Chapter 5

EM for education in a broader context

The previous chapter illustrated EM as an educational technology from the perspective of teaching and learning about computer science. However this thesis argues that EM has potential beyond computer science education. The aim of this chapter is to demonstrate that EM is well-aligned with education in other subjects, adult education or lifelong learning, and collaborative learning.

5.1 Learning in other subjects

5.1.1 A selection of EM models and activity

EM has been used to build models and learn about a wide range of subjects, as can be seen from the EM project archive [EMP]. The breadth of the modelling activity spans mathematics, engineering, science, humanities, arts and business.

Mathematics education is a well established field and it is no surprise that many postgraduate and undergraduate projects have explored this area in relation to EM. Roe has investigated the use of EM for mathematics education [Roe99] [Roe03], starting with model-building in the school curriculum with coordinate geometry [EMP:cogRoe1999], and later in terms of exploratory modelling to understand monotone boolean functions [EMP:fdl4Beynon2002]. Roe also discusses the merits of open-ended environments—in particular using Imagine Logo to develop models of shot put and discus throwing—for putting the learning back into e-learning for mathematics [RPJ05]. Other topics that have been explored by other authors using EM tools can be found for example in a complex number model [EMP:complexGardner1999] and the fractional relationship and equivalence helper [EMP:fractionsCronick2003]. The latter model shows external similarities

Figure 5.1: Car parking simulator [EMP:carparkingMcHale2003].

to Visual Fractions from Logotron† in respect of the use of dependency to experiment with fractional equivalence. However, behind the interface, dependency in Visual Fractions is made possible by some significant procedural programming using Imagine Logo, whereas the fractions model by Cronick is relatively simple to comprehend as a set of observables and dependencies. Another relevant EM environment was created during an undergraduate final year project by Guillou which examined the use of adventure games for mathematics education [Gui03].

Engineering has been an active area of research for EM [FB01] [BNY94], although not primarily in terms of education. One of the most relevant projects to education is the car parking simulator which was developed by McHale for his undergraduate final year project [EMP:carparkingMcHale2003]. The model was designed to aid learner drivers develop their parking skills. The car parking simulator is closely related to engineering—as well as applied physics—because a large part of the project was concerned with the mechanics of cars, from issues like steering and turning circles, to the effects of acceleration and braking. As shown in Figure 5.1, the model makes use of a steering wheel and pedals and is distributed on up to 4 computers to simulate different viewpoints on the car (windscreen, mirrors, and rear window). The flexibility of the EM model allows for

†Visual Fractions (`http://www.logo.com/cat/view/logotron-visual-fractions.html`) is an educational program created using Imagine Logo.

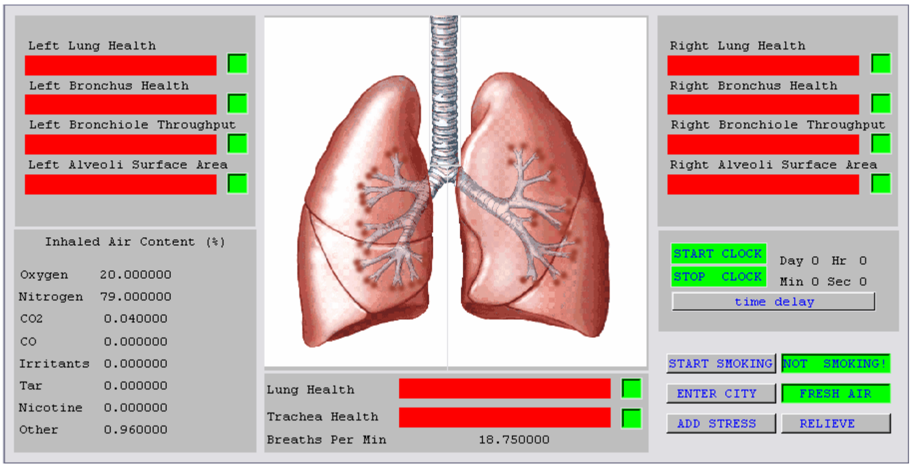


Figure 5.2: An educational artefact for understanding the effects of smoking on the body [WEBEM1].

challenging situations to be practised, such as an obstruction in the rear window or a misaligned door mirror. Another example from engineering can be found in D'Ornellas's project on learning about electronic circuits [DOr98].

Various EM projects have related to areas of science and in many cases the models have educational value. In the area of biology the ant navigation model stands out for its contribution to understanding ant behaviour, as explored in Chapter 6. Another educational artefact relating to biology or medical science was developed by Koorosh Heshmati (submitted to [WEBEM1]) for teaching and learning about the effects of smoking on the body (see Figure 5.2). There have been a number of models that have involved physics in many different ways. Games like billiards [EMP:billiardsCarter1999] and football [EMP:footballTurner2000] have required a physics model of ball motion for example. One model that has a strong physics element is the agent-based bridges model [WEBEM1]. The author of this model developed an environment for constructing simple bridges with partially elastic components that enabled experimentation with different configurations of components and weights.

Humanities has been one of the most promising areas of application for EM, as evident from research in EM together with Willard McCarty into humanities computing [BRM06]. The softer, subjective nature of humanities (compared to science) has much in common with EM, and is not supported particularly well by the systematic structure and formality of programming [BRM06]. A distributed model of the historical Clayton Tunnel railway accident is one of the best known EM models, and is discussed in more detail later in this chapter in connection with collaborative modelling. Care's final year undergraduate project [Car04b] explored the history of planimeters—mechanical devices

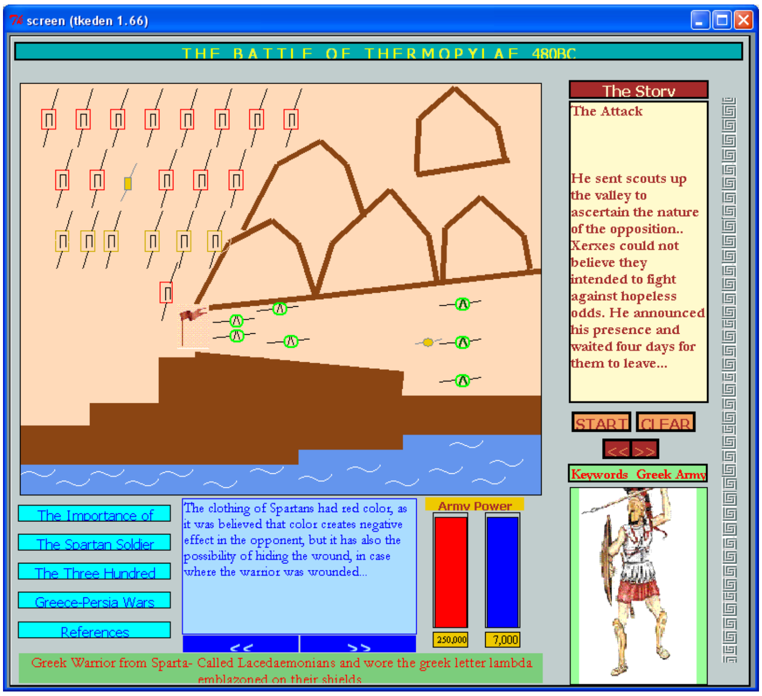


Figure 5.3: A model of the Battle of Thermopylae.

for calculating area—and developed a number of accompanying models for gaining insight into their workings. An account of the learning involved in Care's model-building activity is given in the next chapter. Another historical model is from a famous Greek battle (Battle of Thermopylae), shown in Figure 5.3, built by Theodorou as part of a final year undergraduate project [The05].

There are a number of models relating to musical composition and analysis. The most significant work is Beynon's exploration of Erlkönig (a ballad by Goethe set to music by Schubert) shown in Figure 5.4 [EMP:kaleidoscopeBeynon2005]. The common ingredient in these examples from humanities is that they place the model-builder in an exploratory situation (e.g. in the Battle of Thermopylae). These models offer different qualities to more conventional uses of technology in the humanities. There are many resources available on the Internet about the Battle of Thermopylae including animations, maps and detailed narratives. The Battle of Thermopylae model, on the other hand, is distinctive in the manner in which it offers a unique exploration of a state. The significance of all of these humanities models is that the model-builder is placed in a state corresponding to a situation, and exploration of the state is unconstrained. A model-builder exploring the Erlkönig model is tracing Beynon's unique personal understanding of the music that has arisen through years of practical experience. The visualisation is an attempt to convey metaphorically the relationships between events in the poem and the harmonic effect of the

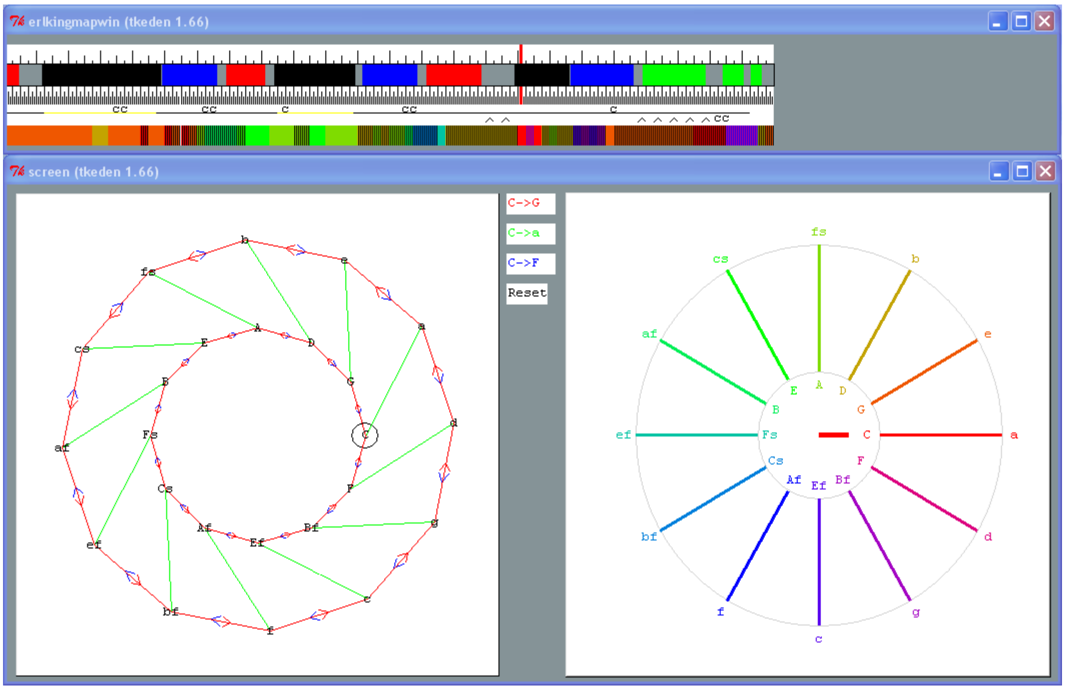


Figure 5.4: A musical analysis of Erlkönig [EMP:kaleidoscopeBeynon2005].

music. This leads Beynon to distort the traditional cycle of keys in a fashion outside the scope of conventional interpretations—the twisting effect on left-hand side of Figure 5.4 reflects this distortion. Interacting with the model of the Greek battle and the model of the Clayton Tunnel accident, there is a sense that not only does the artefact represent a historical event, but that it is a personal interpretation of an event that can be interacted with as if for the first time. In this way, EM captures the aspiration for modelling identified by Dening: "[that we may] return to the past the pasts own present, a present with all the possibilities still in it, with all the consequences of actions still unknown" [Den98:p48].

Other models relating to music are composition focussed and include a keyboard model [Kin07], a musical score creator [EMP:musicWai2000] and a guitar tutor [Kon07]. While Erlkönig is about learning on a personal level by a specific model-builder, these three models are support tools for learners to use in more general settings. For example, the guitar tutor can be used to practice identifying given chords, to record personal chords, and to play a sequence of chords. These more 'generalised' models (supporting more ritualised interaction) have more in common with traditional ET artefacts or microworlds, whilst still offering model-builders the potential to subvert the standard patterns of interaction and to explore situations that are particular or personal to themselves.

Although a detailed exposition of the contribution in each of these subjects is beyond the scope of this thesis, the above discussion demonstrates the possible application of EM to a broad range of subjects outside of computer science. Some, if not all, of these subjects have been the focus of educational technologies that can support a wide range of learning outcomes. The important point is that EM offers a unique perspective on technology enhanced learning as is evident from some of the models introduced above. The next section looks particularly at language learning as a subject in which EM has a unique perspective as far as technology support is concerned and in which EM has the potential to positively change current educational practices.

5.1.2 Language learning

Foreign language acquisition is an area where learners have been quick to utilise new media and technology. Although language books are still seen by many as essential to learning a second language, the arrival of audio tapes, and later compact discs, has transformed the learning experience because of a new emphasis on the spoken form as opposed to the written form. Some language schools have developed techniques, such as the Michel Thomas method [Tho03], that do not make use of any written materials, but in most classrooms it is more common to see books and tapes being used to complement each other. The introduction of television and video for language learning followed after audio technologies, and now, the development of computers and the Internet is leading to new possibilities for language learning as Delcloque suggests [Del00].

Uses of educational technology for language learning are often referred to as Computer-Assisted Language Learning (CALL) or Technology-Enhanced Language Learning (TELL). Warschauer, an eminent scholar in the area of technology for language learning, suggests that there have been roughly three phases in the development of CALL: the *behaviouristic* phase, the *communicative* phase, and the *integrative* phase [War96]. The three phases are described in Figure 5.5. In the *behaviouristic* phase (roughly appearing in the 1970s & 1980s), computers were used to support behaviourist theories and programs consisted of practice, drills and tests. The computer is a particularly effective medium for such activity due to the consistency of materials and the ease of repetition. In the *communicative* phase (during the 1980s & 1990s), in response to a perceived lack of authenticity in the first phase, an emphasis was placed on the computer to take a more communicative approach to teaching. This led to programs where the computer became the language tutor, offering the learner a choice of material and routes through the material. These led to the development of games and other programs that stimulated language learning. Both the first and second phases of CALL highlight the paradigmatic conflict in educational technology, as described in §1.1.4, in this case between the way languages are learnt in an everyday setting and the methods that are employed for computer-based language learning. This is partly because the methods seek to use the computer as a teacher instead of a support for learning. The *integrative* phase (starting around the turn of the century), the one that Warschauer would say we are currently in, has come about because of the integration of multimedia and the Internet. The ease with which multimedia can be combined through hypermedia and made available dynamically through the world wide web has led to new forms of CALL. For example, students learning not-so-commonly-taught languages such as Thai are not only able to access Thai language learning resources[†] but they can also gather up-to-date sources from Thai websites and communicate with Thai people using email and text-based chat for reading and writing skills and voice chat for speaking and listening skills. The Internet itself has become a tool for CALL because language learners around the world can communicate cheaply and quickly using email, instant messaging, Internet voice calls and video conferencing. In this way there are some positive outcomes for using the Internet as a support (rather than a teacher), but there are still large research agendas concerned with emphasising the computer as teacher aspect of language learning. For example, researchers in adaptive hypermedia systems advocate that text, images and videos that adapts to individual learner needs are beneficial because it teaches the most relevant aspect to the learner[‡]. Starting from such a viewpoint is equivalent to the behaviouristic and communicative phases of CALL in the 1970s and 1980s, and while adaptive hypermedia may offer benefits to learners in some situations, it is not comparable to the flexible uses of the Internet for language learning that Warschauer sees emerging in the current *integrative* phase [War96] or to the experimental approaches to language learning suggested by EM later in this section.

