

The points illustrated, can be considered in conjunction with a survey of geography teachers who use Information Technology, Allen (1988). He identified that, in rank order, the following were the advantages for the use of a computer in geography education:

- interests and motivation engendered in the children
- development of problem solving and decision skills
- development of IT literacy and mapwork skills

The Stage model and the proposed modelling specification, have a keen focus on the second of Allen's points. It would also be possible to use the model development for various aspects of values education which was identified by Allen (1988), as a limiting factor in the success of Information Technology in geography education.

Future Developments

In Chapter Two, the issue of the overlay model was introduced. This was expounded by Fung (1993), as a basis for the use of a tool kit approach to modelling tools selection. During the development of the examples in this research, some subsidiary ideas in addition to the development of models were illustrated. First, the development of explanations, particularly in reference to the expert system. And second, the generation of comparisons between the expert model and the user model. Further research would be applicable for the development of a satisfactory method of allowing interaction between the 'expert model' and the user model, that did not directly involve the use of the overlay method.

Conclusion on Application of the Research to the Classroom

Very little in the way of computer based work allows for creativity of answers, so that not only may the inputs be varied, but there is the possibility for the learners to experiment and develop their thoughts. No tool can guarantee, but the product as suggested does not unduly restrict creativity.

The work proposed in this thesis, attempts to contribute to the nature of educational knowledge in three ways. Firstly by supplying a tool that allows pupils to enter their own models into the system. The facility is present, to test and amend the models in the system. It will also allow insight into how the user amends and reconstitutes their models by virtue of the evidence presented.

Secondly, the work contributes to the way in which users attempt to solve problems within geography. It does so by supplying an environment, which is both open ended and structured. Insight can, therefore, be gained as to how the users go about problem solving, and in particular, how they structure their knowledge.

Thirdly, with the teaching of geography, it is important to recognise the different forms of geographical knowledge. The system allows the user to choose different representations and to try out the ideas. Thus it contributes to the way users construct their knowledge in order to solve problems in geography.

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GLOSSARY OF TERMS

declarative method : the description of the representation of the components of a system

expert system : the capturing and representation on the computer, of knowledge from an 'expert' in a particular domain

formative evaluation : the outcome evaluation of intermediate steps in the development of a product

geographical model : a representation of a simplified form of reality that emphasises geographical principles and interpretations

inference method : the rules and procedures by which a computer program will determine the results from a given set of inputs

intelligent tutoring system : a computer assisted learning program that incorporates the representation of the problem domain, the tutoring and learning processes

knowledge base : the representation on the computer of the facts and rules, and rule selection procedures, that comprise a problem domain

mental model : a representation of a problem domain held by a learner's mind

model : a method for representing a simplified form of reality

microworld : a computer based environment in which general principles or underlying axioms may be manipulated, adjusted and developed.

modelling environment : a collection of software that facilitates the building of a model on a computer

modelling paradigm : the basis of the foundation, philosophy and approach of the representation common to a range of models

object methods : the representation of a domain in the form of independent components called objects, which have internal processes and state variables, and which interact with other objects in the domain by the passing of messages *procedural method* : the sequencing and ordering of sub-tasks to complete a certain aspect of a system

process : the sequential set of tasks or activities that are performed within a represented system

prototype : software developed to demonstrate specific, but limited points, of a final computer based product

qualitative modelling : the development of a model based on heuristic values

quantitative modelling : the development of a model based on numerical methods

quantitative revolution : a paradigm for geography, based on statistical and numerical methods, developed during the 1960s

relation : the interconnection and interaction between components within a system

representation method : the structure and form for portraying information and knowledge about a system on a computer environment

simulation : the dynamic representation on a computer system of a problem domain, such that inputs may be adjusted, but the underlying driving mechanism is transparent to the user

system state : the combined timed based snapshot of a system represented by the accumulation of the individual states of each variable

system : a set of elements each with certain attributes that are linked in a particular way, with the nature of the links, not only determining the operations of the system, but also its evolution

systems analysis : a strategy for extracting relevant information from a part of reality and modelling it to produce an analytical description of the domain

systemic geography : the approach to geographical interpretation that is built on the identification of the various components of a system *variable* : an element in the real world that is selected as a component of a system description and which can be represented by a series of changing values

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