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Children and computer modelling: making worlds with WorldMaker

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ABSTRACT

WorldMaker is a new modelling system which can be used by children to explore and create their own computer 'worlds'. While many modelling systems already exist, most involve ideas such as specifying algebraic relationships between variables. But young children think of the world not in terms of variables, but in terms of objects and what they do. WorldMaker allows children to create objects and define the rules which govern their behaviour. Because WorldMaker models are essentially simple, even young children are able to discuss the nature of these models and their relationship to the real world. The importance of children creating their own models is stressed in order that they may understand the nature of computer models and be able to evaluate their strengths and limitations.

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INTRODUCTION

Computer modelling is increasingly important in commerce and industry. Modelling can be cheaper, quicker and more convenient than studying the real thing. More importantly in the classroom it gives children an opportunity to test their ideas about the world by creating 'artificial computer worlds'. A number of useful modelling facilities for older pupils already exist, but these involve difficult ideas like specifying algebraic relationships between variables. Simulations exist for younger children, but in these the rules are hidden and cannot be changed by the user. This paper describes a modelling system 'WorldMaker' [1] which was developed to fill this gap.

Young children think of the world in terms of objects and what they do, not in terms of variables. WorldMaker therefore allows children to make models by creating objects and rules which govern their behaviour. This concept is derived from the cellular automaton, the most famous example of which is perhaps Conway's *Game of Life* [2]. There is growing interest in the use of cellular automata for the study of complex scientific phenomena [3], but there also exist many simple models based on the concept which are potentially interesting and important [4, 5]. The aim of developing WorldMaker was to build on these ideas and to create a simple way of defining rules in order to make this kind of modelling accessible to pupils [6].

MODELLING WITH WORLDMAKER

A hydra is a microscopic pond animal which appears to be attracted to light. Figure 1 shows a WorldMaker model of hydra's behaviour.

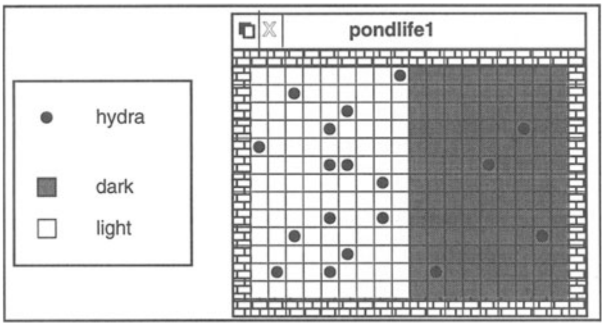

Fig. 1 A WorldMaker model of a hydra

This model contains just one type of object (hydra) and two kinds of background (dark and light) which can be placed in the cells on the grid using a set of drawing tools. When a hydra is placed on the grid, it can be seen to move randomly around the grid jumping from one cell to an adjoining cell—if it is on a cell with a dark background it does this quite often, but rather less frequently when on a cell with a light background. So the hydra moves all over the grid, but spends most of its time in the light region. If lots of hydra are put on the grid, they spread out and continue to move around, but most are concentrated in light areas.

How does this model work? Objects in WorldMaker can be given rules which tell them what to do. Figure 2 shows the list of rules for the object hydra in this model. Each object can be given up to four rules - here, a hydra has just two rules (the others are not used) and the frequency with which the rules are fired can be adjusted using the 'slider bars'. Thus a hydra moves about according to two rules—if it is dark it moves often, and if light then less often.

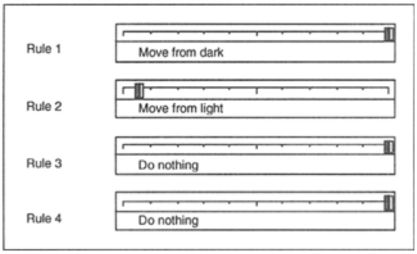

Fig. 2 The list of rules for hydra

Using these simple rules a hydra appears to seek out light areas though in fact it does not have any idea of the direction it needs to go in to find the light areas. Real hydra do the same thing—the lighter it is, the faster they move—and it is an effective way for them to be 'attracted' to the tiny animals on which they feed. These prey animals feed off the plants which are found in areas where there is more light.

