A Framework for Designing Interactive Multimedia to Scaffold Young Children's Understanding of Historical Chronology

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Abstract

Young children's understanding of the historical past is often characterised by a lack of temporal differentiation and a sense of total discontinuity with the present. Research has suggested that this situation may be caused in part by their formation of inappropriate representations when solving problems of chronology. To help children construct appropriate external representations for particular tasks and reason more effectively with them about chronological concepts, we investigated how interactive multimedia might be put to use. In this paper we report on our design and pedagogical approach to developing effective dynamic, interactive representations and activities at the computer interface, aimed at bridging the conceptual gap between concrete experience and abstract concepts. Evaluations of the software built using this framework showed that the program was well received by children and teachers alike, and that it was able to facilitate children's understanding of, and ability to reason about, chronology.

Keywords: interactive multimedia, external representations, scaffolding, chronology, history, cognitive interactivity, interface metaphors

1. Introduction

Educational research has revealed a widespread difficulty among young children to construct coherent chronological representations of events and personalities in the past beyond their direct experience. Indeed, their conception of history has been characterised as "an undifferentiated time of wars, peopled by dinosaurs, kings and sometimes Jesus" (Lynn, 1993, p. 26). For example, when given the task of arranging a set of cues (i.e. pictures or artefacts) in chronological sequence they may resort to naïve theories of the historical past as being 'colourless' and discontinuous with the present.

Yet an understanding of chronology — the ability to match events and personalities to dates and historical periods and place them in order of occurrence (cf. Hoodless, 1996) — is a fundamental cognitive skill in learning history, providing a "mental framework or map which gives significance and coherence" to pupils' studies (National Curriculum Working Group, 1994, p. 29). Achieving such a level of understanding, however, requires a lengthy developmental process involving the elaboration, restructuring and synthesis of children's knowledge. This process extends over most of the primary school years and may even remain unresolved when children enter secondary school (Haydn, 1999).

This state of affairs leads us to ask how we can support the process of understanding historical chronology more effectively in an educational setting. How can we promote more effectively the integration of children's experience of chronology in relation to their lives with the more abstract knowledge of historical events and personalities? Is it possible to develop pedagogical techniques which can make this learning process more obvious and more coherent to the child?

1.1 Scaffolding understanding: external representations and the role of interactive multimedia

One well known approach to facilitating learning, especially the acquisition of and reasoning with abstract concepts, is through scaffolding (Wood et al., 1976), in which various kinds of learning materials are used to help the child accomplish problem-solving tasks that initially lie beyond their ability. Integral to this process is determining how best to help learners understand and learn how to use the form(s) of representation most suited to the problem at hand, something which they find difficult when reasoning by themselves.

Interactive multimedia (IMM) has been proposed as a powerful environment in which this kind of scaffolding might be realised (e.g. Hartley, 1994; Kirsh, 1997; Scaife & Rogers, 1996). A central role of the software is to support the learner in accomplishing specific activities so that they can gain mastery over them and subsequently perform them independently. Animations, diagrams, text, speech and video can be combined to provide interactive simulations and other 'hands-on' activities that support learning in ways not possible with traditional media such as books and videos. In particular, IMM has the potential to provide new means of interacting with various representations of information, offering learners the ability to explore ideas and concepts in innovative ways. For example, it can render an abstract concept more explicit, allowing the learner to visualise and interact with varying representations of the same concept, as exemplified in the ecological software PondWorld, developed by Rogers & Scaife (1998). Or, it can enable learners to interact with representations that are grounded in their previous experience (Jackson et al., 1994). For example, the Model-It software provides familiar objects from which learners can build more abstract simulations (Soloway et al., 1996).

A further benefit of IMM is that it can provide various means of enabling the learner to collaborate with the computer to construct new forms of knowledge. For example, Luckin (1998) has implemented a software program, called ECOLAB, based on Vygotskian ideas of the Zone of Proximal Development. Another approach is to represent concrete 'real-world' manifestations of the concepts being learnt, through largely masking the abstractions. Examples of such programs are animated programming tools such as ToonTalk (Animated Programs, 2001) and model-based simulations, in which learners can become aware of the underlying model through the effects of their actions in the simulated world.