While it is true that multimedia, hypermedia, and the Internet are being used for *integrative* CALL, many applications of CALL (e.g. latest language-related technologies promoted at Warwick's e-learning Showcase Day 2007 [UoW07]) would be classified by Warschauer as *behaviouristic* CALL and most exemplify traditional audio/video techniques. For example, the current iPod (or mp3 player/phone) craze is seen as an ideal opportunity for language learning on the move. This is pedagogically similar to 20 years ago when Walkmans (portable cassette players) were being used for language learning.

[†]See the extensive language site developed by a school in Thailand at `www.learningthai.com`.
[‡]See [DeB02].

Stage	70s-80s: Behaviouristic CALL	80s-90s: Communicative CALL	90s-00s: Integrative CALL
Technology	Mainframe	PCs	Multimedia and Internet
English-Teaching Paradigm	Grammar-Translation & Audio-Lingual	Communicate Language Teaching	Content-Based, ESP/EAP
View of Language	Structural (a formal structural system)	Cognitive (a mentally-constructed system)	Socio-cognitive (developed in social interaction)
Principal Use of Computers	Drill and Practice	Communicative Exercises	Authentic Discourse
Principal Objective	Accuracy	And Fluency	And Agency

Figure 5.5: Warschauer's three phases of CALL [War00].

There have been technical advances in that mp3s are quicker to copy from device to device than cassette tapes, but the style and content of the learning remains the same. In this way current practice demonstrates that there has been little departure from conventional language learning techniques. The main improvements that have arisen so far from educational technology are to communication and the transmission of information. In many respects educational technology remains unsuitable for providing support for learning in an everyday sense (as depicted in Figure 1.1 on page 13) because it lacks experimental, flexible and meaningful characteristics.

5.1.2.1 Approaches to language learning

Before evaluating what EM may contribute to language learning, it is essential to understand the approaches to the subject. First of all, as acknowledged by Milton's review of language learning and technology [Mil02], language learning is difficult because it involves a combination of learning explicit formal vocabulary and grammar rules, and developing fluency which may include informal and cultural aspects. The basic approaches to understanding language learning fall within two camps. In the one camp there is the behaviourist approach which views language learning as essentially a repetitive engagement with vocabulary and phrases. In the other camp there is the cognitive approach which views language learning as a more gradual subtle process of gaining ability and understanding through experience of a language in ways that are not necessarily formalised. The behaviourist approach is aligned to the formal aspect of language learning where explicit vocabulary and grammar rules are emphasised, whereas the cognitive approach is relevant to the informal aspect of gaining fluency in a language. So although these two approaches are generally seen as coming from separate camps, successful language acquisition is likely to include both [CHM04].

The use of educational technology, such as digital audio and video, generally follows the behaviourist approach. Most CALL, especially from the behaviouristic and communicative phases, focuses on supporting the formal aspect of langugage learning. This may be due to the emphasis that has been placed on formal interpretations in software development. Brian Cantwell Smith identifies two aspects to the interpretation of software [Smi96]. First, there is the relationship between the *program* and the *abstract process* that is treated explicitly as having a single unambiguous interpretation[Smi96]. Second, there is the relationship between the *abstract process* and the *world* or *subject matter* which can have many interpretations and cannot be easily formalised [Smi96]. Smith criticises software development for focussing too heavily on the first interpretation and not giving enough attention to the informal aspects of software [Smi96]. This imbalance suggests that software leans towards supporting domains that can be formulated explicitly and that have one unambiguous interpretation. It is therefore well-suited to repetitive tasks in language learning, as is evident from the common use of software for spelling correction, vocabulary reinforcement, and grammar suggestion. The support for the informal aspects of language learning using computers is not obvious. Interacting with a computer (using CALL from the behaviouristic or communicative phases) may teach the definition of "tea", but it is unlikely to be able to explore the implied meanings of an ambiguous phrase out of context such as "would you like to come for tea?". Such situations that are natural for native speakers can sometimes lead to misunderstandings between native and non-native speakers[†]. Where misunderstandings occur, there is a mismatch in expectation, and this realisation is what leads to 'conceptual change' in the learner as described by Strike & Posner [SP85] (see §1.1.4). Language learning in the world, in an everyday setting, involves informality that educational technology with its background in logic does not satisfactorily support. The argument in Chapter 3 is that EM offers support for learning (and more generally computing) that can involve both formal and informal aspects. Therefore EM should be well-suited to supporting language learning.

Figure 5.6 highlights some aspects of language learning that can be closely related to characteristics of EM as explored in Chapter 2. This is to show that EM has much in common with language learning and that the activity of learning a language has many

[†]One of my friends was pleasantly surprised when expecting a cup of tea to be served what he would have called dinner!

Language learning...

1. is an incremental process of gaining understanding of a language and its usage
2. requires repetition of familiar situations and interactions
3. is deeply embedded in context and culture
4. does not require a complete understanding of a language to be able to make use of it for meaningful communication

Figure 5.6: The characteristics of language learning that are well-aligned to EM.

of the same ingredients as using EM to create an artefact. In the following case study involving learning Thai language, it is shown that through these similarities EM is much better aligned to supporting not just the formal aspects of language learning but also the informality that is required for deeper learning leading to fluency and cultural transfer.

5.1.2.2 A case study from learning Thai language

To illustrate the potential of EM for language learning and the close connection between language learning and EM, an exercise in creating a language learning artefact is undertaken by the author. The topic of this case study is "buying items at a market in Thailand". The specific situation could be: an individual has a shopping list of grocery items and is going to visit a market to find and buy the items. This situation was chosen because it is an activity that happens in most countries, it would be familiar to most people, and it invokes a variety of language aspects:

- understanding items on a shopping list (items and quantities)
- finding items within a market (navigation)
- asking about items (vocabulary of items)
- paying for items (numbers and currency)

These are some of the aspects that can be formalised or that can be made explicit and expected from a visit to a market. There are other informal aspects that are just as likely to occur but which might not be specifiable so clearly, or which cannot be formalised in a computer-based artefact. For example, how to deal with unexpected occurrences like a market seller trying to engage in everyday conversation. The informal aspects may be tied up with culture and context like a situation where it is not known whether the price is fixed or whether you are expected to bargain for the price.

There are two sides to this case study: the construction of an artefact that represents interactions at a market, and the exploration of the artefact by the learner (in this case, the author). These need not be viewed as two separate stages (as demonstrated with the TLJ model in §4.1); both activities can be interdependent in an EM environment and the learner is likely to be switching from one activity to the other as their learning progresses. Similarly, the learner will often be involved in two related activities: understanding the language, and understanding (or making sense of) the situation. For example, in a market the learner might be grappling with questions about the prices, whether there are any hidden charges or discounts, or whether bargaining is expected. In an unfamiliar cultural context understanding the use of language is often intimately linked with understanding the situation.

5.1.2.3 Establishing an initial model based on existing understanding

The initial construction of the artefact involved using existing knowledge to create an environment that was similar to a market. This activity, like any other EM activity, is guided by the modeller or learner in such a way that the artefact will represent their idea of a market, and their personal experience of being at a market.

An initial artefact was constructed with typical photos from a market as shown on the left of Figure 5.7. This included images of market stalls containing different items (fruit, vegetables, meat). At this point, a learner could browse the 'virtual' market as a passive observer, unable to perform any actions in the environment. The next stage was to extend the artefact with the potential to enquire about and ask for items on the market stalls. A further development to the model enabled the keeping of a shopping list and a shopping bag, with the idea of buying items and placing them in the shopping bag in order to fulfil the shopping list. Figure 5.7 is a model of a market situation, constructed using the GEL notation [EMP:gelHarfield2007] (see Figure 4.5 on page 93) that was developed by the author as introduced in Figure 4.5 on page 93.

This was considered a basic starting point for the market artefact. At this point, the artefact was at a basic conceptual level, using only English language, as a means of formalising my personal understanding of interactions at a market (see Figure 5.7). This may be

Figure 5.7: The initial market model before adding Thai.

a typical conception of a market for an English person. In this way EM supports the qualities of language learning as necessarily incorporating repetition of existing understanding and practice as highlighted in Figure 5.6.

5.1.2.4 Embellishing the model with Thai language

The first steps towards creating a Thai language artefact involved translating some of the text contained in the artefact into Thai. Instead of using Thai characters, which may be unfamiliar to most learners, the Royal Thai General System [Kan06] for transliteration to roman characters was used (see the text in Figure 5.8 for example). Although this distances the learner from the reality of a Thai market, transliteration is commonly used as a stepping stone for English speakers towards understanding the Thai alphabet.

Even when translating some of the basic elements of the artefact from English to Thai as shown in Figure 5.8, difficulties arise and changes must be made to the artefact. On a sentence level, there are components that must be reordered or reconstructed. For example, if you translate "how much are the bananas?" into Thai then you can literally say "banana how much?". In Figure 5.8 the option "...tao rai?" meaning "how much?" is selected and "gluay" meaning "banana" has been entered in the text box. In modifying the artefact in response to translating the "how much?" question, the subject of the sentence has moved to the beginning and, in the artefact, the position of the subject text box has changed. It may seem obvious that sentences cannot be translated word for word, but building an artefact magnifies this fact to the learner (cf. Jonassen's maxim that if you can build a model of something then you understand it [Jon06]). At least in my interactions with the market model, I was forced to think carefully about how to express sentences in Thai and consider the differences between Thai and English. The benefit of EM over traditional programming environments is that such refinements to the artefact

Figure 5.8: The Thai market model.

can occur as part of the interaction with the artefact and as part of the learning process (as opposed to the 'correcting' of programs which requires a developer or at the very least returning to the development environment). As the artefact is developed, the refining of the details goes on endlessly. If the artefact was modified to use Spanish then there would no doubt be other details to be considered—on a word level the artefact would need to cater for the gender of the words. A specification of the artefact could not capture all the possible details that might go into the artefact, and so it is natural to need to develop and refine these details as the artefact is developed. In this way EM more naturally supports the quality of language learning as incremental and not necessarily complete from the beginning as highlighted in Figure 5.6.

5.1.2.5 Exploring cultural aspects of Thai language

The "how much?" example is concerned with the more formal aspects of Thai language because it is related to the ordering in sentences which can be explicitly defined to some extent. There are other issues addressed that relate to more informal aspects of Thai language. For example, if you asked the question "can I have 5 apples?" in Thai then you might simply get the answer "yes" because "can i have" would likely be interpreted by the seller as a question instead of a request for apples. The second option in Figure 5.8 ("kor... dai mai?") is a fairly close translation of "can I have?", according to a native Thai speaker, but such is Thai language that you can actually say it more bluntly (from an English point of view) as "I want..." and add an extra word on the end to make it polite (such as "krub" for a man or "ka" for a woman). There are many similar subtle issues that could be taken into account in the Thai market model, and through interaction the model

```
/* Adding polite endings to sentences */
howmuchare_text is "... tao rai" // ending // "?";
mayihave_text is "kor ... dai mai" // ending // "?";
doyouhave_text is "mee ... mai" // ending // "?";
idontwant_text is "mai aow khorb khun" // ending // ".";

/* Defining the ending */
sex = "female";
ending is sex=="male" ? "krub" : "ka";

/* More complicated ending */
cute = 0;        ## set to 1 to sound cute
closefriend = 0; ## set to 1 if speaking to close friend
ending is (cute ? "na" : "") //
    (sex=="male" ? "krub" : (closefriend ? "ja" : "ka"))
```

Figure 5.9: Redefinitions to the market model to add Thai polite endings to sentences.

can be refined to reflect new understanding by the learner. The use of dependency for flexible redefinitions is one example of how EM can help a learner take account of nuances in a language. The polite sentence endings "krub" and "ka" which change depending on the sex of the speaker are one such example. By redefining a small set of definitions as in Figure 5.9, every sentence in Figure 5.8 is appended with an appropriate ending. The 'ending' observable in Figure 5.9 is dependent on the sex of the speaker and therefore any change to the 'sex' observable will select the appropriate ending. More complicated endings, such as those appropriate for speaking to a close friend and to make the sentence cuter, can be easily incorporated by redefining the ending observable as given in the last definition in Figure 5.9.

Another cultural aspect of the language incorporated in the market model is that bargaining is accepted and expected in a Thai setting. Refining the model to reflect the structure and vocabulary of different contexts or cultures as is necessary to learn about bargaining is much the same as making any other interactions with a model (e.g. the redefinition of the 3D room in Figure 4.8 on page 100 or the modification of the HTML environment in Figure 4.14 on page 111). The use of dependency in EM, as in Figure 5.9, provides a support for exploring issues where language learning is deeply embedded in context and culture as highlighted in Figure 5.6.

5.1.2.6 The advantages of never finalising a model

As described in §2.2.5, there is not necessarily such a thing as a 'complete' artefact when engaging in EM. Although the Thai market example may reflect all of the learner's current understanding, it still has the potential as an instrument for developing the learner's understanding further. Similar sentiments are expressed by Kynigos in a paper on 'half-baked' microworlds where he suggests that partially developed microworlds offer potential for constructionist learning because they encourage learners "to build on them, change them or de-compose parts of them in order to construct an artifact for themselves or one designed for instrumentation by others" [Kyn07]. In the market model, the learner might want to take a step towards learning the Thai alphabet, or may be interested in developing the market artefact towards conducting business. As with the potential for using language, there are many possibilities for the market model and it can serve as a 'half-baked' starting point for learners as Kynigos advocates. In this way EM supports the qualities of language learning as not requiring a complete understanding of the language in order to make use of it for meaningful communication as highlighted in Figure 5.6.

The artefact itself might not appear to be particularly useful to others once the learner has finished with it. As characterised in Chapter 1, learning is an active process that requires interaction to benefit from any artefacts. Model-building with EM involves essentially two elements: *artefact* and *interaction*. The potential for developing understanding is in the process of constructing and exploring the artefact. Therefore, unlike most conventional educational technology where the program stands out, the EM artefact may not appear on its own as impressive or useful, but through interactions the usefulness of the artefact may emerge.

There is potential for other learners to make use of the artefact for learning Thai in that the artefact could be used as scaffolding for someone less experienced in Thai. Although this is not explored in this case study, the artefact could be given to a beginner and through interaction the person may be able grasp some elementary Thai. A more experienced learner would be able to extend and refine the model in light of their knowledge of Thai language and related cultural issues. As Kynigos states, the benefit of 'half-baked' artefacts is that they can be unpicked, built upon and combined for the benefit of the learner [Kyn07], and EM provides a suitable environment (i.e. using dependency) in which this activity can occur.