How are the rules of objects defined? Each rule in the list can be 'opened up' to give a window in which the behaviour of the rule is defined pictorially. Figure 3 shows the rule definitions for the two rules in this model. All WorldMaker rules have essentially the same form. On the left is a picture which shows the condition of the rule; on the right is a picture which shows the action to be taken if the condition of the rule is met.

All WorldMaker rules are local—they only involve the cell in which the object is located and the neighbouring cells. However local rules can often lead to global behaviour as this model shows.

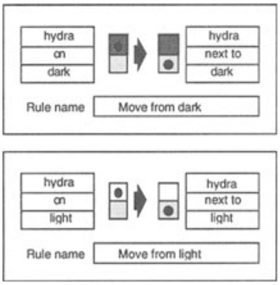

Fig. 3 The rule definitions for hydra

MODELLING TASKS

Pupils using WorldMaker are able to come up with many ideas which they would like to try. The problem is to ensure that their exploration is productive. We have found in trials with pupils aged from 9 to 17 years that a problem-solving approach has been the most successful. The tasks developed cover three learning stages ('exploring a world', 'changing a world' and 'creating a world') and most relate to science, mathematics or geography. Some examples are briefly described below.

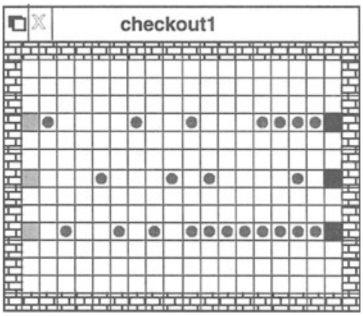

Fig. 4 Modelling queues in a supermarket

Pond life: Pupils can experiment with the model shown in Figure 1 by changing the numbers of hydra and the sizes and shapes of the light and dark regions, predicting the behaviour of a model or trying to work out the initial conditions needed to achieve a certain behaviour.

Checkout: In a model of the checkouts in a supermarket shoppers appear randomly at the entrance on the left, move across to the right and disappear randomly through the checkout. Figure 4 shows three checkouts; even though the probabilities of the events are the same for each the queues are of different lengths at each checkout. One problem for pupils is to change the probabilities by adjusting the slider bars on the rule list to find out how quickly people must be served to avoid a long queue.
Rabbits: In this task pupils can create their own model of a predator-prey system by thinking of behaviours which can be represented by rules. Such rules might include rabbits moving, breeding, eating grass or foxes eating rabbits, and so on.

Glue: We have seen that objects can move, appear and disappear. In this model, objects also change into other objects—'glue' comes out of a 'tube' and eventually becomes 'solid' (Fig. 5). Pupils can experiment with glues of different 'runniness', putting the tubes in different places to find out how to produce different kinds of shapes. Though it is fun, this task also has a more serious point—the shapes of volcanoes are determined by how 'runny' the lava is.

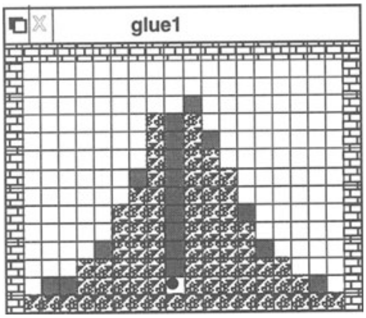

Fig. 5 Modelling the formation of a volcano

Bounce: In this model pupils are provided with a set of 'bouncy balls' and 'walls'. The problems involve positioning walls in order to make the balls follow certain paths or to make balls avoid collisions with each other. Solving the problems may involve concepts such as number patterns or ratios.

Pests: In this model 'farmers' move around changing 'bare earth' into 'crops', while the 'pests' eat the 'crops'. Pupils are set problems to find the numbers of objects and the rule probabilities to produce certain patterns and through this are learning about system stability and equilibrium.

Tasks have been developed about many other ideas such as diffusion, buses and traffic flow, chemical reactions, crystallization and coastal erosion. The models in all of these tasks use rules of various kinds, some examples of which are shown in Fig. 6.