The potential versatility of IMM for scaffolding the progression from concrete experience to reasoning with more abstract representations suggests that the learning of historical chronology might be more effectively supported in this way. However, it is not obvious how to design IMM to fulfil these objectives. As described above, a range of techniques are available for implementing different forms of scaffolding. A key question in deciding which one to use when developing IMM is how best to reveal to learners the computational power of abstract representations in a way which is manageable by them, and which they can relate to their existing knowledge. This requires the multimedia designer to deploy interactive representations that will work in concert with the learner's emergent cognitive processes for reasoning about the domain.

This paper reports on an approach we have developed to achieve this: to design an IMM program to support the learning of, and reasoning with, abstract representations of historical chronology. Whilst our approach focuses on teaching history-related concepts, it has also been developed to be generalisable to other domains where abstract concepts need to be learned and used to reason about phenomena in those domains — and where children (and adults) currently have a difficult time using existing materials and methods.

1.2 Our methodological approach

Our general approach to developing IMM representations to support the acquisition of abstract concepts of a domain comprises four phases:

1. Investigating the cognitive issues: i.e. the cognitive tasks involved in problem-solving in the domain and the conceptual 'road-blocks' that impede learners' reasoning.

2. Studying the pedagogical context in which these problem-solving activities take place, in particular the types of representation deployed by the teacher in the classroom.
3. Eliciting from stages 1 and 2 material for a conventional requirements analysis, and also a set of external representations that might potentially be implemented in an IMM program. These representations are then analysed in terms of their 'cognitive characterisations' that can facilitate or impede specific problem-solving activities. The cognitive benefits of these interactive representations, in terms of the form of scaffolding they support, are also identified at this stage.
4. Applying the outcome of stage 3 to the conceptual design of the IMM program, from which prototypes are iteratively developed, evaluated and refined.

The approach is underpinned by the methodology of 'informant design', in which designers work with different children and/or adults at different phases of the design process, according to the skills or specialisations required by a particular phase (Scaife et al., 1997). These encounters are typically mediated in the early stages by the use of low-technology prototypes of the envisaged representations.

The remainder of this paper demonstrates this approach, describing how we designed a prototype interactive multimedia program to assist the emergent understanding of historical chronology in young children aged five to seven.

2. Phase 1: Analysing the cognitive issues

2.1 Temporal reasoning in the everyday world

To determine how to represent historical chronology in IMM format, we begin by analysing the generic properties of temporal systems and how they feature in young children's adaptation to chronology within their own lives: that is, to patterns in the natural environment and the social system in which they live (cf. Friedman, 1982). The intellectual tools that mediate this adaptation are a set of culturally-defined, conventional systems that represent temporal progression: clock, calendar and historical time.

From becoming aware of temporal regularities in their own lives and reasoning about them in a rudimentary way, young children must learn the elements of clock and calendar time and, ultimately, learn to operate on the 'conceptual features' of conventional temporal systems. Specifically, they need to develop the ability to:

- Describe the sequence in which events occur.
- Incorporate cyclical patterns such as the seasons or days of the week into conventional time systems such that "two Tuesdays or two summers [can be] similar and different" (the concept of 'order and recurrence': Friedman, 1982, p. 172).
- Co-ordinate different temporal systems: for example, days with weeks.
- Link temporal systems to number concepts, in order to achieve a quantitative understanding of recurrence and duration.

On the basis of Friedman's research, it seems reasonable to expect most children to begin to perform these operations between the ages of six and eight. For example, with appropriate support their range of temporal awareness should extend from daily and weekly to annual patterns and they may begin to associate many of these elements with personal experiences, religious festivals or natural phenomena such as the seasons.

2.2 Limitations in young children's reasoning about the historical past

However, whilst a child may get to grips relatively easily with the chronological concepts and temporal systems encountered in everyday life, applying these concepts and systems to reason about events in historical time can be an entirely different matter. An important focus of our IMM program, therefore, was to enable children to recognise their mistakes in this respect and to help them rectify the sources of their misconceptions.

