What is the modelling curriculum?

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Abstract

This paper describes the benefits which might accrue from modelling as an activity for learners. Some approaches taken to teach modelling are discussed and criticised. The learner's purpose for modelling is suggested to be critical in engaging them in this formal and theoretic field and it is suggested that presentation and communication of ideas in the context of project work may be appropriate. An analysis of parts of the modelling process is presented to highlight some of the 'hidden steps' which learners may usefully have disentangled by modelling software. Finally some prototype software developed by the Integrated Modelling Project to explore these problems is described.

What is modelling?

The English language terms 'modelling' and 'model' are used to describe many different activities and objects. Even in mathematics or science a 'model' may be any one of several quite different things, ranging from physical apparatus to an equation. An extensive discussion about geographical models, but having broader application, may be found in Minshull.[1]

Computer-based modelling

This paper is concerned with a particular meaning: that which defines 'modelling' as the use of a formal language (symbolic or diagrammatic) to represent some knowledge and 'model' as being that representation. In particular, this paper considers the activity of using a computer to express the model with the subsequent aim of using the computer to explore possible consequences of the model. This in turn implies that the formal language used to represent the model is also executable in some way by a computer and that the elements of the representation may be manipulated and transformed by computer processing.

Other models

This kind of modelling is unable to deal directly with many of the models encountered in a range of disciplines. Such models are not always expressed entirely formally: diagrams, text and mathematical expressions often use informal conventions which suffice for human understanding but not for computer processing. Nevertheless it is considered to be a valuable educational exercise to engage in computer-based modelling, for two major reasons.

Expression and evaluation

Firstly, the computer's demand for formality in expression forces the modeller to discover more precisely what their knowledge is and secondly the computer's ability to 'execute' a model leads to the possibility of evaluating that model whether it is the learner's model or one given. The evaluative feedback may then motivate the learner to question the model and improve it through re-expression. This basic design cycle of expression and evaluation using computers may be seen operating to good effect in the use of Logo programming[2]. It is not impossible to achieve the same results on paper, but greater skills of processing are then required and the process can be demoralisingly slow.

Learning modelling

This paper is concerned with the difficulties faced by the learner on confronting modelling for the first time. What problems do such learners face? What concepts and skills do they need? What approaches will support them?

What approaches have been taken?

These approaches are described here in terms of the style of modelling, the formal language for modelling and learner's view of the purpose of modelling.

Systems modelling

Much of the work on computer-based modelling derives from the systems dynamics approach of Forrester and the simulation language DYNAMO, described by Roberts et al.[3] Systems dynamics defines a model as a system of interacting elements (numeric quantities) between which relationships (mathematical functions) are defined. Relationships are defined by considering changes in the elements over time and deciding which elements influence this change. It is important in systems dynamics to consider the system boundary, including relevant elements and excluding others. Closed feedback loops lead to effective models in systems dynamics by helping to define the system boundary and because the causal relationships contained within such loops are argued to be the most important.

Roberts et al also describe a sequence of activities for developing a model (see fig 1).

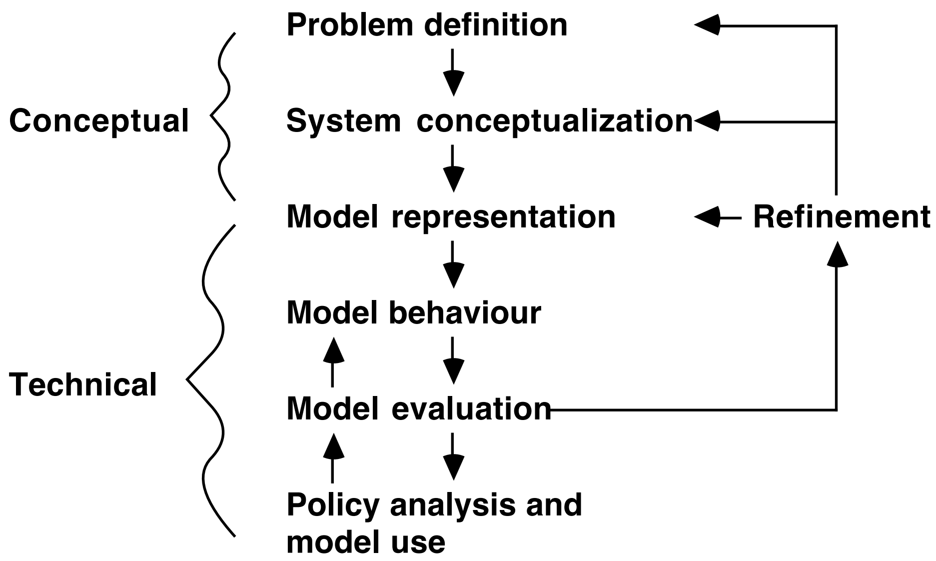

Figure 1 : Phases in the model-building process -systems dynamics[4]

To some extent they base the organisation of their course for understanding systems dynamics and using DYNAMO on this 'model' for model development.