5.1.2.7 Evaluation of case study

One criticism of the case study is the extent to which attention may be placed on model-building that is not connected with the target language. This concern is inevitable with any subject, but it could be argued that learning about the mechanics of the situation and

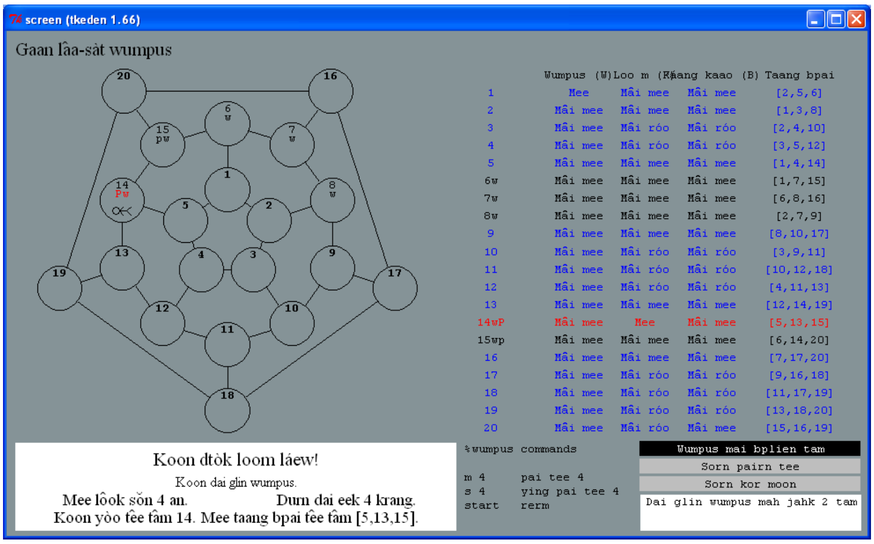


Figure 5.10: The wumpus model in Thai.

the context is also valuable in that it is emphasising the characteristic that all learning is situated and relating to authentic experiences. In cases where there are suitable models to be reused (or 'half-baked' models), much less time could be taken up with building a model of the situation. In the case study Rungratanaubol's Thai number model [Run02] was reused for talking about quantities and prices at the market. It is possible that existing models may be used for language learning in a specific domain. As an example, I took the wumpus model by a student as a submission for WEB-EM-1 [WEBEM1] (discussed further in Chapter 6) and, as a model-building exercise, I translated the game into Thai (see Figure 5.10). Such activity requires only a minimal amount of model-building, and hence the challenges were all related to understanding the language in a specific situation. The types of learning that were encountered include: increased vocabulary, improved grammar knowledge, skills for reading and writing, specific domain language understanding for the wumpus game. It is not necessary to undertake the building of a large model in order to use EM for language learning. Furthermore, artefacts already containing suitable language, like the wumpus model in Thai, could be used initially by other learners with little or no model-building experience.

The Thai market case study demonstrates that the practice of EM is well-aligned to the nature of language learning in an everyday sense as described in Figure 5.6. EM as a support for language learning can also be seen as departing from conventional approaches to CALL (e.g. the early uses of CALL described by Delcloque [Del00] or the current usage of mp3 players and other technology used at university level [UoW07]). In particular, EM supports an approach to language learning that surpasses the behaviouristic and communicative phases of CALL defined by Warschauer [War96] because it is concerned with more than transmission and communication. It fits into the current integrative phase of CALL because model-building using EM can be seen as a cognitive support for learning instead of a teacher or communicative tool. However, EM has many distinctive features that differentiate it from other educational technologies that might be classed as integrative CALL. As shown in the case study, dependency plays a key role in model-building, as does the incremental nature of construction with EM.

This case study is by no means intended to be complete, and purely offers an example of a subject area outside of computer science to which EM can support more of the everyday characteristics of learning. The extent to which EM can support language learning is currently dependent on the learner's capacity to build models using the current tools. It is not clear whether other model-builders could exploit the tools for language learning in the same manner as the author—with better tools this might be possible. A wider investigation is needed to evaluate the application of EM to language learning. The discussion of the Thai market model only provides an insight into what might be possible (using better tools) on a much larger scale with different languages and levels of learning.

5.2 Learning through lectures and presentations

Chapter 4 explored a specific example of constructing a presentation environment with the 3D room viewer to teach and learn about 3D to 2D transformations in computer graphics. It demonstrated that EM tools are flexible because we can reuse and combine models (see Figure 4.10 on page 103) to be taken in a new context relevant to the model-builder. A concrete example of development has discussed how a model-builder plays the role of student, teacher and developer in a single environment (see Figure 4.16 on page 113). This section examines the potential of the EM Presentation Environment (EMPE) [EMP:empeHarfield2007]—see Figure 5.11—as a teaching and learning tool, contrasting its use with more common tools for preparing and giving lectures or presentations.

The EMPE was first used for the presentation of a paper at ICALT 2006 [BH06] as shown in Figure 5.11. During the presentation I demonstrated that: the clock model could be exercised in ways that need not be preconceived (e.g. linking the clock model to the current time); the presentation could be changed on-the-fly (simultaneous construction and use); and the EMPE itself could be changed in response to audience feedback or other factors in the environment (e.g. varying the slide colour based on the time shown in the

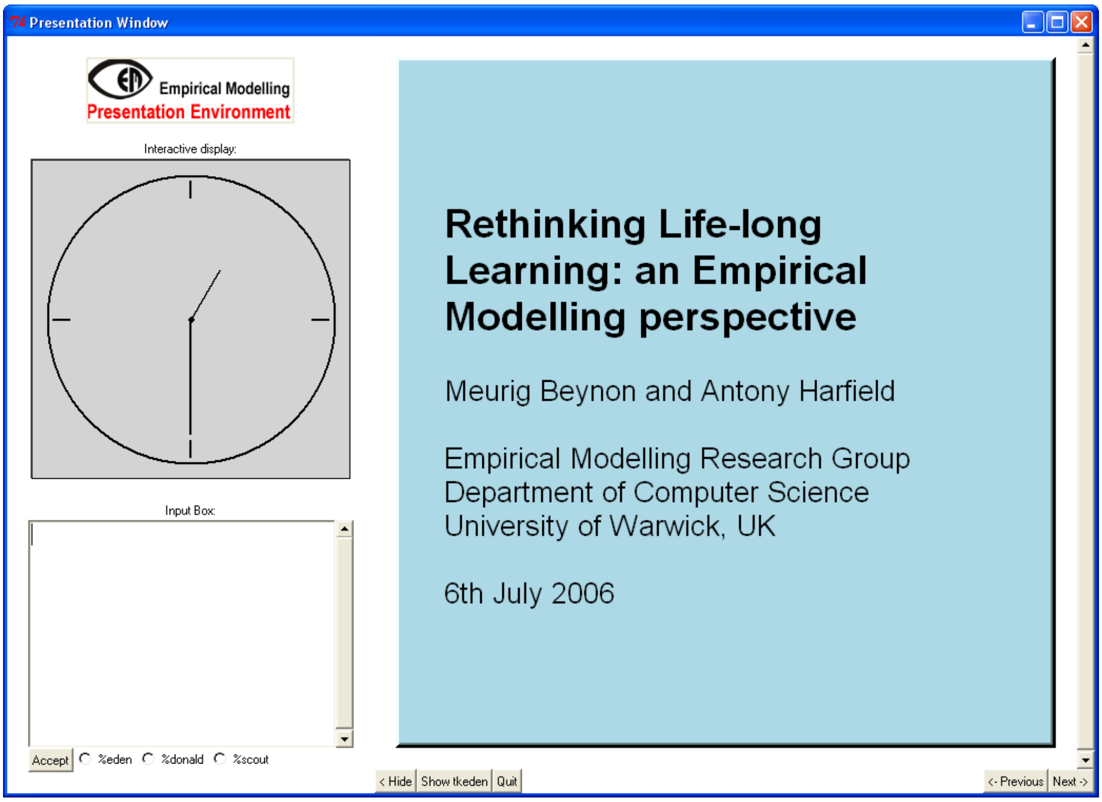


Figure 5.11: An early version of the EMPE as used for a presentation at ICALT 2006.

clock model). During the *preparation* of the presentation, I was not just creating the presentation slides and model, but also extending the EMPE, the HTML Environment and the GEL notation at the same time, as discussed in §4.2.2.

The development of the EMPE, as discussed in §4.2.2, has shown that, as a tool for presenting, it has a number of features that differentiate it from other presentation tools. Firstly, the EMPE allows the model-builder to create and reuse models (such as the 3D room viewer in Figure 4.8 on page 100) within and connected to the presentation. Parts or all of the model can be displayed within the presentation window (although the assumption here is that there is enough screen space)—for example the clock model used in the presentation for ICALT 2006 [BH06] shown in Figure 5.11. The presentation can be connected to the model by creating html slides that are dependent on observables in the model (using the `<eden>` tag) and creating html slides that trigger agent actions within the model (using the `<script>` tag). A model-builder has the potential to manipulate and change slides on-the-fly during the preparation of the presentation and during the presentation itself if required.

The EMPE offers the potential for EM activity (i.e. observation and experimentation) in a presentation. The contribution of this thesis is to show that EM can benefit learning, and therefore, the EMPE—as a technical contribution specifically for teaching and lecturing—offers a positive support for learning. It is important to acknowledge that the EMPE will not instantaneously make better teachers or better learners. However, following EM principles, the use of the EM tools can enhance and deepen significant learning as characterised in Chapter 1. It is challenging to take account of how much influence the quality of the teacher has on the learning experience, including the ability and confidence of the teacher to make use of educational technology. The suggested benefits of the EM approach are that the support offered by the EMPE can assist teaching and learning in novel ways that were previously inappropriate with traditional educational technology.

The model-building approach may present a formidable challenge for teachers. In offering flexibility, the EMPE is not as easy-to-use as other means of presentation, such as using a blackboard or projecting presentation slides. The simplicity of 'writing on the blackboard' is lost, and so is the simplicity of creating presentation slides which require very little effort on the part of the presenter—instead the EMPE requires the model-builder to write slides in HTML. The EMPE in its current state offers a very primitive presentation tool, but as an EM model there is potential for it to evolve, just as it evolved from an environment for documenting models (as discussed in §4.2.2)—future features might include slide effects and timed actions as are found in other presentation tools, or specialist input devices such as Wii remotes† that are not standard features of presentation tools.

5.2.1 Traditional presentation tools

Presentation tools, such as Microsoft PowerPoint‡, are commonly used as teaching aids in academia and industry. Lecturers use presentation tools to teach undergraduates, and researchers use presentation tools to demonstrate their work to other academics at workshops and conferences. In the business world, the presentation tool has become an essential office application, not just for marketing purposes, but also for training and education. Microsoft PowerPoint has become the most popular and widely used presentation tool [Wik07a]. Using a presentation tool like PowerPoint is considered the standard, and in many contexts is considered a requirement for a 'good' presentation. Despite this tool being regarded as one of the most successful applications for the PC, the role it plays has been criticised by some, such as Norvig [Nor03], for 'dumbing down' presentations.

† I have developed an extension to `tkeden` that enables Nintendo Wii remote controls to be used as input devices, along with some examples of how they could be used to augment existing models [EMP:wiimoteHarfield2007].

‡ Microsoft and PowerPoint are registered trademarks of Microsoft Corporation.

Research into undergraduate courses shows that although students generally prefer PowerPoint lectures [BC03] [FB02], the use of PowerPoint often does not have a positive effect on student grades [SH00].

In a long exposition on the failures of PowerPoint, Tufte [Tuf03] states that the basic problem with PowerPoint is that it "is entirely *presenter-oriented*, and *not content-oriented, not audience-oriented*". In terms of learning, the presentation tool is not a *teaching* aid but a *teacher* aid—it makes presentations easy for the presenter. Tufte says that the focus on the presenter is damaging to both content and audience and results in:

> "foreshortening of evidence and thought, low spatial resolution, a deeply hierarchical single-path structure as the model for organizing every type of content, breaking up narrative and data into slides and minimal fragments, rapid temporal sequencing of thin information rather than focused spatial analysis, conspicuous decoration and Phluff, a preoccupation with format not content, an attitude of commercialism that turns everything into a sales pitch." [Tuf03]

He calls this the 'cognitive style of PowerPoint', which I am going to compare to the use of the EMPE [EMP:empeHarfield2007] with specific reference to the 3D room presentation [EMP:graphicspresHarfield2007].

Before the arrival of PowerPoint presentation tools, lecturers mostly used blackboards as teaching aids. A teacher using a blackboard has to construct material on-the-fly, working through arguments in real-time instead of serving up bullet points on ready-to-digest slides. The blackboard approach is more content-oriented, and makes for a narrative that the audience can follow (or if the audience gets involved then they can guide the narrative). Tufte agrees that presentation tools should show more support for this style of *good teaching* instead of supporting the 'cognitive style of PowerPoint': "Teachers seek to explain something with credibility, which is what many presentations are trying to do. The core ideas of teaching—*explanation, reasoning, finding things out, questioning, content, evidence, credible authority not patronizing authoritarianism*—are contrary to the hierarchical market-pitch approach [of PowerPoint]" [Tuf03]. In examining the use of the EMPE, as in the computer graphics presentation in §4.2.2.3, it is shown that these core ideas of teaching highlighted by Tufte are much better supported by the EMPE than by PowerPoint.