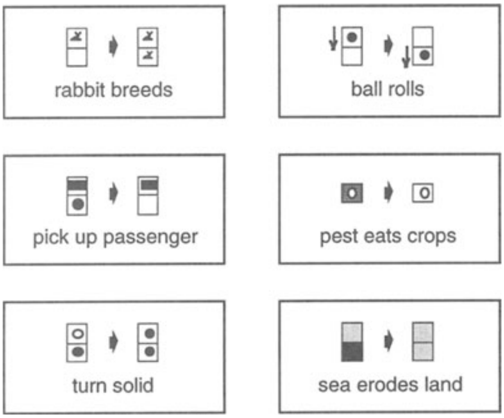

Fig. 6 Some examples of different kinds of rules

PUPILS AND MODELLING

Some issues about modelling with WorldMaker will be illustrated using examples of pupils' performances on tasks from the three learning stages.

Exploring a world

Here pupils make models using objects which have already been created. Though the rules are hidden, they can see what happens to these objects when placed on the grid and can make inferences about their nature by experimenting and seeing how these behave in different situations. For example one group of 10-year-olds which worked with the 'Bounce' world, was trying to find where walls were needed to make the ball bounce and follow particular paths. They solved the first problem by trial-and-error, but the next one was more difficult. One pupil tried to understand the ball's behaviour by systematically varying its starting position and tracing its path. In another task a group of 11-year-olds were watching a model of crystallization and one explained that:

> "'Sticky' balls stay still all the time and when 'random' balls hit they turn into sticky balls as well."

These pupils are beginning to understand and explain the behaviour of a model in terms of the behaviour of its parts. While a model can help us to explain the real world, sometimes children use reality to explain the model. Here a group of 10-year-olds explain why in a 'Rabbits' model the population is getting smaller:

> "Oh, they are less now, because they are moving and they are going away.
> They died.
> Because they were old age.
> And people killed them.
> But there is no one to kill them."

People killing rabbits may be an explanation in the real world, but not in this case, as one pupil realized, since 'people' were not represented in the model.

The relationship between models and the real world is subtle and by no means easy to grasp. A number of groups of 12-year-olds was asked some questions about two WorldMaker models about buses travelling along roads. One was a simple model which suggested a reason why buses tend to group because of positive feedback; the other was a more complex model, but lacking this essential feature. Most pupils agreed that buses' tendency to travel in groups was a real phenomenon and that the drivers did not do it on purpose. The simple model proved that buses travel in groups and most thought that it could be helpful in explaining why. However, most pupils believed that a complex model would necessarily be better and that its behaviour would prove what happened in the real world.

Where pupils have some experience of the real world situation, they are in a position to judge how good a model is by how it behaves. A group of 10-year-olds were exploring a model of shoppers in a supermarket:

> "It is realistic, it never moves ... you have to wait for ages in the real shopping queue anyway.
> Yes, but it depends on what country it is. If you are in Russia it isn't realistic, there is a longer queue. In Paris it is realistic."

Simple models can lead to quite sophisticated discussion. Models with objects which simply move around the screen bouncing off walls can be easily explored by young children, but these have also been used by groups of 16-year old science students to model diffusion. Thinking about whether the objects should move randomly or in straight lines, and what (if anything) represents the 'pull' of the vacuum has provoked interesting discussions.

Changing a world

Here pupils modify the behaviour of backgrounds and objects by changing the 'slider bars' of their rules. Even young children can predict correctly the behaviour of a model when the setting of one rule is changed. A group of 9-year-olds who used the 'Pests' model, tried to change the rule settings so that the grid looked like the picture on their worksheet, showing mainly 'crops' but some 'bare earth':

> "'Eat crops'—just put it down.
> Zero.
> No, no! Because they eat some—look. (He points to picture on worksheet.) They have to eat some."

Sometimes it is easy to recognize the effects of changing more than one rule. An 11-year old changed two rules for a 'rabbit' and noted the effect:

> "The rabbit goes fast and eats slow."