The learner is usually involved in a study of a real world system and is concerned to find a solution which effectively represents that system.

Software : MODL[5], DMS[6], CMS[7] & Stella[8]

These four software packages all derive from the systems dynamics approach. Hartley and Lewis are quite clear that MODL is only a small part of a teaching plan and is to be used after the model is defined in order to evaluate the model. Both DMS and CMS begin to help the learner express the model by providing simple editing tools in an integrated environment. CMS in particular aids the learner by displaying on screen all the elements in the model and their state.

Stella takes this approach one step further - not only is each element on the screen, but may be 'hooked up' to other elements. The elements in a model take appropriate form for their function - stocks, flows or information. Once elements are graphically connected, the system aids the learner to complete mathematical expressions for each element by listing the other elements connected. The model is constructed in pieces, but the full list of resulting equations can be consulted. As with CMS, the state of the model is represented and elements are animated as execution proceeds.

In each case, the model elements are simple numeric quantities and the notions of time and change through time are important if not essential.

Spreadsheets

The spreadsheet takes a different approach for models. The question of time is not usually considered, although some systems permit iteration. The relationships represent static or declarative knowledge. Like CMS and Stella, elements are numeric quantities and are displayed on screen showing current values. Spreadsheets permit a high degree of control over presentation, enabling the learner to place elements in appropriate positions, specify numerical formats and document the model.

The emphasis for the learner moves away from simulation to communication and presentation.

Expert Systems

Similarly, expert system models do not usually contain representations of time. The elements in an expert system model are usually clauses which may be true, false or unknown. Relationships are declarative, logical rules connecting the clauses to express knowledge about a domain. Elements are usually hidden but may be presented on the screen piecemeal.

The overt purpose of designing expert system models is perhaps to support decision making.

Concepts and skills in common

Despite the differences found in spreadsheet and expert system models it would seem that there are many concepts and skills to be learnt in common with the systems dynamics style of modelling.

Difficulties in common

Each of these approaches confines the learner to one or a few kinds of elements - the approaches are centred on the style of modelling or computation. Surely learners bring a range of ideas to bear when trying to model and are least able to say which kind of modelling system is best suited for a problem.

Similarly the purpose of modelling seems to be centred on the approach used rather than on the learner's motivations and aspirations. Surely if these can be harnessed the study of formal, theoretic systems might be made more attractive.

Purposeful modelling

The approach proposed by the Integrated Modelling Project, a collaboration between the Advisory Unit, Hatfield and the Centre for Educational Studies, King's College London, might be described as purposeful modelling. By this it is meant that the learner has a clear purpose which is inherently motivating and derives from their interests.

Concern for presentation and communication

In developing writing skills with a word-processor, it has been proposed that a first stage for learners involves a concern for neatness of presentation (often to the exclusion of accuracy)[9]. This desire for 'good-looking' displays can be exploited in an approach to modelling. The teacher may set the task for the learner to communicate ideas through a model, perhaps as part of a GCSE project, in order to capitalise on this motivation.

Combining modelling with constructing an interactive simulation

Further motivation may be found by providing tools for designing interactive simulations. Simple interaction with a model provides a far more interesting exercise than observing passively.

Picturing the end-product

When attempting to model a system, it is probably beneficial to consider the end-product, the display of results. By drawing or painting a picture on screen of the model a clearer idea of the limits of the system being modelled may be conceived and a basis made for identifying elements. Thus a whole view is represented before breaking down the model into parts. From this position one can work back to the low level, identifying key features of the picture and naming them.

Identifying elements

The process of identification of elements is paid relatively little attention to in existing approaches, yet it is one of the hardest things to do, particularly for beginners. There are questions of system boundary - which elements should be included or excluded - and system level - what scale of detail should this model work to. Merely finding appropriate names for elements that have been identified is difficult.

Many elements in a model do not match a real-world object, but some are statistics about the real world. For example, the height of a tree maps closely onto a visible characteristic of trees. The total number of trees is a statistic about a woodland which is more abstract. Does this cause difficulties and can they be overcome by a modelling approach which clearly differentiates between these kinds of elements?

Characterising elements

Having identified an element in a model, there is the question of what attributes the element has - most modelling approaches assume a single number or logic value. It seems quite obvious that for many models it would be sensible to identify as an element something which has a variety of attributes, but this structuring can rarely be realised in modelling systems.

Of particular importance is defining the range of values for each attribute of an element. Several ways are desirable, from the simple numeric or logical to the unordered or ordered list of values.

Identifying relationships

Identifying that a relationship exists between elements is a considerable step, but in most modelling systems this decision is bound up with the characterisation of the relationship in the form of a mathematical formula or logical rule. A separation of these stages may be helpful if made possible but not necessarily enforced.