5.2.2 Contrasting PowerPoint with the EM Presentation Environment

One possible reason for the cognitive style of PowerPoint is that it is limited to static information (slides with text, graphics, audio, and video). Tufte points to "a deeply

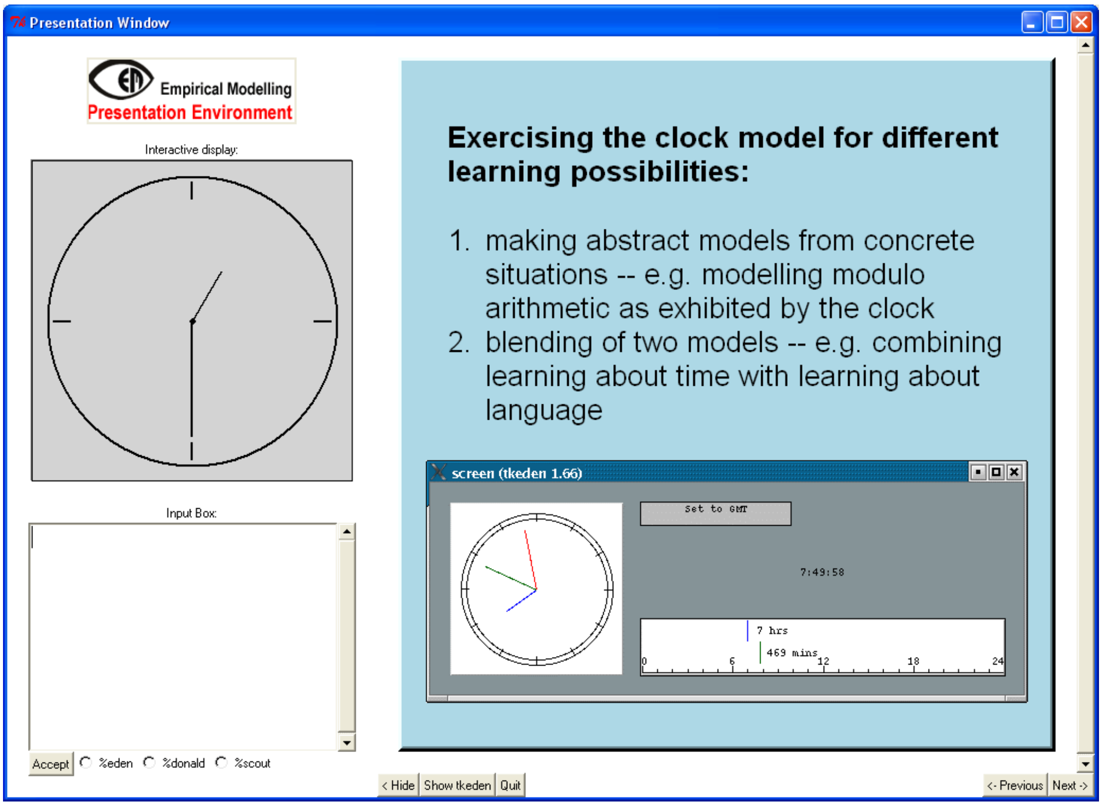


Figure 5.12: Introducing the clock model in the ICALT 2006 presentation.

hierarchical single-path structure as the model for organizing every type of content" as the problem [Tuf03]. PowerPoint provides support for communicating information, that Tufte calls the "sales pitch", but little support for the process of teaching (or learning about) the ideas behind the information. There is very little scope for demonstrating practical elements relating to the content within a presentation. Contrast this with the EMPE where there are circumstances when the model can take centre stage, as shown in Figure 5.12, and the slides are more like pointers to parts of the model to be demonstrated and exercised (e.g. the scripts in Figure 4.9 on page 101 offer some suggested interactions with the 3D room). It is the model that contains the concepts and ideas which the teacher hopes the students will take up for themselves. The slides can be part of the model themselves, displaying relevant parts of the model using dependency, and affecting the model through agent actions such as hyperlinks.

The use of PowerPoint presentations encourages dissemination of information from presenter to listener. Whereas attending lectures enhanced by PowerPoint is a passive instructional activity [FB02], the use of the EMPE can encourage active participation either during or following on from lectures. In a lecture environment, the teacher is actively participating in the model whether there are students who are engaged or not. Participation, through interaction involving redefinitions of state, is an activity in which

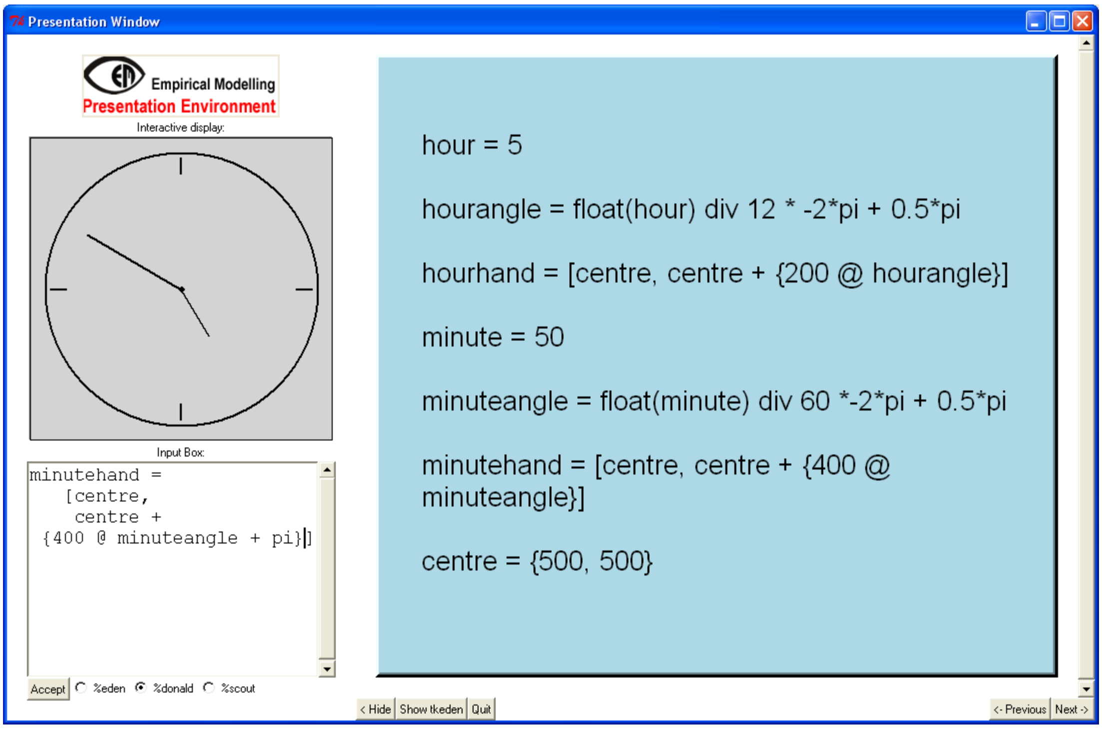


Figure 5.13: Making redefinitions to the clock model during a presentation.

exploration of the domain plays a significant role. Therefore, instead of encouraging the "foreshortening of evidence and thought" (i.e. simplifying facts and ideas to fit into concise bullet points or diagrams) that Tufte criticises [Tuf03], the EMPE supports exploration of evidence and thought through model interaction. Although the slides in the EMPE may suffer from the same "low spatial resolution" as PowerPoint [Tuf03], the model can offer a depth to the exploration space by allowing interaction and experimentation. Rather than foreshortening thought, model interaction and experimentation gives rise to the potential for extending evidence and thoughts. For example, when discussing orthogonal projection in the 3D room presentation, by redefining the eye distance a practical appreciation of the relationship between making the eye distance large and orthogonal projection could be obtained (see Figure 4.8 on page 100). A few fragments of script on a slide can be exercised to understand the model, as depicted in Figure 5.13, and then modified to find new ways of interacting with the model (e.g. in Figure 5.13 the minute hand is being redefined to be half an hour fast), potentially leading to practical evidence for such understanding.

Tufte also criticises PowerPoint for "breaking up narrative and data into slides and minimal fragments" [Tuf03]. Sometimes the use of bullet points is justified as a means of reminding the presenter (like notes on a piece of paper) of the story they are telling, and similarly as a reminder of the story for the audience should they return to the presentation slides after the presentation. However, there is a tendency for the presenter to make the bullet points the *whole* story and rely on them more than their own knowledge of the story. This might be where Tufte's disapproval lies, and he blames PowerPoint for encouraging this tendency. Although there is nothing to stop a presenter using the EMPE for similar lazy presentations, the EMPE changes the focus of the presenter to the model. The EMPE encourages the presenter to explore the model and to tell a story with the model. Furthermore, a student exploring the presentation in the environment can create further narratives that differ from the original presenter's narrative. For example, Beynon's extensive walk-through [Bey07b] is a story of his interactions with the 3D room model, which happen to uncover certain aspects that are particularly relevant to 3D to 2D transformations in computer graphics. As a subsequent explorer of the 3D room model, I have developed my own story of the 3D room model which relates to how the EMPE can assist technology-enhanced learning in a unique way.

The final criticism of the cognitive style of PowerPoint is that it is too concerned with "conspicuous decoration and Phluff, a preoccupation with format not content" [Tuf03]. The EMPE is not concerned with decorative slides, design templates and fancy graphics (as is evident from Figure 5.13). Slides are created from basic html, usually as a commentary on the model. Clean, smart, or fanciful slides are not important, it is clear, intricate, imaginative and interesting models that have the focus of the presentation. Individual style is still important, especially when exercising the model, as is the ability of the teacher or student.

5.2.3 Implications for learning through presentations

This thesis is concerned with addressing the issues around educational technology supporting learning as characterised in Chapter 1. The examination of the PowerPoint style of presentations has shown that this commonly-used technology often leads to education that: does not involve *experimentation* (e.g. it values passive transmission not active construction of knowledge), is not *flexible* for the learner (e.g. presentations have a prescribed outcome and follow a preconceived path), and lacks *meaningful* engagement (e.g. cannot be related to practical situations or experiences). Therefore PowerPoint does not appear to be a satisfactory educational technology for supporting the eight significant characteristics of learning.

Contrast this with the example of the 3D room presentation from §4.2.2.3, which is focussed on observing and exploring a model. The EMPE can be used for experimentation, questioning aspects of a model (e.g. 'how can the camera angle be changed?') and trying out theories or ideas (e.g. 'if the camera x-position is incremented then panning can be simulated'). The use of the EMPE can be flexible in nature (as described in §1.2.4 & §1.2.5) because learning need not have a prescribed outcome—it can offer the flexibility of being able to explore a wide range of potential learning opportunities—and learning does not necessarily follow a planned route—it can be guided by the presenter or the listener in response to their questions and experiments. The learning material can incorporate a variety of sources by including new and existing models into the presentation environment, either to add depth an idea or to make it relevant to a particular learner. The use of the EMPE addresses Tufte's suggestions that presentation tools should pay attention to meaningful content [Tuf03] because the EMPE, like good teachers, is focussed on explanation, questioning, and finding things out. As seen in the example, the 3D room model enables meaningful explanations to be found (e.g. of why different projection functions cause certain effects) because they are derived from practical interactions (e.g. 'what happens if the eye distance is negative?').

The EMPE may not be the easy-to-use tool that is expected in PowerPoint style applications because it requires some effort to become a model-builder and to experiment with a model. However, as a support for learning, it offers potential to assist learning that involves experimental, flexible and meaningful characteristics as discussed in Chapter 1. The contribution of this section to the overall thesis is to show that model-building with EM is not only of interest as a personal, individual activity that is peripheral to traditional educational practices—it is possible that practices such as lecturing using presentation tools can benefit from an EM approach.

5.3 Lifelong learning

In the previous section the focus has been on the benefits of EM principles and tools for teaching and lecturing activities. The aim of this section is to illustrate the benefits of an EM approach to lifelong learning†.

The term 'life-long learning' has become prominent within the educational community and in government proposals. In the UK, the Secretary of State for Scotland has declared that "Lifelong learning is a feature of modern life and will continue to be so" [TSO98].

†The material in this section is based on a joint paper with Meurig Beynon presented at the International Conference of Advanced Learning Technologies 2006 [BH06], which was subsequently published in an extended form in the Journal of Computing [BH07].

The use of the word 'lifelong' is somewhat difficult to interpret as it can refer to all kinds of learning, encompassing pre-school, school, higher and further education, as well as both formal and informal learning. For the purposes of this thesis, 'lifelong learning' will be taken to mean learning activity that takes place as a part and expression of living. This accords with the popular archetype for life-long learning: adult education outside the schooling years through work (e.g. in training courses) and also for pleasure (e.g. night classes, etc). It also embraces the kind of unsupervised, self-motivated learning that is associated with over-a-lifetime learning of specialist disciplines, hobbies and skills outside the classroom.

5.3.1 Characteristics of lifelong learning

As Piaget discovered in his detailed childhood studies, a child's conception of the world can be very different from an adult's [Pia29]. It follows from this that there may be differences in the way children and adults learn. The word 'andragogy' was originally formulated by Alexander Kapp in 1833 to mean "the art and science of helping adults learn" in order to differentiate it from 'pedagogy' which originates from the study of learning in children [Smi99]. Knowles, one of the most prominent researchers in andragogy, defines the following five differentiating characteristics of adult learning [Kno84:p12]:

1. As a person matures, they become more self-directed.
2. Adults have accumulated experiences, which can be a rich resource for learning.
3. Adults become ready to learn when they experience a need to know something.
4. Adults tend to be less subject-centred then children; adults become increasingly problem-centred.
5. For adults, the most potent motivators are internal.

The role that educational technology can play in supporting these characteristics in relation to lifelong learning has yet to be clarified. There are reasons to suppose that current technology is well-suited to supporting independent learning activities on the periphery of established educational frameworks [BEC04], but optimism is tempered by the knowledge that educational technology has yet to live up to its expectations within these frameworks [McP05]. This ambivalence about the potential of technology is reflected by Gulati: "The impact of formal education continues to limit the flexibility and learner choice in online learning, through increased focus on surveillance and compulsory participation ... if we are to realise a lifelong learning society, and to enable self-reflexivity and innovation, then we need to challenge the limiting influences of the dominant educational discourses." [Gul03]. The limitations of current educational technologies are confirmed by recent research findings revealing that greater online interaction does not significantly improve student grades [DG05]. Though there has been a trend towards many more online students and classes, there have also been exceptionally high drop-out rates—up to 80%—for online courses [Car00].

This section argues that adapting the conventional e-learning environment to support lifelong learning is exceptionally challenging because of the mismatch between the characteristics of lifelong learning and the traditional conception of development and use in computing (as described in §1.1.4). In some respects, a more appropriate orientation is found in the computing technologies behind recreational activities such as game-playing, digital photography or electronic music. The principles that are emergent in these technologies have yet to be properly recognised, and are in tension with the established framework of computing that is based on the view of a program as an input-output relation. Stein, from her experiences teaching novice programmers (in CS1), argues that programming should be more concerned with everyday concurrent environments ("computation-as-interaction") and less concerned about input-output relations [Ste99]. Furthermore, the thinking that underlies classical computer science and the input-output relation leads to a duality between development and use, as discussed in elsewhere in this thesis (§3.1). As Stein would argue, an alternative conception of computing is needed in order to take account of interaction in applications such as online chat [Ste99]. In terms of education, a view of computation as interaction is needed *to liberate the constructionist ingredients essential for life-long learning* [BH06]. Building on critiques of conventional programming in support of constructionism [BH05b], model-building based on Empirical Modelling (EM) principles is suggested as an alternative approach that is particularly well-suited to the demands of lifelong learning.

5.3.2 Educational technology for lifelong learning

Technology as a medium for communication is the current driving force behind lifelong learning. There are two aspects to this communication. Computers have become popular for the distribution of information since the birth of the World Wide Web, and are now commonly used as resources of downloadable course material. Developing web resources is perceived as enabling learning outside the classroom, allowing learners access to information in an ubiquitous manner. Computers have also been used for two-way communication in environments where students and teachers can interact. Such communication in support of e-learning can be synchronous, asynchronous or a combination of both. For example, a teacher can communicate with a student by email or organise an online session to instruct many students at the same time. This potentially provides universal access for learners to teachers and virtual classrooms.