Research suggests that children's capacity for reasoning about temporal relationships in the historical past is complicated by several factors, most notably the linkage of temporal systems to numbers. Children's difficulties with the mathematical component of historical time have been extensively investigated, for example by Jahoda (1963), Hodkinson (1995) and Haydn (1999). However, Haydn notes that these difficulties may be caused in part by a failure to 'teach' historical time concepts systematically in the primary school, and West (1981) showed that children *can* successfully sequence cues from the past if these are presented as a set of strongly contrasted artefacts or pictures rather than as a series of dates.

Another factor is the abstract, and frequently arbitrary, nature of conventional time systems, which young children can find difficult to grasp. For instance, even though calendar time is anchored in an observable natural phenomenon (i.e. the sidereal year), children must acquire highly abstract representations (as verbal lists) of the months and their lengths in order to operate on its conceptual features. An incomplete grasp of the daily, weekly and annual cycles that define the units for superordinate systems (Friedman, 1982) such as historical time can lead to misconceptions such as "the 1960s were a few months ago" (Masterman, 1998).

A further problem with acquiring an understanding of historical chronology is the impossibility of enacting the passage of time other than through the very process of living. However, merely to enact chronology by following it "along the simple and irreversible course of events" (Piaget, 1969, p. 269), does not lead to any kind of understanding. Only by developing the capacity to reflect on that course of events can the individual become aware of patterns such as sequence, change and causation. In relation to historical chronology, this constraint on children's reasoning is compounded by the remoteness of the phenomena from their direct experience. Lacking a frame of reference, they thus resort to the naïve theories of discontinuity and colourlessness referred to earlier.

A fourth and final issue to consider is the impact on children's reasoning of the representations that they use and construct when solving problems relating to time: primarily, verbal representations — which focus on semantically related concepts — and image representations. Here, it is the *form* of representation that children spontaneously choose when engaging in their temporal problem-solving which is of interest to the design of our IMM program. Friedman (1982) found that in children under ten verbal processing appears to precede image processing and pictorial representations to predominate over spatially-organised diagrams. These findings were reflected in our own informal study, in which we asked a small group of eight- and nine-year-olds to depict a Victorian school-child's day. They produced exclusively either verbal or pictorial narratives, rather than the time-charts that we had envisaged they would create on the basis of their previous exposure to these forms of representation in the classroom (Masterman, 1998). This suggests that, in contrast to adults, children may find it more difficult to select the optimal form(s) of representation in order to solve a particular type of problem, thus hindering further their ability to reason effectively. The study therefore provided us with another focus for our IMM program: namely, to develop computer-based activities that could help the child learn how to select the most appropriate representations when solving temporal problems.

2.3 Guiding children towards more effective representations for reasoning about historical chronology

Thus, it seems that, although young children do have an emergent set of skills and representations for reasoning about chronology in the everyday world, these tools are still incomplete in key aspects that are relevant to reasoning about the historical past. As a consequence, children can often make mistakes in their reasoning and find it difficult to reflect on chronology at a more abstract level. To help them progress through this learning process, we propose that what is needed are explicit representations that allow them to understand better how different temporal systems are related to each other and to know how to use those representations as computational tools with which to reason about the domain. At the same time both the form and content of these representations should address the naïve theories that children use to compensate for the inaccessibility of the phenomena about which they are reasoning.

3. Phase 2: Analysing the pedagogical issues

Having identified the major impediments to children's reasoning about historical chronology, the next phase is to analyse the classroom activities — in particular, the external representations — through which teachers address these issues, with a view to supporting or extending them through our IMM program.

A central feature of current practice is the use of the children's own life stories and immediate environment as a starting point for moving back in time through family history to finding out about life beyond living memory, as required in Key Stage 1 of the National Curriculum for England and Wales (DfEE, 1999). For example, children might start by discussing their daily and weekly regularities and representing them in time-lines. Then, they might compare their daily lives with that of a historical personage, such as the 17th-century English diarist Samuel Pepys, through the medium of another chronological representation: i.e. his diary. In this way, the restricted chronology of 'yesterday-today-tomorrow' evolves into the sequence of known events, people and developments in relation to which children can begin to sequence events, people and developments beyond their immediate experience (cf. Smart, 1996). Moreover, the use of stories helps to impart a sense of context to children's understanding, without which the mere knowledge of time concepts and dates is meaningless: "If children cannot envisage an Iceni, a Roman, a Saxon, a Dane or a Norman in any way 'from the inside', there could be no purpose in their being able to place them in correct order in a time chart" (Partington, 1980, p. ??).