More challenging is to work out the rule settings needed to produce a certain effect where a systematic approach is necessary. An example of this is a group of 10-year-olds who experimented with the 'Checkout' model seeing what affected the length of the queue:

> "Look how they are going. There is no queue! They stop when it is 100 (shoppers leave).
> Make it 0 (shopper enters). No-one will come in.
> Go to 10 (shopper enters).
> Put on 10 on both of them.
> Put it (shopper leaves) on 10, and see if the whole thing is crowded. And then put 100 to the entrance."

In terms of the interface the changing of rule settings places less demand on pupils than creating entirely new rules, but this does not mean that the effects are easier to understand. Pupils often make predictions about the effects of changing rule settings by inferring from real world knowledge of the situation represented, rather than from the rules of the model itself. This suggests that pupils should be encouraged to build their own models as soon as they are sufficiently familiar with the interface.

Creating a world

We cannot expect children immediately to invent suitable contexts within which they could create a world containing entirely new types of objects and rules. Modelling with WorldMaker means choosing aspects of the real world which can be naturally conceived as consisting of interacting objects. This is not at all trivial. Having decided this behaviours need to be represented as rules in the model. While pupils can readily identify behaviours represented by WorldMaker rules, thinking of behaviours which can be defined is more difficult, since an understanding of the kinds of possible rules is needed. Pupils can be given support to do this in a number of ways. One is to suggest kinds of behaviours which might be represented. Having been given some examples of rules in a 'foxes and rabbits' world and some examples of other kinds of behaviour they might exhibit, a group of 12-year-olds was easily able to represent these behaviours as rules.

Another approach is to give some abstract rules and to ask the pupils what behaviours (real world or imaginary) these could represent. Some pupils may find thinking about imaginary (and perhaps crazy) rules easier than others. For example in a world of sharks and fishes some 10-year-olds are experimenting with a rule which says that when a shark is next to a fish, the shark disappears. We could think of this as a 'fish eats shark' rule, but because this does not make sense in the real world, the pupils are having trouble interpreting it.

"The shark jumps, you see.
No, the shark ate the fish.
The shark jumps to an empty cell and then the fish is there."

Eventually a pupil sees what the rule could be, but is not believed.

"The shark jumps away from the fish - maybe the fish ate the shark.
Oh no, don't be stupid!"

Yet another approach is to construct a new model by analogy using rules from another context. Even very young pupils have been able to do this, such as the groups of 9-year olds who were able to think of a number of different meanings for a rule in which a gardener planted a flower by substituting different objects for the gardener and the flower. Seeing fundamental similarities between superficially different situations is an important lesson to be learnt from modelling.

MODELLING IN THE CURRICULUM

How can we build progression into pupils' modelling activities? One approach is to treat modelling as a technique to be learned with pupils starting by exploring simulations (that is models created by other people), learning to take more control over such models, modifying them and after many years of practice finally creating their own models. This is the approach taken by the National Curriculum for England and Wales in which typically a pupil aged 11 would be 'using simulations to detect patterns and relationships' while a typical pupil aged 16 would be able to 'design a computer model which meets identifies needs' [7]. But it is not at all obvious that modelling should be treated in this way. Mellar [8] has argued how such an approach would be nonsensical if applied to another 'technologically aided activity' such as photography. It would imply that children would need to spend many years studying photographs before they could use a camera to take their own photographs.

Another approach sees progression in modelling as being achieved by the increasing complexity of contexts and models both built by children themselves and by others. Evidence has been found from children's use of several different kinds of modelling software that children who have created their own simple models are more able to evaluate the strengths and limitations of models built by others [9].

WorldMaker has allowed us to take the second approach developing a wide range of models set in very different contexts and at different levels of difficulty which can be used in many areas of the curriculum and with pupils of a wide range of ages and abilities. Children can begin at an early age to see how computer models are built, build their own models and think about how these could be evaluated. They can consider whether the model too simple, leaving out something important from the real world, or whether it is too complex. They can generalize patterns of behaviour by asking whether one model could represent more than one situation in the real world. These ideas are fundamental in understanding computer models. By working at the level of objects and their behaviour WorldMaker can help to make these ideas more accessible to pupils.

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