Organised learning activity that exploits technology as a communication medium in these ways is not well-matched to the needs of the lifelong learner. Typical e-learning environments are best-suited to supplying the framework for the systematic exposition of a discipline. Such environments perform best where the learner 'begins at the beginning' and follows the prescribed learning paths sufficiently conscientiously to enable the system to build up a useful learner profile at every stage. Ideally, it should be possible for the learner to enter the framework at any point without having to incur a large overhead in supplying the contextual information about their learning status that is required by the system. In practice, any customisation of resources to the learner has to rely heavily upon the previous history of interaction with the learning environment. This is one of the problematic issues for e-learning environments, accounting for the frustration felt by learners who wish to engage with advanced topics, but are first obliged to perform routine exercises in order to inform the system of their status. Friesen, in a paper stating objections to learning objects and e-learning standards [Fri04], criticises the military approach to education that views any learner as just another component to be specified in a 'learning management system'.

In the context of lifelong learning, the casual use of the internet both to acquire information and to use or download interactive 'learning objects' has greater promise as a model for e-learning. Though the web does not necessarily provide the electronic analogue of an accredited teacher or secure classroom, nor the structured framework of a school curriculum, it meets the needs of the independent learner in some respects. The choice of resources offers the opportunity for self-directed learning; material is generally more self-contained and can be accessed and adapted as required; the range of perspectives represented can be rich and wide. These potentially dangerous characteristics are virtues for learners with the appropriate level of discrimination and experience. The limitations of the web as a medium for life-long learning relate primarily to the predominantly passive and unstructured nature of the learner's interaction. In a keynote address at ICALT 2006, Oleg Liber proposes that "personal learning environments" be developed to enable learners to combine structured education with informal resources and communities through the Internet so that learning can be realised as not just "life long" but also "life wide" (i.e. engaging with a wide variety of content, people and activities, particularly outside of the educational system) [Lib06].

Both e-learning environments and the web typically offer relatively limited and closed forms of interaction for the learner. Because so much lifelong learning is self-motivated, a greater degree of autonomy in interaction is desirable. The environment that best suits the lifelong learner is then one that contains elements that are constructionist in spirit [PH91], and gives opportunities for learning by building in an experimental, flexible and meaningful manner. Since lifelong learning also typically takes place in close association with concrete external activities, it is natural to consider using microworlds to provide a virtual environment within which exploratory learning can take place in context.

5.3.3 Model-building for lifelong learning

The concept of lifelong learning clearly invokes an evolution over time, both in respect of the learner's experience and of the context for learning. Such evolution is of course conceived in traditional environments for e-learning, but is typically constrained to follow prescribed paths and preconceived outcomes—as criticised in Chapter 3. In such environments, the learner is exposed to new concepts, experiences and contexts in a systematic fashion, and the exposition is managed in such a way as to keep track of the learner's performance. But whereas the classroom learner's experience is shaped in an artificial closed environment, that of the lifelong learner is not. As Knowles describes, when a person matures they become more self-directed, they draw on accumulated experiences, they become more problem-centred and they develop their own motivations [Kno84:p12]. The lifelong learner frequently combines a sketchy explicit understanding of fundamental principles with a depth of experience and a familiarity with practical contexts of application that seems incongruous and inappropriately advanced.

In these circumstances, the e-learning environment that is designed to suit the learning purpose best under stereotypical conditions is no longer necessarily effective. It may be appropriate to address topics in any order, to make opportunistic, serendipitous links, or to change the strategy mid-process in the light of developments in the open world outside the classroom. Such issues can only be addressed to a limited degree by the preconceived design of an e-learning system. It is hard enough to develop adaptive systems that are selective and discriminative when the learning trajectory has been comprehensively monitored; it is impossible when the learner's engagement is casual and incidental to much broader interaction in the outside world. In the typically informal and unstructured setting of life-long learning, the onus of bridging the gap between standard textbook knowledge and procedures and their often disguised or distorted real-life counterparts then has to fall upon the learner.

Such 'soft' learning needs can be addressed by developing technology to support the learner in sense-making activities. In a lifelong learning setting, this sense-making can take many forms. It may involve making a model of a situation drawn from the learner's working environment that can be used to gain a deeper understanding of what relationships and mechanisms are at work. Alternatively, it may involve a process of concretisation: constructing a physical artefact to embody an abstract process whose practical relevance and application is obscure. As a prominent component of much lifelong learning is the exposure and rationalisation of activities and concepts of which the learner already has implicit informal knowledge, the construction of models and artefacts cannot in general be based on a pre-existing theory. As in constructionism, the process of building can itself be a process of active learning, through which connections are made and relationships between different experiences come to be better understood.

The nature of the model-building activity that can meet the life-long learner's requirements is depicted in Figure 5.14, and is an elaboration for lifelong learning of the artefact/referent in Figure 2.5 on page 39. The added layering in Figure 5.14 is used to convey the idea that the relationship between the artefact and its referent evolves over time. The context in which the artefact and referent are being experienced is constantly changing, and invokes a change in the implicit knowledge of the artefact. As is to be expected in the lifelong learning setting, both the experience of the learner and the context for the exploratory interaction develop over time.

5.3.4 Illustrating EM for life-long learning

Traditional e-learning environments rely upon crafting the learning context through imposing specific patterns of interaction. This is a good strategy when learning activity

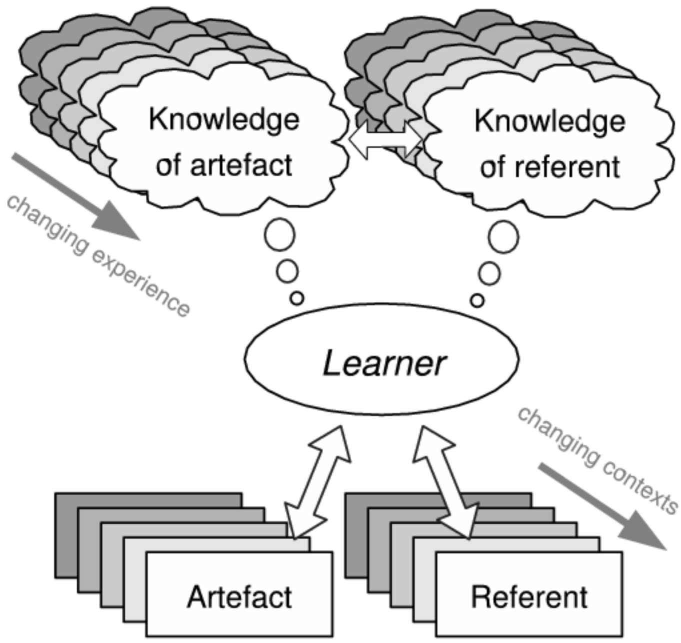


Figure 5.14: Learning through model-building with changing contexts and evolving experience.

can follow a preconceived plan. Such environments can be built by traditional programming, where construction is driven by identifying the required use-cases and optimising for these. By contrast, the experienced life-long learner will typically bring an individual, possibly idiosyncratic, perspective to bear on issues to be learnt. To accommodate this, a learning artefact for lifelong learning needs to be conceived in quite a different way from a conventional program. As discussed in [Run02], EM is an alternative approach to computer-based model-building that suits the vision of learning depicted in Figure 5.14. An extended example will serve to illustrate the principles of EM in relation to lifelong learning. The theme of this example—that of learning about time and clocks—is too simple to be fully representative of the applications of EM to lifelong learning, but highlights many of the essential characteristics, as discussed in §5.3.1.

As remarked above, the sense-making activity depicted in Figure 5.14 can reflect many different kinds of learning. Relevant topics might relate for instance to: being familiar with clock mechanisms; understanding the relationship between digital and analogue representations of time; appreciating how the analogue clock concretises abstract relationships in modulo arithmetic; or knowing how to tell the time in different languages and in different time zones. In a life-long learning context, each learner will bring a different orientation and experience to these diverse perspectives on clocks and time. The process of construal that EM supports reflects this rich and potentially confusing combination of concerns. The various perspectives and their interrelationships are reflected in variants of what can be

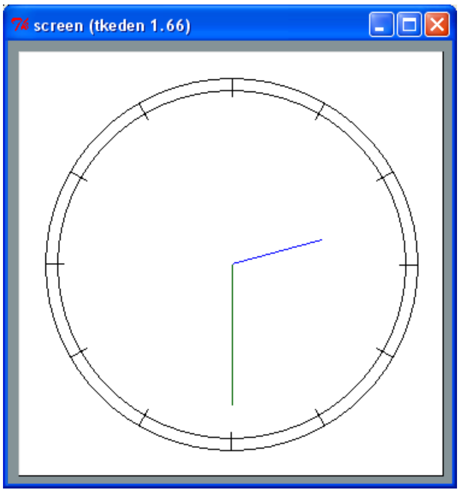


Figure 5.15: A screenshot of the basic clock model [EMP:clockHarfield2006].

regarded as one model, as developed in different directions according to the learner's particular needs. An important feature of this model is that in principle it concurrently offers the same potential for redefinition and adaptation to all participants in the learning—whether model-builder, teacher or learner. In this way, it can serve in many different educational roles as a learning artefact—some aspects being developed autonomously by the learner, some supplied by an expert modeller, and some adapted and customised by a teacher.

The simplest form of sense-making model takes an analogue clock as its referent as shown in Figure 5.15. The relevant observables in this context include the current local time, the time as shown on the clock, the radius of the clock face and locations of the marks around its rim, and the lengths, colours and positions of the hands, as shown in Figure 5.16. Relevant dependencies link the position of the hands to the time as shown on the clock (e.g. in Figure 5.16, `hourAngle` determines the angle of the hour hand and `hourHand` determines the line representing the hour hand), which in turn may depend on the current time in a variety of ways according to the status of the clock. For instance, the clock may be fast or slow, refer to a distant time zone, or take account of daylight saving, as shown in Figure 5.17. To reflect the physical integrity of the clock, the positions of the marks on the rim and the lengths of the hands depend upon the radius of the clock face (e.g. the definition for `noon` in Figure 5.16). In developing the EM construal, the geometric elements of a line-drawing to depict the clock can be specified as points, lines and circles whose attributes are linked by definitions to scalars and textual data that represent times, dimensions and other geometric attributes such as colours and line styles. The `clock/t` observable in the DoNaLD script (Figure 5.16) is referred to in EDEN as `_clock_t` as

```
%donald
openshape clock
within clock {
   point centre
   centre = {200, 200}
   real radius
   radius = 150.0
   circle edge
   edge = circle(centre, radius)

   real sixthpi
   line eleven, ten, nine, eight, seven, six
   line five, four, three, two, one, noon
   sixthpi = 0.523599
   eleven = rot(noon, centre, -11 * sixthpi)
   ten = rot(noon, centre, -10 * sixthpi)
   nine = rot(noon, centre, -9 * sixthpi)
   eight = rot(noon, centre, -8 * sixthpi)
   seven = rot(noon, centre, -7 * sixthpi)
   six = rot(noon, centre, -6 * sixthpi)
   five = rot(noon, centre, -5 * sixthpi)
   four = rot(noon, centre, -4 * sixthpi)
   three = rot(noon, centre, -3 * sixthpi)
   two = rot(noon, centre, -2 * sixthpi)
   one = rot(noon, centre, -sixthpi)
   noon = [centre+{0,0.9*radius}, centre+{0,radius}]

   int t  # representing time elapsed in minutes
          # from midnight (i.e. 1440 per day)
   int minute, hour
   minute, hour = t mod 60, t div 60

   real minAngle, hourAngle
   minAngle = (pi div 2.0) - (minute * pi div 30.0)
   hourAngle = (pi div 2.0) - (hour * pi div 6.0)

   line minHand, hourHand
   minHand = [centre + {0.75*radius @ minAngle}, centre]
   hourHand = [centre + {0.5*radius @ hourAngle}, centre]
}
```

Figure 5.16: A DoNaLD script describing the clock face.

shown in Figure 5.17 redefined for different time zones. Full details on the scripts that I have developed for this model can be found in the EM archive [EMP:clockHarfield2006], as well as notes on how this clock model differs from the original clock model by Beynon [EMP:clockBeynon2001].

The merits of the EM construal as a learning artefact relate to the open-ended interactions that it enables. Though the clock exhibits standard modes of interaction and behaviour, its observables, dependencies and the agency to which it is subject are all open to revision at the discretion of the learner—whether or not they respect the boundaries of common-sense. This is in keeping with the principle that the engineer learns most not just by observing the clock in normal operation, but by dismantling and rebuilding it, and the user learns most by interacting with the clock in exceptional contexts and exploratory ways.

```
%eden

/* Making the clock 5 minutes slow */
_clock_t is greenwichmeantime - 5;

/* Introducing a new time zone (9 hours ahead) */
japanesestandardtime is greenwichmeantime + (60*9);
_clock_t is japanesestandardtime;

/* Adjusting a time zone for daylight saving */
daylightsaving is 1;
mexicotime is greenwichmeantime - (60*6) + (daylightsaving?60:0);
_clock_t is mexicotime;
```

Figure 5.17: An EDEN script containing modifications to the clock model for displaying the time in different time zones and with daylight saving time.

By way of simple illustration, in the clock model as described above, the positions of the hour and minute hands are independently determined by the current time (e.g. in Figure 5.15, the minute hand is showing half past the hour but the hour hand is not half way between two and three). In practice, the hands of a mechanical clock are linked so that you can move the minute hand and the hour hand moves at a slower (but proportional) rate. The clock artefact can be adapted to exhibit this behaviour by introducing the dependency that links the position of the hour hand to that of the minute hand as depicted in Figure 5.18. Underlying the design of the analogue clock as an engineering product are simple principles to connect elapsed time in hours and minutes modulo the number of minutes in an hour and hours in a day. The abstract relationships between 'time as recorded by hours and minutes elapsed in a day' and 'time as displayed on digital and analogue clocks' are given concrete expression in the variant of the original clock model shown in Figure 5.18. This variant is derived simply by giving visual expression to scalar relationships that are already explicit in the original clock model.