Another key activity is 'sequencing', where children arrange a set strongly contrasted everyday objects or pictures in order of age. These 'concrete' arrangements then form the basis of more abstract representations such as time-lines, with whose canonical structure the children are already familiar. Figure 1 shows an example of a time-line scaffolded in this way. From constructing time-lines of concrete artefacts, children can progress to sequencing propositions from a historical narrative adapted from, say, Samuel Pepys' diary.

[Figure 1 goes here.]

A strength of sequencing is that it need not involve the numerical aspect of historical time. Nevertheless, as Figure 1 shows, numbers *can* be introduced at this stage, in terms of 'how many years ago' or, for the more distant past, 'how many lifetimes ago'.

However, whilst teachers have a repertoire of methods for introducing chronology to young children, it seems they could benefit from additional resources to help scaffold the learning of chronological concepts — especially for helping children reason with them more effectively. Our suggestion is to provide computer-based external representations with which the children can interact in ways which are not available using traditional teaching methods, and which help to construct a more robust bridge between their own everyday experience and the abstract nature of the historical past and the concepts associated with it.

4. Phase 3: Selecting and designing appropriate external representations to support the learning of abstract concepts

Phases 1 and 2 have pointed out the importance of providing task-appropriate external representations in order to foster change at the conceptual level. The generic representations relevant to children's understanding of chronology include timelines, story/picture sequences and family trees. The next stage is to consider how to optimise the selection and design of interactive external representations that will work *in concert* with the learner's emergent cognitive processes in each problem-solving task.

The theoretical framework that we use to inform the design of interactive multimedia for learning about chronology is ‘cognitive interactivity’ (Rogers & Scaife, 1998). This approach emphasises:

(i) The process by which new information is integrated with existing knowledge and then re-represented, and

(ii) The cognitive benefits and costs of particular forms of representation.

The framework allows us to identify the properties of external representations in terms of their ‘computational offloading’. This refers to the extent to which different external representations reduce or increase the amount of cognitive effort required to understand or reason about what is being represented, and is directly related to the amount of scaffolding to be provided for the task. In high computational offloading (i.e. heavy scaffolding) much of the effort is offloaded onto the representation, requiring minimal effort on the learner’s part to accomplish a given task. By contrast, in low computational offloading (i.e. light scaffolding) much cognitive effort by the learner is required.

We should note, however, that high computational offloading risks compromising the learner’s understanding of the domain by delegating the bulk of the problem-solving activity to the representation. Hence, a key issue in designing an interactive external representation is to get the balance right between providing too little offloading (making it hard for the child to learn initially) or too much offloading (making it too easy and hence more difficult later on to generalise and solve other problems through having only superficially learnt the concept). For example, although initially learning the abstract structure of a diagram — for example, a family tree — may be more difficult than reading a prose passage, mastering the canonical form of that structure can provide the learner with a powerful generalisable skill. That is, the learner should subsequently be able to work out more easily the solution of equivalent problems represented using that structure than if they had merely been given those problems in prose form.

The three main forms of computational offloading are: re-representation, graphical constraining, and temporal and spatial constraining.

Re-representation refers to how different external representations which have the same abstract structure make problem-solving easier or more difficult. For example, the relative proportions of the monastic day spent in different activities can be identified more quickly from a diagram than from a prose description (see Figure 2(a) and (b)). This is because diagrammatic representations in which key elements are arranged spatially makes it easier to perceive those elements at the same time than do sentential representations, where more explicit inferencing has to be done to come to the same conclusion (Larkin & Simon, 1987).

[Figure 2 goes here. It takes up a full page.]

Graphical constraining refers to the way graphical elements in a graphical representation are able to constrain the kinds of inferences that can be made about the underlying represented concept. A circular time-chart (Figure 2(b)) allows inferences to be made about recurrence (in that the day comes ‘full circle’ at midnight and starts again), while a time-line (Figure 2(c)) does not. This advantage, though, may come at the initial expense of too much computational offloading: learners may be easily misled by the superficial resemblance of Figure 2(b) to a conventional clock face and hence reason through analogy to this kind of temporal concept rather than about the inherent properties of the time chart as represented in a circular form.