Characterising relationships

One step in characterising a relationship is in deciding what changes are dependent and which independent. In systems dynamics this is achieved by drawing causal diagrams indicating cause and effect links, drawing directed lines between elements. This step may be taken before the precise formulation of the relationship, in which the learner is more concerned with how one element varies or changes with another and what mathematical or logical function is appropriate to model this change.

Not in sequence

None of the ideas expressed above are to be taken as a rigid step-by-step sequence to be followed in the definition of a model. Sometimes new elements in a model are identified when the relationships between existing elements are defined. What is argued is that the software used for modelling should allow the separation of these ideas whilst allowing a non-linear approach to model building.

Prototype software

The Integrated Modelling Project has taken the approach of trying out some of the above ideas by developing exploratory prototypes.

One prototype is the PAGE program, in which the idea of supporting stages in the expression of a model is explored by calling undefined elements to the learner's attention before executing the model (see figure 2).

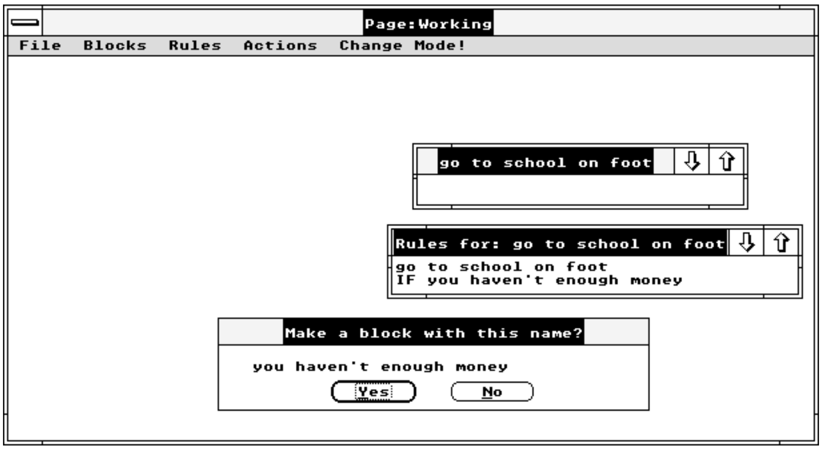

Figure 2 : PAGE : a prototype rule based modelling system

The program allows the learner to make 'blocks' on the screen representing elements in their model. Each block may have an associated 'rule block', in which an expression which defines the value for that block can be placed. When the model is executed, the rule is checked for syntax and any undefined blocks mentioned in the rule are presented to the user with the question 'Make a block with this name?'. The user may choose to do this or cancel and correct the rule (if a mistype or misconception occurred). In this way, all the elements in the model, whether identified by initial planning or arising from defining the relationships, are displayed on the screen.

Expert Builder

A second prototype is Expert Builder (see figure 3). In this program the learner constructs a simple expert system by placing blocks on the screen and threading them together to make IF-THEN rules. The computer can execute this model in order to provide advice based on the rules.

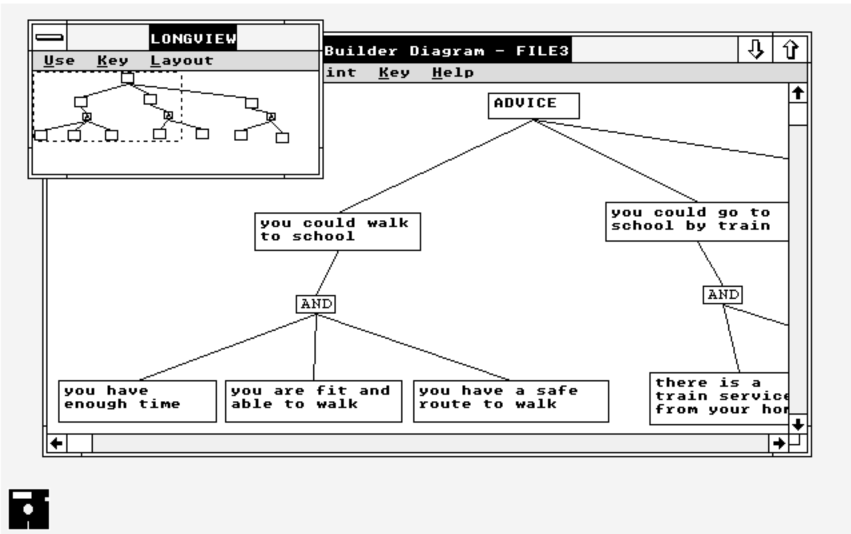

Figure 3: Expert Builder: a protoype

This prototype ensures that all elements are visible and that relationships are explicitly represented. Moreover, when the model is executed, in this case by asking for advice or testing a block, the state of the system is represented by colouring blocks to show their value as the inference proceeds.

Conclusion

This paper has discussed potential improvements that can be made in the approach to modelling which are based on analysis of some existing approaches and a break-down of the modelling process. Software for modelling is considered to be directed at experienced modellers with mathematical and logical competence. If a wider range of learners are to gain from modelling activities, more attention will have to be paid to some of the hidden steps and to the learner's purpose.

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