By way of further illustration, the time as shown on the clock can be redefined in such a way as to be totally independent of the current local time, or so as to reflect the time in another time zone (as shown in Figure 5.17). The significance of specifying the time difference between Japan and UK time as plus 9 hours, rather than minus 15 hours, or even plus 5 hours, exposes the physically constrained and socially constructed nature of world time. The focus on clocks and time in physical and cultural context is well-oriented to life-long learning, where contextual factors potentially both enrich and obstruct understanding. For instance, it is indicative of the imperfect and potentially confusing nature of learning to read clocks in a real-world setting that (e.g.) the hour hand may be misaligned so that it is not quite vertical at midday. It is easy to tweak

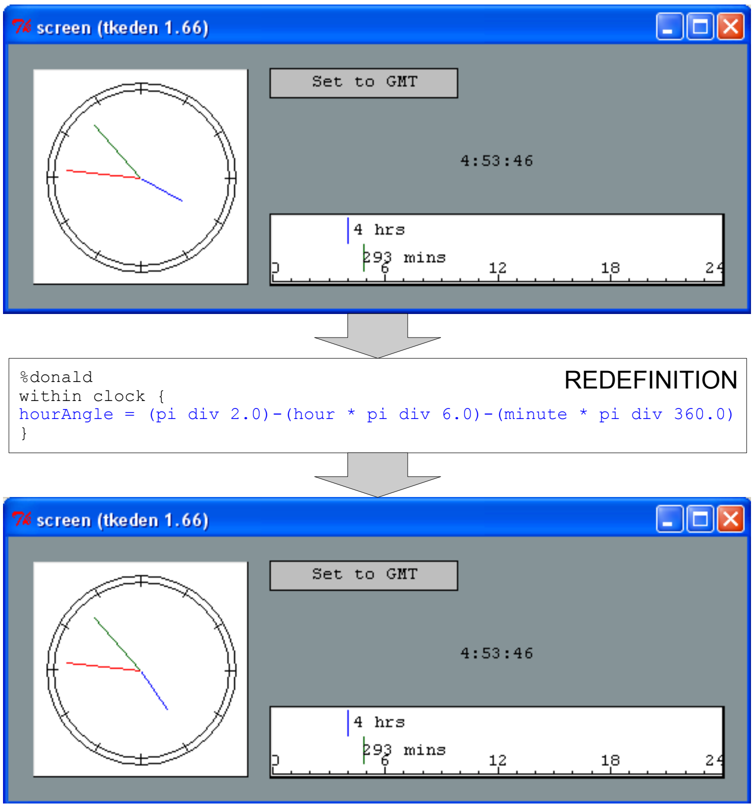


Figure 5.18: A redefinition to the clock model to make the hour hand dependent on the minute hand as would be found in a mechanical analogue clock.

definitions to imitate this condition, or to express more dire forms of mechanical failure, as when the minute hand comes loose and hangs vertically downwards.

The EM construals described above illustrate how Figure 5.14 applies both to the modelling of a concrete referent, and to the concretisation of abstract relationships. Because of the dynamic and provisional nature of the relation between artefact and referent in Figure 5.14, it is also possible to regard it as a framework within which two or more artefacts can be combined and can evolve into a new learning artefact. Previously, an EM artefact for learning about counting in different languages was built by Rungrattanubol [Run02] as introduced in §5.1.2. By placing this artefact in conjunction with the clock artefact, and adding new observables and dependencies it is relatively easy to derive an artefact for telling the time in different languages (as well as different time zones). Figure 5.19 depicts the artefact displaying the time in Japan whilst expressing the time in Thai.

5.3.5 Further thoughts on lifelong learning

The above discussion has focussed on a small example of the clock model to illustrate several features of EM that are well-oriented towards lifelong learning. The purpose of this exercise is to demonstrate the wider applications of EM principles to learning beyond

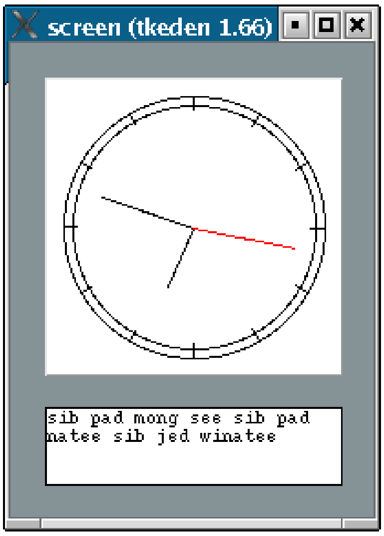


Figure 5.19: Combining the clock model with the Thai number model.

school and higher education. Lifelong learning is a particular area where EM has significant advantages over conventional e-learning environments because EM allows learners to take account of something of the 'superabundant' nature of our experience (to paraphrase William James [Jam12]). Where current educational technologies are best oriented for well-planned and organised learning situations, learning in a real-world setting typically begins in some degree of chaos and confusion. EM principles and tools, although still at an early stage of development, show promise in supporting learning activities that integrate educational roles (as discussed in §3.3), promote flexible opportunistic learning, and blend the concrete and the abstract across disciplines. These are qualities that can be most helpful in engaging the lifelong learner.

5.4 Collaborative learning

The focus of this thesis has mainly been on individual model-building and personal learning, as is evident from the previous section on lifelong learning. Although student, teacher and developer perspectives are examined in terms of model-building, the majority of the discussion has been concerned with one model and one learner at any one time. The aim of this section is to explore the potential for EM to be used collaboratively with more than one learner at a time.

As discussed in section §1.2.7, Lave & Wenger [LW91] suggest that all learning is embedded in the activity, context and culture of the situation. Social interaction is a critical component of situated learning because individuals become involved in communities of practice where shared ideas, beliefs and skills are acquired [Wen99]. Similarly, according to Gerhard Fischer, the power of the unaided individual human mind is highly overrated [Fis05]. Much of human creativity is social, either arising in social situations or as the product of social interaction. Fischer points out that innovation (a leap in learning) usually emerges from "joint thinking, passionate conversations, and shared struggles among different people" [Fis05]. It therefore seems crucial that the social aspect of model-building for learning is examined from an EM perspective.

A large area of research into educational technology is concerned with collaborative learning. This mostly falls within research associated with the term 'computer-supported collaborative learning' (CSCL). The EM approach departs in some respects from the common application of CSCL as will be highlighted in the following sections.

5.4.1 Previous research on EM and collaboration

There are a few projects in EM that have touched upon the topic of collaborative learning, but there are no in-depth accounts of collaborative learning using EM. However, there are many more projects which have involved the construction of distributed models which may be relevant to collaboration (e.g. Clayton Tunnel rail accident [EMP:claytontunnelChanHarfield2005], 5-a-side football [EMP:footballTurner2000], planimeters [EMP:planimeterCare2005], car parking simulator [EMP:carparkingsimMcHale2003]).

The most significant contribution to collaborative learning with EM tools to date is by D'Ornellas [DOr98] and Sheth [She98]. In their project on group learning, they construct a model for exploring electronic circuits and examine its potential for facilitating interaction in the classroom. The electronic circuit simulator is a distributed model, with the teacher controlling the server and a student interacting at each connected client. Four means of interaction are discussed: students interacting independently on their own client; students sharing parts of their model with the teacher or rest of the group; students interacting solely on global model; and the teacher leading the interaction or moderating the students' interaction.

The wide range of activities that D'Ornellas and Sheth were able explore with their electronic circuit model using EM is due to the flexibility of the EM tools [DOr98]. Taking one student's work and linking it to another student's work could well be a major operation if the implementation was undertaken with procedural programming tools and would almost definitely require recompilation and a restart of the environment. The advantage of EM is that collaborations with other model-builders or connections to other models can be treated just as any other interaction. Model-builders have essentially the same mechanism for state-change (in the same way that there is no difference in the way students, teachers and developers interact with a model—see §3.3). Furthermore, the use of dependency is a powerful tool for connecting models in that aspects of one model (on one computer) can be dependent on certain features of another model (on another computer). The benefits of dependency can be compared to a spreadsheet where a cell is dependent on a cell in another spreadsheet on another computer, or on some piece of information on the Internet†. As D'Ornellas and Sheth suggest [DOr98], EM's potential for learning is enhanced by dependency that enables models to be connected together to create new models in a distributed and collaborative manner.

5.4.2 Three types of collaborative learning with EM

Before exploring any particular examples of collaborative EM, it is worth reflecting on what collaboration may entail. A wide variety of activities can be considered collaborative even in terms of model-building. The following three types of collaboration (inspired by Resnick's categorisation of distributed constructionist activities [Res96]) explain the nature of collaborative activities that are relevant to EM:

1. discussing models;
2. sharing models;
3. building models.

Discussing models is the simplest level of collaboration, involving communication between two or more people relating to a specific model. Examples might include a teacher discussing the TLJ model with a student, students discussing the computer graphics 3D room model amongst themselves, or an online discussion of the jugs model in a student forum. The extra computing technology that may be required for this type of collaboration ranges from nothing to instant messaging, voice calls, and video-conferencing. In terms of EM, models could be discussed without any special tools, just as students undertaking an EM project discuss their models with each other. This type of collaboration is already occurring frequently.

On the next level of collaboration, instead of communicating thoughts about models, the models themselves are communicated by sharing parts or all of a model. This can

†Some online spreadsheets, such as EditGrid (`www.editgrid.com`), feature limited forms of dependency that pull data from remote sources on the Internet [Gib06].

occur informally, such as between teacher and student or between students themselves, like when giving the students a small script to achieve a particular function. Otherwise there may be a formal way of sharing models, such as the EM projects archive [EMP], where students can download other models, to explore or reuse, and also upload their own models for others to use. Model reuse was discussed in relation to the computer graphics presentation in Chapter 4. At the most advanced stage of sharing models, it is possible that two or more model-builders can collaboratively develop a model by sharing it backwards and forwards, constructing the model asynchronously. The computing technology required for this type of collaboration is email, network file-sharing, or file version control (such as Subversion [CFP04]). Once again, collaboration in this manner has been occurring in EM through the projects archive and through model-builders sharing models (or often snippets of models) with each other. This type of collaboration is encouraged among model-builders but so far the only formal place to share models is the EM project archive.

The third level of collaborative learning involves multiple learners constructing a distributed model at the same time. This is the area which is the most complex, and relatively unexplored. Computer technology for supporting this type of interaction is generally quite specialised—a collaborative whiteboard as in Microsoft NetMeeting [Mic04] used by many participants to construct a drawing is a simple but specialised example. Other tools such as the 3C platform [CKW05] support 'desktop sharing' for collaborative construction in any application. This type of collaboration using EM has been explored by D'Ornellas [DOr98] and Sheth [She98] as a potential technology for learning. Even though the EM tools have been used to create distributed models, there is little evidence that any collaborative model-building has taken place. The rest of this section will be devoted to explaining and comparing EM technologies that can support such collaborative learning.

Each type of collaboration is a specialisation of the previous levels as depicted in Figure 5.20, in that the basic type *discussing models* is also used in all levels of collaboration. Therefore *building models* can involve *sharing models* and *discussing models*. Tools such as NetMeeting or MSN Messenger support specialised third level activities (e.g. a collaborative whiteboard), backed up with first and second level discussion and sharing tools (e.g. chat and file sharing). In the following sections I discuss how EM tools can be adapted for *building models* collaboratively, and in the spirit of EM, it should be possible to build further models for sharing and discussing models, leading to an integrated environment that could be used for collaborative learning (as well as collaborative software construction

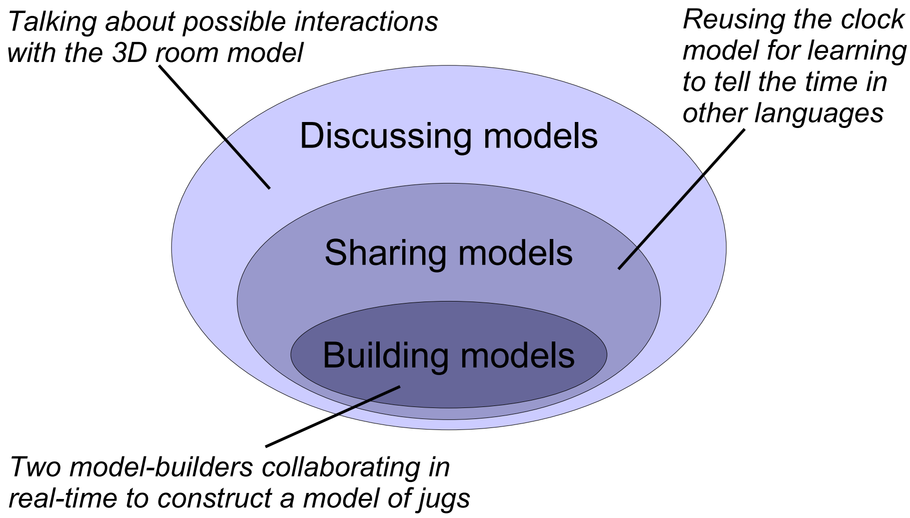


Figure 5.20: Three types of collaborative learning activity.

as envisaged by Chan [BC06]).

5.4.3 A simple example of collaborative model-building

The jugs model is introduced in Chapter 3 as an artefact for learning about the greatest common divisor in mathematics. A simple example of building a distributed jugs model serves the purpose of illustrating the principles of collaborative model-building with EM in order to demonstrate the potential for collaborative learning. This may be contrasted with the lone model-builder version of the jugs model. There are two new aspects to the jugs model discussed in this section: the model is distributed across multiple machines; and the model-building is a collaboration between multiple model-builders.

The distributed model-building tool that is used for EM is `dtkeden`. It was originally developed by Sun [Sun99] as a distributed version of the `tkeden` tool introduced in Chapter 2. The motivation behind `dtkeden` was to enable the development of distributed models [BS99], but further work has realised the potential of `dtkeden` for collaborative model-building [BC06]. To start a distributed modelling environment there must be one server instance of `dtkeden` running, and one or more client instances of `dtkeden` connected to the server (`dtkeden` runs over TCP/IP on a pre-specified port). The `dtkeden` server can be configured to run in a number of modes (described in the `dtkeden` manual [SC98]), depending on the intended collaborative activity. The default mode (also known as 'Normal' mode) gives each client their own personal model-building space and allows the model-builder to define observables within the model which can be shared (using the `%lsd` notation [SC98]). A special mode, developed as part of this thesis† together with

†Available in a special version of `dtkeden` from `www.dcs.warwick.ac.uk/~ant/dtkeden/`.

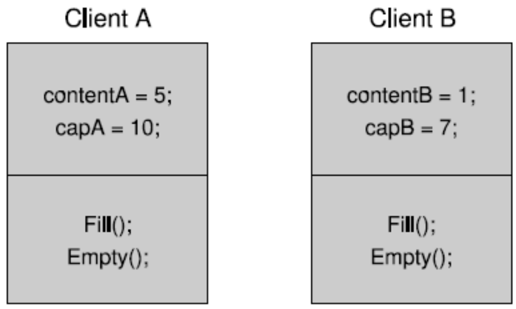


Figure 5.21: Executing definitions in a local context only.

Chan whose interests lie in collaborative software construction [BC06], enables all model-building activity to take place on a single shared model (cf. Newell's blackboard metaphor [New69]). This 'Blackboard' mode enables model-builders to interact in the same way that multiple people gathered around a blackboard can all contribute to a single space by adding, changing and erasing various items.

In order to illustrate the differences between the 'Normal' and 'Blackboard' modes of model-building, two mini experiments are described and evaluated in terms of their potential for collaborative learning.