Temporal and spatial constraining refers to the way different representations can make relevant aspects of processes and events more salient when distributed over time and space. Examples of its use include animations and the highlighting of significant parts of a representation.

Thus, in analysing the diagrams that are used to represent abstract chronological concepts, we can determine their cognitive properties and how they work when used to reason about the domain they represent. This allows us to consider which external representations can provide an appropriate level of computational offloading to support effective learning without imposing too steep a learning curve, and to include those representations in our IMM program.

5. Phase 4: Conceptual design of the IMM program

In this phase we describe how we used the analyses from the first three phases to develop a conceptual design of an IMM program to foster a sense of historical chronology in young children and, in particular, to help them reflect and reason more effectively about the nature of chronology. The approach focuses on how to exploit the cognitive benefits of multimedia by determining how to select, design and combine appropriate external representations for supporting the acquisition and subsequent use of abstract concepts relating to chronology. We start by establishing an overarching framework for the learning process. This enables us to contextualise the representational activities that we have identified as needing to be supported.

5.1 Establishing a framework for learning: The metaphor of time-travel

The progression from the concrete, or familiar, to the abstract, or unfamiliar, depends in part on the presentation of a convincing and enticing ‘parallel world’ to which the unfamiliar knowledge domain can be mapped. To support this learning process we selected a metaphor based on time-travel. The metaphor of time travel — in which chronological sequence is represented as a route along which an individual journeys — has exercised a potent appeal since at least H.G. Wells’ day. Since travel is a part of children’s experience from infancy, and time travel features in the films and TV programmes seen by many six- and seven-year-olds (Masterman, 1998), we considered this metaphor to be ideal for introducing young children to historical chronology. Moreover, a metaphorical journey also offers possibilities for a motivating ‘game’ that can exercise learners’ cognitive skills as well as engaging their fantasy.

To determine how best to convey to the learner the metaphor of time-travel, we developed a prototype ‘road map’ using pen and paper. This had two principal potential advantages. First, the map could represent both dynamic and temporal dimensions. Second, by bending a linear sequence of time into a winding road and using perspective to compress longer intervals between dates in the distant past, we would be able to display the whole ‘route’ on a single screen (in contrast with conventional time-line programs). We then tested the paper prototype with eight ‘informants’ from the program’s target age group. The children demonstrated an appreciation of the use of perspective to indicate distance in time, and created their own imaginary journey, by naming events and personalities from their fragmentary knowledge of history, placing these in sequence along the road (Figure 3) and designing their own ‘time machines’ in which to travel.

[Figure 3 goes here.]

The interface of the software prototype builds on this initial design, in that the learner takes on the role of a traveller in a time machine, which is represented on the screen as an animated icon on a road map. (This icon was designed by an older child ‘informant’.) Along the route, the learner can interact with personalities such as Anne Frank, Samuel Pepys, and King Alfred, who are represented on the road by icons (Figure 4). These personalities were selected for their relevance to the theme of chronology: for example, by being associated with a diary, chronometric artefact (such as a candle clock) or, in the case of Simon Bening, illustrations to a Book of Hours in which he depicts scenes from 16^{th}-century life for each month in the year. They were included to add contextual depth to learners’ understanding of chronological concepts (cf. Partington, 1980).

To visit a particular person, the child clicks on the relevant icon and the time machine moves along the road to that destination. As the time machine icon travels back and forth the personalities that it passes changes from colour to half-tone (or vice versa), depending on whether those personalities are in the future (half-tone) or the past (colour). Distances between personalities on the road are approximately proportionate to the number of years being travelled, and the time machine moves more slowly on the longer stretches in order to reinforce the illusion of travelling through longer periods of time.

[Figure 4 goes here.]

5.2 Mapping cognitive processes to interactive representations

The next stage in conceptual design involved proposing design features that could address the specific cognitive issues identified as central to the learning of historical chronology in Phase 1 (Section 2), on the basis of the cognitive properties of external representations identified in Phase 3 (Section 4).

Returning to the core operations on conventional temporal systems identified by Friedman (1982), we identified a number of ways in which to counter the specific difficulties that young children experience in their operations on historical time. For example, to underline the distinction between order and recurrence within temporal systems, a linear structure was used to represent a unique sequence of events (such as the week in which the Fire of London occurred: Figure 5) and a circular structure was used to focus on generic or recurring properties of the temporal system (such as the characteristics of the seasons of the year).

[Figure 5 goes here.]

To obviate children's difficulties with the numerical aspect of historical chronology, the signposts on the road map show the 'number of years ago' rather than actual dates (Figure 4), since earlier work with child informants had shown them to be more at home with the concept 'how long ago'. Furthermore, the road map itself, and the animated travels of the time machine along it, are intended to replace children's lack of differentiation in their conception of history with the notion that events happened in succession.

A further aspect of the conceptual design task was to identify, on the basis of the cognitive properties identified in Section 3, how the interactive representations in the program might most effectively support the desired cognitive operations. This task was facilitated by a set of design concepts that have been devised by Rogers and Scaife (1998) to operationalise the cognitive activity framework outlined in Section 3. These concepts include:

- *Visibility and accessibility*. The representation should assist the learner in drawing inferences about elements or processes that may not be perceptually obvious but are useful or essential for the learning task.
- *Cognitive tracing*. The learner should be able to develop his or her own understanding of the content by modifying or annotating the given representation.
- *Creativity*. The learner should be able to create new representations from the content as a way of understanding the concepts presented.

The design of the time machine supports inferencing in a number ways. First, the time machine's animated journey along the road is intended to reinforce the notion of the sequential nature of historical time. Second, as already noted, inferences about order and recurrence are supported through the use of representations with circular and linear structures respectively. Third, to prompt inferences about similarities and differences between past and present we drew learners' attention to specific details in pictorial images and provided games in which children decide whether statements such as 'When Pepys woke up he looked at his watch' or 'Pepys helped to put out a fire with a fire extinguisher' are anachronistic, in an 'extension' activity designed to take their reasoning a step further. Fourth, to address children's naïve theories regarding the past as devoid of colour, we aimed to use colour images from primary sources only (although this precluded the use of Victorian and early twentieth-century monochrome photographs).

Cognitive tracing is supported by 'learning through doing' activities, including rearranging representations whose elements are initially jumbled. Examples include a story sequencing task, in which learners use 'drag-and-drop' techniques to place propositions from Pepys' diary in the correct order using the temporal cues embedded in them (the solution is shown in Figure 5), and an exercise in matching the days of the week to the deities from whom their names are derived (Figure 6).

[Figure 6 goes here.]

Informants were extensively involved in the development of these learning activities. The simplified diary and jumbled propositions were tried out on a child from the target age group to ensure that they were pitched at an appropriate reading level. A paper card-sorting prototype for the day names activity was tried out on a group of older children, whose suggestions led to the provision of a 'how-to-do-it' demonstration in the program itself.

To enable learners to create their own representations, the software was designed to furnish learners with a log book in which to paste images and narrative passages, along with the representations completed in 'learning-through-doing' activities.

5.3 Mapping pedagogical issues to learning activities within the program

In conjunction with implementing the design features needed to support learners' conceptual operations on historical time, we worked out what might be an effective way to support the pedagogical approach outlined in Phase 2 (Section 3).

A central tenet of our pedagogical approach was that the IMM program should be designed as one form of scaffolding to be used in conjunction with other forms — namely, the teacher and other classroom activities. The design therefore presupposes that some interaction takes place between teacher and pupil beyond the bounds of the software, and that the program can be used as an extension of non-computer-based activities, such as diary writing and picture or story sequencing. The program was designed such that, on any 'visit' to a personality, the learner interacts with a 'key representation' — that is, a pictorial or verbal narrative associated with that personality — and a number of ancillary representations relating either to the key representation or to some aspect of contemporary life such as homes, transport and food. Thus, the child should be able to move from his/her immediate experience of chronology to a vicarious experience of the historical past through the representation, in an unfamiliar context, of everyday themes in a familiar form.