5.4.3.1 Normal mode for working in local and global contexts

The first experiment in collaborative model-building was performed during the 'Introduction to EM' module (discussed further in Chapter 6) when one laboratory session was dedicated to distributed and collaborative modelling using `dtkeden`. Previous lab sessions had introduced the jugs model [EMP:jugsBeynon1988] as an educational artefact designed to introduce pupils to the idea of the 'highest common factor of m and n' by allowing them to fill, empty and pour between jugs of integral capacities m and n (as discussed in §3.2). While the original jugs was designed for one pupil at a time, this lab considered a distributed variant of the jugs model in which each pupil owns one jug, and pouring involves transferring liquid from one pupil's jug to another's.

Working in pairs or threes on neighbouring workstations, each group started a `dtkeden` server and then each person in the group connected a `dtkeden` client on their workstation to the server. The groups were then instructed to begin their model-building by constructing a single jug for themselves within their own local context (i.e. not sharing the observables). After completing this task, each client would have a set of observables and procedures that were only available to themselves, as shown if Figure 5.21. In reaching this state there was a little discussion (level 1 collaboration) about the jug and appropriate dimensions for the

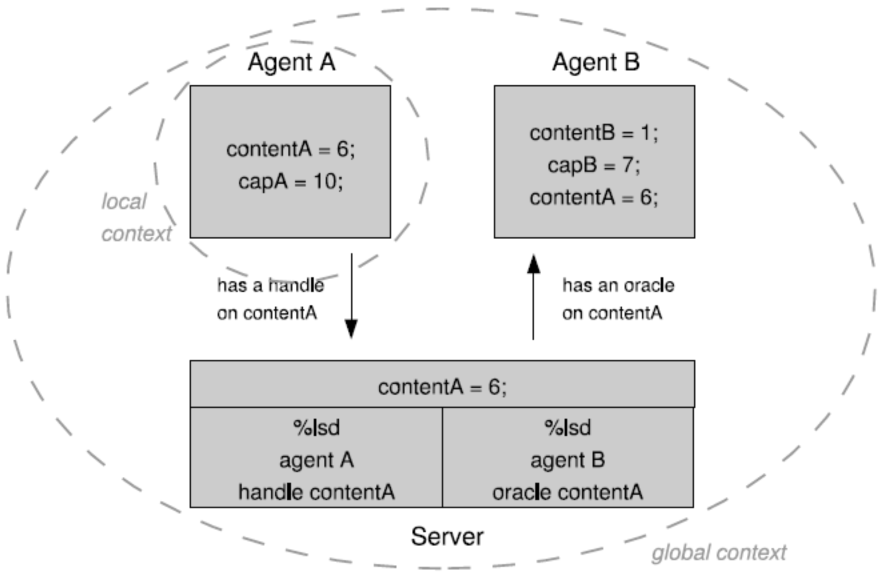


Figure 5.22: Executing definitions in a global context from client A.

jug, and some scripts were shared (level 2 collaboration) to enable others to construct a jug quickly.

In the second phase of the lab, the students were introduced to the `%lsd` notation (as described in the `dtkeden` manual [SC98]) for defining *oracles* and *handles* to specify what observables a client is privileged to observe and change in the global context. The global context is the collaborative modelling environment where clients communicate and share observables as shown in Figure 5.22. A *handle* is an observable in the global context which a client can change. An *oracle* is an observable in the global context which a client can respond to (or is aware of). The students were first instructed to add oracles and handles so that each person was aware of their collaborator's jug capacity and content. Then they were asked to add oracles and handles so that they could pour from their jug into another jug. Some students attempted to implement the full repertoire of interactions required for achieving a specified target collaboratively.

As an outcome of this experiment, it was demonstrated that it is possible to use `dtkeden` to build models collaboratively. Also important is that EM activities can be performed in a collaborative environment. Furthermore, there is evidence that learning by model-building with EM is possible in a collaborative environment. This shows some potential for learning activities with experimental, flexible and meaningful characteristics to be undertaken not just by solo model-builders but also through collaborative model-building.

The problems with the methods for collaborative model-building in this first example is that they require a significant knowledge of how to use the tools collaboratively. This may prove difficult for learners if they need to be too concerned with the technical issues. Even if model-builders grasp the concepts of global and local contexts, they must also spend a lot of time organising which observables should be global and which should be personal (or local) to each model-builder. These technical problems stem from the fact that `dtkeden` was designed for distributed models, and not collaborative model-building.

5.4.3.2 Blackboard mode for working in a simplified global context only

The use of local and global contexts (using the `%lsd` notation) can involve a significant effort by the model-builders, and they must coordinate their efforts with each other in order that effective communication of observables takes place. It is possible that better tools may decrease the cognitive load that is put on the model-builders having to consider local and global contexts, but these have yet to be developed. In response to the difficulties of the above type of collaboration, a simplified mode was designed by Chan and myself to allow for the situation where the model-builders wish to share all of their observables and therefore are not concerned with local and global contexts. Such a situation is metaphorically similar to the collaborative use of a blackboard where each person has their own chalk (and board rubber) and can freely draw on (or erase) the global workspace. The motivation for developing the simplified mode was because of the inspiration that collaborative activities in real life are performed in a global space that everyone has access to, and such activities can either be constructive (i.e. like the chalk) or destructive (i.e. like the rubber) towards the overall creation. The disadvantage of the blackboard metaphor for model-building is the possibility of interference between model-builders in the global space. To test the potential of this simplified mechanism for collaboration, a second mini experiment was performed whereby Chan and myself undertook a collaborative exercise involving the construction of a jugs model in a similar manner to the laboratory session discussed above.

Figure 5.23 shows the two model-builders constructing a jugs model (taken from the video footage of the entire experiment). Starting completely from scratch both model-builders created a standard jug or container on the screen with basic procedures for filling and emptying. Throughout the activity both model-builders could observe the entire model as well as see what changes the other model-builder had made, as can be seen in the history window of Figure 5.23. Figure 5.24 is an extract taken from the history window

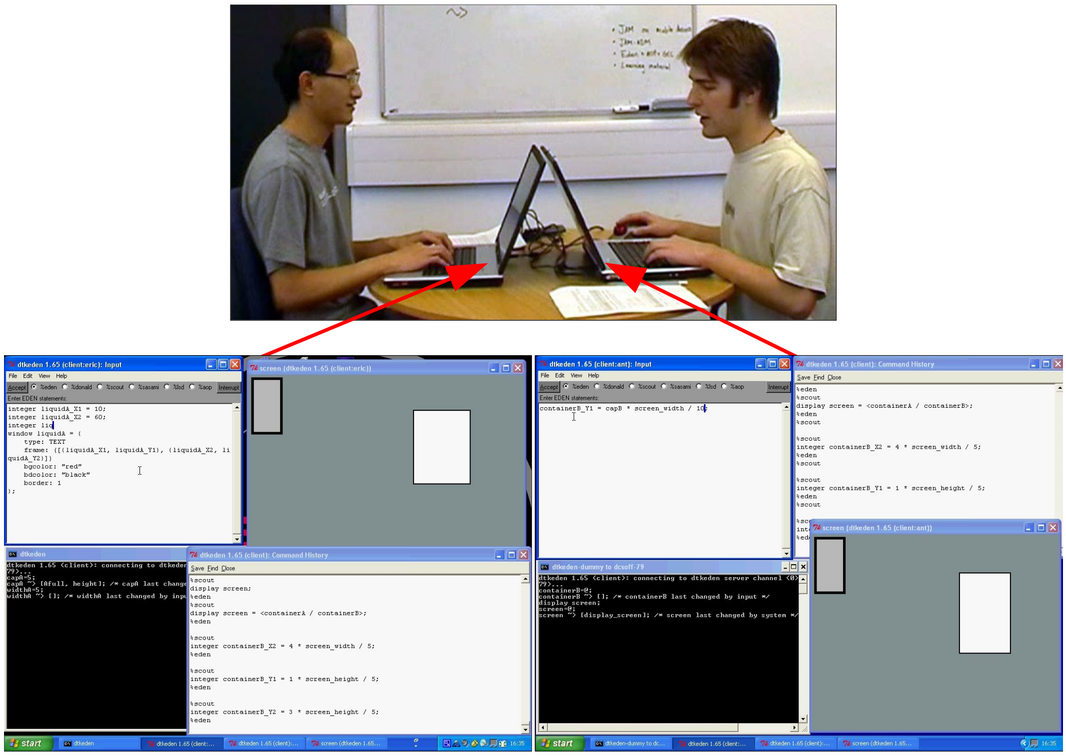


Figure 5.23: Chan and Harfield collaboratively building a jugs model.

detailing the early stages of collaborative model construction. The annotations describe the actions of each model-builder (A and B). After this early stage of construction, both model-builders would be looking at the screen shown in Figure 5.25. It is interesting to note that even at this early, almost preparatory, stage there was evidence of collaboration: when creating the coordinates for the jug, model-builder 'B' used the word 'container' rather than 'jug', and a few steps after model-builder 'A' drops the word 'jug' and replaces it with 'container' to match his fellow model-builder. As the model-building progresses there is further evidence of collaboration when one model-builder reuses the other's procedures for filling and emptying. Such sharing and communication was not common in the previous experiment with the 'Normal' mode.

The experiment highlighted a number of issues with collaborative model-building using `dtkeden` in the 'Blackboard' mode. Firstly, working in a global context creates an added concern about conflicting observable names and other types of interference between model-builders. Secondly, as there is no local context in which to work, it is not possible to test a part of a model in the individual's personal space before making it available to other model-builders. Despite these two concerns, building the model is much more of a fluid activity—as described in Chapter 2—because there is little need to stop to plan the building activity. Unlike the first experiment when a model-builder has to work blind

```
/* Begin */
integer jugA_X1 = 10;
>>
integer containerB_X1 = 300;
>>
integer containerB_X2 = 400;
>>
integer containerB_Y1 = 100;
>>
integer containerB_Y2 = 400;
>>
integer jugA_X2 = 60;
integer jugA_Y1 = 10;
integer jugA_Y2 = 110;
>>
window containerB = {
   type: TEXT
   frame: ([{containerB_X1,containerB_Y1},{containerB_X2,containerB_Y2}])
   border: 2
   bgcolour: "white"
   bdcolour: "black"
};
>>
screen = <containerB>;
>>
window containerA = {
    type: TEXT
    frame: ([{jugA_X1, jugA_Y1}, {jugA_X2, jugA_Y2}])
    bgcolor: "grey"
    bdcolor: "black"
    border: 5
};
>>
containerB_X1 = 3 * screen_width / 5;
>>
display screen = < containerA / containerB >;
>>
containerB_X2 = 4 * screen_width / 5;
>>
containerB_Y1 = 1 * screen_height / 5;
>>
containerB_Y2 = 3 * screen_height / 5;
```

>> marks end of input

A's first input.

B's first few inputs set up the coordinates of a jug.

And then A follows suit.

B creates the SCOUT window.

B adds his window to the screen.

A catches up with a window for his jug.

B redefines his jug coordinates.

A redefines the screen to take account of both jugs.

B makes further changes to his jug so that it is dependent on the size of the screen.

Figure 5.24: The script resulting from initial stages of collaboration by two model-builders.

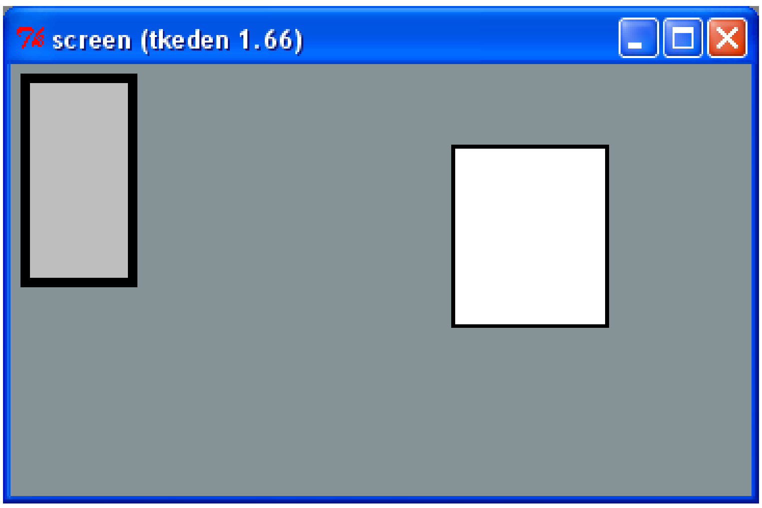


Figure 5.25: A screenshot of the jugs model at an early stage of collaborative model-building.

to another's model and therefore much discussion was needed, the blackboard metaphor enables all model-builders to see each others work. As all aspects of the entire model are open to negotiation through redefinition, connections in the form of dependencies can be quickly created between each model-builder's work. Although the 'Normal' mode has the advantage of a private local space that is useful for testing, in the spirit of experimental model-building as encouraged in EM, it can be useful to try things out in the global space for all to see. In fact, it opens up the possibility for other model-builders to offer suggestions as was found during the experiment. The benefit of not having to deal with observables in two different contexts is that the collaborative model-building flows more naturally and encourages experimentation.

One technical contribution of this work is that Chan and I have invented a new mode for `dtkeden` that is especially designed for collaborative model-building. As model-building with EM can be beneficial for a conception of learning that can be characterised as experimental, flexible, and meaningful, it is suggested that such learning can also be achieved with a collaborative element. This section has demonstrated that collaborative model-building for learning is possible. The next section explores a specific example of a historical rail accident that highlights how learning in a collaborative EM environment offers benefits over other forms of CSCL.

5.4.4 Learning about the Clayton Tunnel accident

The jugs model serves as a simple illustration of the ideas behind collaborative model-building in EM using `dtkeden`. In order to show potential for collaborative learning, it must be shown that model-building collaboratively can be extended to more interesting situations where there is greater scope for the development of understanding. The following example is based on a larger model, that has been developed by a number of model-builders, over a period of a number of years. The Clayton Tunnel model was an exercise in building a distributed model to reconstruct a famous accident in 1861 [Sun99]. Subsequent work on the model by Chan and myself has demonstrated the potential for the model in learning about the history of the Clayton Tunnel accident[†].

[†]This section draws on material from a poster presented at Kaleidoscope 2005 and used subsequently for EM demonstration purposes [HCW05]. The Clayton Tunnel model discussed in this section is the Chan and Harfield version [EMP:claytontunnelChanHarfield2005].

Figure 5.26: A photograph of the Clayton Tunnel (reproduced by permission of English Heritage.NMR).

5.4.4.1 Background to the model

The Clayton Tunnel model was not constructed in a collaborative manner (i.e. built by multiple model-builders collaborating together at the same time), but the model is distributed across multiple computers. It is discussed as an example of what can be achieved with the current EM tools, with the vision for such models to be constructed collaboratively in the future (e.g. using the 'Blackboard' mode described in §5.4.3.2).