A simple fictitious scenario illustrates how the program is designed to contribute to children's emergent understanding of historical chronology. As part of a curriculum topic on the days of the week, let us suppose that a class of children have each kept a diary for a week. The teacher then sets the children a 'mission': (i) visit Samuel Pepys to find out about a particular week in his life, and (ii) visit King Alfred to find out how the days of the week got their names.

To accomplish these tasks the children depart, singly or in groups, on their virtual 'voyage' by time machine. They read the key representation associated with Samuel Pepys: a verbal narrative consisting of simplified extracts from his diary for the week 2nd-8th September 1666, covering the Fire of London (an optional voice-over is provided for the benefit of less able readers). They might also complete one of the associated ancillary representations: the story sequencing task referred to in Sections 5.1 and 5.2 and illustrated in Figure 5. They then return to the time machine and travel further back in time in order to carry out the day-name activity (shown in Figure 8), which is an ancillary representation associated with King Alfred. Finally, the children 'return' to the present with a 'log book' containing their findings, which consist of images and text from Pepys' diary that have appealed to them, together with the completed activities.

6. How effective were the IMM representations in fostering reasoning with chronological concepts?

The time-travel program was designed to help young children construct a temporal framework in which to locate their emergent knowledge of the historical past, and to appreciate that "all people and events happen in time, however short a time ago" (Blyth, 1990, p. 3). To test our cognitive assumptions about the value of providing time-travel representations to foster reasoning in this way, various evaluations of the time-machine program were carried out. These included getting feedback on pen-and-paper prototypes during the design phase, together with an evaluation study in which pairs of children interacted with the software prototype. Structured pre- and post-testing were considered inappropriate, since we would be unable systematically to measure learning effects that could be attributed to a specific design aspect of the software. Moreover, our belief is that learning, especially the ability to reason and reflect, is a complex process that cannot be reduced to single cause-effect processes arising from particular pieces of software functionality. Having a combination of representations available to interact with, and having a teacher to help the children to learn how they correspond to each other, is what we believe fosters children's ability to understand how to reason with concepts. It would have been inappropriate, therefore, for us to have tried to test the effects of interacting with the software program in an isolated laboratory-style setting.

6.1 Evaluation of the time-travel metaphor

Throughout the various forms of contextualised testing, it was clear that the children were at ease with the time-travel metaphor (something which had not been anticipated when the metaphor was initially devised), and had no difficulty accomplishing activities whose abstract structure was already familiar to them. Indeed, one child commented that what she liked best about the program were: "Questions and answers that were just fit for me — they were like the kind of things that I would have to do". Most children were able to explain why the icons on the road changed colour as the time machine travelled past them. However, one child thought that the time machine was moving *backwards* in time from King Alfred to Queen Victoria.

6.2 Reasoning with chronological concepts

Five pairs of children aged six and seven took part in a study which focused on examining whether and how the multimedia program was able to facilitate their ability to reason with the chronological concepts. The activities in sequencing and quizzes involving anachronistic statements provided the most fruitful exercises in temporal reasoning. In one exercise, the children sequenced a set of 16th-century pictures depicting the seasons on the basis of the evidence in those pictures. The events of the Fire of London (Figure 5) were successfully sequenced by the children. Most pairs also showed evidence of reasoning in their lively debates over each quiz question, particularly when asked to spot anachronisms in an account of the Great Fire: "*Had* fire extinguishers been invented yet?" "Did people *really* put sugar in their beer?" "*Would* they have eaten chips like us?"

Three teachers interacted with the program and were then given a questionnaire to complete. This questionnaire was designed to ask them questions about the relevance of the program to the curriculum and its learning value. All teachers thought that the program offered something that was genuinely different from other ways of teaching about historical chronology. In particular, they all thought the interactive learning activities provided in the program were excellent. One teacher complimented the quizzes for stimulating children to think. Another teacher praised the program for its incorporation of different narrative genres, as required by the National Literacy Strategy (DfEE, 1998).

7. Discussion and conclusion

Our study has shown that it is possible to develop an interactive multimedia environment that can facilitate the learning of abstract concepts. Software was developed that exploits the unique properties of computer-based representations; dynamic and interactive representations were designed to encourage the children to relate their current understanding to the concepts being represented and to test their assumptions vis-à-vis these concepts. In so doing, new combinations of external representations were provided that constrained the learning space. Moreover, the kinds of activities that were constructed helped the children understand the appropriateness of using different graphical representations to reason about different aspects of chronology. In our evaluation of the software, we found that the children were able to understand the concepts presented and moreover, were able to make a number of inferences about sequencing, order, recurrence, and similarities and differences with past and present.

To design our IMM program, we followed a design approach which combined top-down methods (theory-informed requirements) with bottom-up techniques (i.e. informant design). In particular, we focused on how best to present a combination of interlinked representations that mapped onto the complex, abstract concepts (e.g. sequence, recurrence) in an explicit way that was intended to be logical to the children such that they could integrate them with their existing knowledge of the domain. Importantly, it took into account how the software was to be used in the context of other classroom activities and in the general framework of teacher-based scaffolding.

Our study showed, however, that designing IMM to support learning is not straightforward, but requires making many design decisions, often in the face of conflict. One of the main problems is knowing how to deal with the various trade-offs that invariably arise when trying to satisfy a number of requirements. For example, we focused on the problem of using different kinds of graphical representations to make learning easier. A trade-off we identified was that if we were to represent the underlying concept to be learned in a graphical form that made it easy to perform certain kinds of problems, then the child's understanding might remain fixed at that level. That is, there is a risk that they will only understand the problem space at the level at which it is represented and be unable to reason about the domain at a more generalised level. A specific challenge, therefore, is to present an integrated set of representations in a form through which the child can move back and forwards so that they can build up their own understanding of the representations and how they relate to each other. A further technique is to provide a range of activities which allows the child to reflect upon and test their assumptions. Here, a driving force is to allow the child to build up their reasoning skills through exploring and manipulating multiple representations. In the case of our software, we provided them with interlinked representations of historical chronology that they could explore in relation to their understanding of chronology in their own lives — something that is different from just using static learning materials or arrangements of tangible artefacts.

Bruner once wrote: "it requires a combination of deep understanding and patient honesty to present physical or any other phenomena in a way that is simultaneously exciting, correct, and rewardingly comprehensible" (1960, p. 22) — which is very much the spirit we have adopted in developing IMM to support learners' emergent representations of a specific knowledge domain. Our approach has laid strong emphasis on firstly, the developmental issues underlying learners' misrepresentations of the domain and, secondly, how they can be helped to form appropriate external representations in their problem-solving at school.

For an educational multimedia program to present — or, rather, to enable children to *re*present — abstract concepts in a "correct and rewardingly comprehensible" manner, external representations must be chosen according to their cognitive characterisations and to the levels of abstraction at which children in the target age range can normally operate. As well as continuing to inform the design of IMM through theory-driven research, it is profitable also to turn to informants, in order to corroborate the findings of others, to clarify grey areas and, even, to uncover the unexpected.

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Captions for figures

Figure 1: A time-line of toys, showing how a familiar topic can be used to extend the concept of sequence into the past beyond children's experience. Pupils brought toys owned by parents and grandparents to school and sequenced them according to age (Cumnor School, May 1997).

Figure 2: One sentential and two graphical representations of the same information about the Medieval monastic day.

Figure 3: The original prototype road map, with stopping-off points suggested by the children.

Figure 4: An early interface of the software prototype, with the time machine currently 'visiting' Samuel Pepys. The icons for Pepys and the personalities preceding him in time (i.e. from Henry VIII backwards) are intended appear in colour; the icons of the personalities in the future (i.e. Queen Victoria onwards) should be in half-tone, to indicate that they do not 'exist' yet. Hannah and Gregory are modern children who act as guides to the learner on his/her time travels.

Figure 5: The sequence of events during the week of the Fire of London in 1666 is represented in a linear structure.

Figure 6: Children are presented with two sets of propositions: descriptions of pagan deities and the days to which they lend their names. Their task is to drag each god to the appropriate day name. On this screen, Tuesday and Saturday have already been matched to their respective deities, and the mouse pointer indicates that the user can drag the statement 'I am the Moon' to a destination (i.e. Monday).