The model is a reconstruction, created using `dtkeden`, of a stretch of railroad in England between London and Brighton that includes a tunnel as pictured in Figure 5.26. The Clayton Tunnel, as it is called, was built in the 1840s, stretches 1.25 miles and contains two rail tracks, one northbound and one southbound. In 1861, it was equipped with what was believed to be the most advanced safety system of its day. It was operated by two signalmen, one at each end of the tunnel, 24 hours per day. The tunnel used a space-interval system whereby only one train was allowed to occupy the tunnel (in any one direction) at a time. The signalmen guarded the tunnel using a combination of telegraphs, warning signals and traditional semaphores.

In order to appreciate the causes of the accident, it is necessary to explain the protocol for safe operation of the tunnel. Between the signalmen at each end of tunnel, a needle telegraph was used to communicate the status of the tunnel. When a train entered the tunnel, an 'occupied' message was sent, and when a train exited at the other end then a 'clear' message was returned. Communication between the signalman and the train driver relied on an automatic warning signal and traditional semaphore flags. At a safe stopping distance before the tunnel, the signal indicated to the driver whether the tunnel was currently ‘clear’. After the train passed this signal, a treadle in the track caused the signal to automatically set to the ‘caution’ state. When the signalman received a message that it was clear, then the automatic signal was set to ‘clear’ again by the signalman. The protocol for the driver was that if the signal was in the ‘caution’ state, then he must slow the train and wait for the white flag from the signalman before proceeding into the tunnel. If automatic signal failed then an alarm would signal in the signalman’s box and he could revert to semaphore flags (e.g. a red flag for stopping the train).

The Clayton Tunnel model is distributed on up to six workstations to enable up to three train drivers, two signalmen and one god (for causing signal failures) to take part in operating the stretch of railroad reconstructed from 1861. The original model, initiated by Taylor [Tay97] and subsequently developed by Sun [Sun99], runs on six workstations each running `dtkeden`. The 3D VRML version, initially created by Woodforth [Woo00] and revised by Chan and myself in 2005 [EMP:claytontunnelChanHarfield2005], offers more flexibility in terms of which people take part in the model.

5.4.4.2 Significance of the EM approach

In evaluating a traditional CSCL application, it would be appropriate to consider the significance of the EM approach firstly for *constructing* the model and secondly for *exercising* (i.e. playing or using) the model. Usually these two issues would be treated separately, one being concerned with software development and the other with software use. The first significant advantage of the EM approach, as introduced in §3.1.5, is that there is little difference between modelling activity that leads to construction and modelling activity that does not involve construction (i.e. exercising a model). From the point of view of a software developer it may be difficult to see the benefits of a blurred distinction between development and use, but for an active learner the benefits are clearer: learners can engage in open-ended *experimentation* through construction; learners are able to *flexibly* choose their own learning path not just exercise a preconceived program; and therefore, learners can explore models in ways that are *meaningful* to their own life and interests.

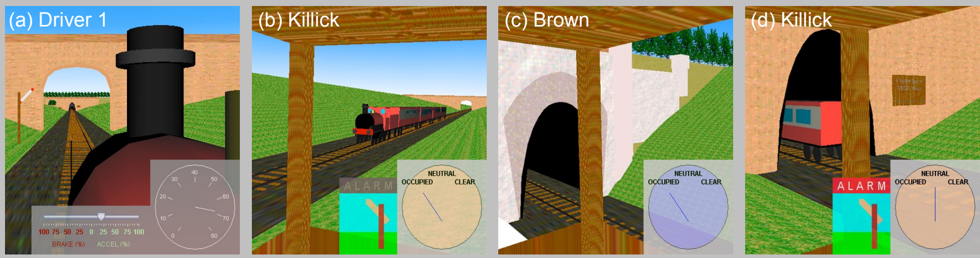
As an example, in exercising the model to understand the causes of the Clayton Tunnel accident, it was advantageous to semi-automate some of the agent’s actions due to a lack reliable train drivers in the department. One action to be automated was stopping the train when a red flag is shown at the entrance to the tunnel. This was achieved by adding a dependency to reflect the observation of a red flag by the train driver and a triggered action to apply the brake to the train. Such a change to the model could be considered building a new feature into the model, but it was performed in-the-flow of exercising the model, even whilst the trains themselves were running and being controlled by one of the collaborators. This small automation enables the signalman (whose observation is restricted to the entrance of the tunnel) to experiment with putting the flag out at different times to see whether firstly the train can stop before the entrance to the tunnel, and secondly, whether the signalman is able to determine if the train driver has seen the flag and is stopping—both of which were important details in the events that led to the accident.

The experimental and flexible characteristics of EM enable collaborative model-builders to explore 'what if' scenarios in a completely unrestricted way. Whereas microworlds generally offer a pre-selected set of parameters for experimentation [RB07], in an EM model the whole environment is open to change. The model-builder can experiment with familiar or expected occurrences (e.g. signal failure or brake failure) as easily as unfamiliar or unexpected occurrences (e.g. a train driver acting out of character by stopping at a 'clear' signal, a train disappearing from the tunnel, or a signalman with a sixth sense for detecting imminent train arrivals). EM, by providing the mechanisms with which to explore the domain, offers the potential for a richer experience of the signalman and driver roles that can lead to a deeper understanding of how and why the accident occurred.

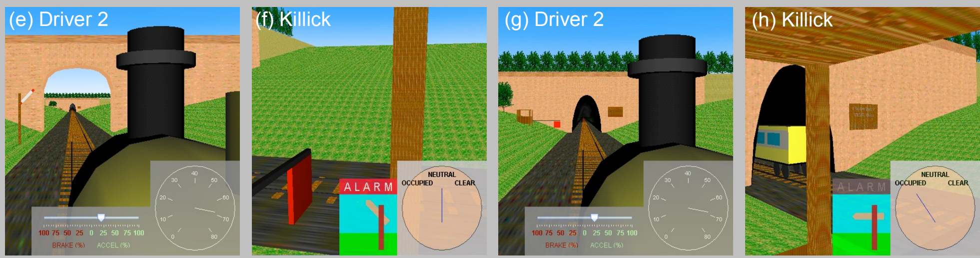
5.4.4.3 Potential for learning

There are a number of ways in which the EM approach to the Clayton Tunnel model could be useful for learning. From a personal point of view, I have been involved with exercising and demonstrating the Clayton Tunnel model over a long period of time, as well as making changes and improvements to the model. In this time I have found that my understanding of the accident has become stronger and can be backed up by experiments in the model. The first few times I observed the model I could not see its significance, and when I exercised one of the agents myself I had very little idea why the accident occurred. Through repeated interaction with the model and through attempts to change it, I started to appreciate some of the reasons why the crash occurred—one being that Killick (the signalman at the entrance to the tunnel) misinterpreted a telegraph message

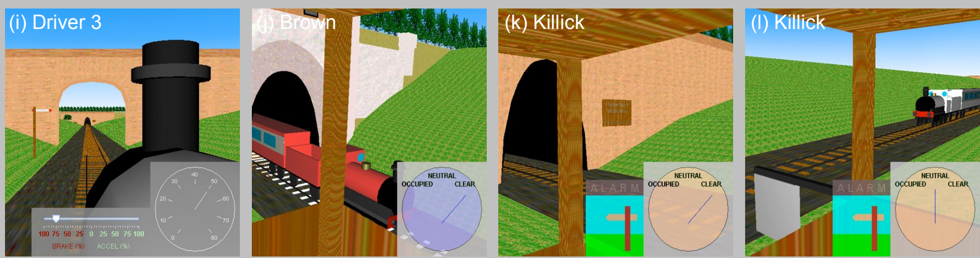
On Sunday 25th August 1861, there were trains due to depart from Brighton station at 8:05, 8:15 and 8:30. The trains were running late, but eventually they were dispatched by the stationmaster in quick succession at 8:28, 8:31 and 8:35 respectively, thus disregarding the 5 minute interval that was required between departing trains. And so began an unfortunate sequence of events.



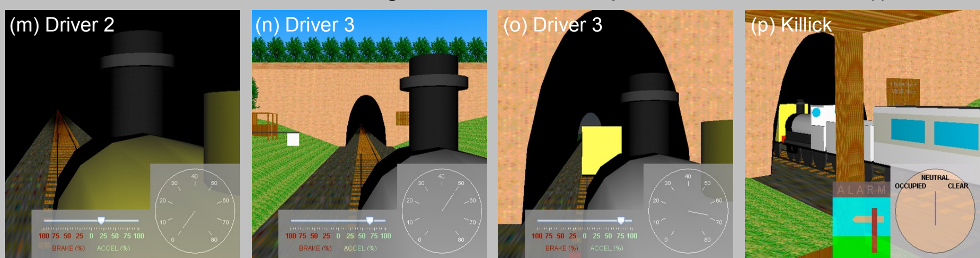
As the first train driver approached Clayton Tunnel, he observed the 'clear' signal (a) and proceeded into the tunnel (b). The signalman at the entrance to the tunnel, Killick, sent a message to Brown at the other end to indicate the tunnel was occupied (c). Killick realised that the automatic signal warning the next train that the tunnel was occupied had failed to set to caution (d).



Before Killick had time to reset the failed signal, the second train was approaching. The driver observed the `clear' signal (e), not realising it had failed, and proceeded towards the tunnel at full speed. At the last minute, Killick waved a red flag (f) but he was unable to determine if the driver saw it before he entered the tunnel (g). Killick sent an occupied message and reset the failed signal (h) to protect the next train.



As the third train approached, the driver observed the caution signal (i) and prepared to stop before the tunnel. Killick was unsure whether the second train had exited the tunnel and so he sent a message to Brown, asking if it was clear (j). Brown, unaware of the second train, responded with a `clear' (k) as he had just observed the first train leaving the tunnel. Now the Killick had been given the all clear, he waved a white flag at the third train to proceed into the tunnel (l).



However, the driver of the second train had seen the red flag and was able to stop his train inside the tunnel (m). He decided to reverse the train out of the tunnel to find out the problem. The third train had already begun to accelerate (n) when the driver realised there was a train in the tunnel (o). It was too late and the trains collided inside the entrance to the tunnel (p). The crash, one of the biggest in British railway history, killed 22 people and injured 177 people.

Figure 5.27: An account of the Clayton Tunnel accident reconstructed from historical sources and experiments with the model.

for Brown (the signalman at the exit). In seeking accuracy for the model I found out that one historical account gives the times that the trains left the station giving an indication as to how much time there was between each train. Then by playing Killick's role, I was able to appreciate how little time he had to react when the automatic signal failed, and thus I learnt that the station-master at Brighton played a part in the accident by despatching the trains in quick succession. My current understanding is shown in the account of the accident in Figure 5.27, together with pictures of the reconstructed events from the viewpoint of the relevant agents.

The EM approach is potentially useful for historians trying to understand the problems or errors that led to the accident. By reconstructing the accident as in Figure 5.27, it is possible to view the situation from purely one viewpoint, such as train driver 2, and reason as to whether he acted correctly. An investigation in 1861 into the accident attempted to take the train driver and Killick to court for negligence, but neither was convicted. This seems to me a correct decision, because after playing the accident from each viewpoint there is no single person to blame. In my account (see Figure 5.27), I have come to the conclusion that there were four factors contributing to the accident: the three trains were despatched too close together; the automatic signal failed; Killick misinterpreted the telegraph message from Brown; and train driver 2 decided to reverse in the tunnel. By experimenting with different circumstances it is possible to show that if any of the four factors had not occurred then the accident may well have been avoided. These conclusions arose out of collaborative use of the model, recreating the accident and experimenting with alternative situations. It questionable whether I would have arrived at the same conclusions from written accounts of the accident alone.

The collaborative EM approach could be used for teaching history in a group situation such as the classroom. The agents can be automated to use the model as a demonstration tool, or students can take control of each of the agents to learn about the scenario collaboratively. From experience of demonstrating this model to university students, it is quite difficult to orchestrate the accident as it happened following the scenario in Figure 5.27—it is more likely that students will crash the trains accidentally in trying to understand their role in the scenario and learning to master the controls a train driver should be familiar with. However, learning about operating trains and tunnels is a necessary part of being able to understand the accident. Once mastered, it can lead to more advanced interactions, such as 'what if' scenarios to be explored as an aid to learning more about (e.g.)

the reasons behind railway accidents.

There is further potential for EM to be used to support training signalmen or drivers using a collaborative environment like the Clayton Tunnel model. The emphasis on open-ended model-building enables many different situations to be played out that would be too difficult and time consuming to arrange in the world—e.g. reconfiguring the track, changing the position of the signals, or driving different types of trains.

5.4.5 Review of EM's approach to CSCL

One of the benefits of educational technology that has utilised the Internet is that it can enable collaborative learning by a group of people not necessarily in the same physical location. Discussing and sharing are the two types of collaborative activity on the Internet that have been most popular in CSCL to date, but collaborative building is the activity that is emerging as offering the most potential for learning from a constructionist viewpoint [Res96]. The ambition for collaborative building is evident in the Kids' Club project at the University of Joensuu in Finland [ESV02], where school children, collaborating with university students and researchers, build novel technologies using programming environments, robotics and control systems to learn problem solving, creative thinking and ICT skills. Physical construction using intelligent bricks (I-Blocks) developed at the University of Southern Denmark have proved worthwhile in collaborative problem solving at schools and universities in Africa [LV04]. On a more general level, Web-based applications, such as EditGrid [Gib06] developed by Team and Concepts, enable collaborative construction of spreadsheets in an open-ended manner on the Internet. With the advances to EM tools for collaboration highlighted in this thesis (e.g. the 'Blackboard' mode), EM can be seen as the next step in widening the possibilities for collaborative learning by providing a methodology for open-ended model-building that could be used in a broad range of areas. The EM approach to CSCL is unique because it is fundamentally different from programming and it is concerned with learning through collaborative model-building that emphasises the experimental, flexible and meaningful characteristics of learning, as described in Chapter 1 and as demonstrated in Chapter 4.

The jugs experiments have demonstrated that collaborative model-building is possible within an EM framework using the `dtkeden` tool. The first experiment led to the development of a new mode, based on the blackboard as a metaphor, for collaborators to build models that were not possible in previous versions of `dtkeden`. The second jugs experiment highlighted the benefits of the 'Blackboard' mode as offering more potential for the collaborative exploration of models that is in the fluid spirit of EM. The Clayton Tunnel model is introduced as an example of what could be achieved through collaboration and as an example of learning in a specific domain. The author's experience of building and interacting with the Clayton Tunnel model has led to a deeper understanding of the operation of the tunnel, and of the sequence of events that resulted in the famous accident in 1861, than could be expected through written accounts alone.

The jugs experiments and the Clayton Tunnel model have introduced an EM approach to CSCL. Provided that they had an appropriate level of proficiency in `dtkeden`, there is no reason why other model-builders could not collaboratively build, interact and learn in other domains, whether it be historical events like the Clayton Tunnel accident, or aspects of computer science as discussed in Chapter 4, or languages as discussed earlier in this chapter. In fact, there is potential for any of the models demonstrated in this thesis to be used collaboratively for learning; learning that still emphasises *experimental*, *flexible* and *meaningful* characteristics.