Intelligent tutoring: from SAKI to Byzantium

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Keywords *Education, Learning, Technology, Cybernetics, Learning styles*

Abstract *Describes Byzantium, an intelligent tutoring system for teaching the concepts and skills of accounting. The generic design philosophy of Byzantium and its associated intelligent tutoring tools are described, together with commentary that places Byzantium in the tradition of the adaptive teaching machines and conversational tutorial systems (SAKI and CASTE) developed by Gordon Pask.*

Introduction

"Teaching is the control of learning" is one of Pask's early aphorisms (Pask, 1961) that provides immediate insight into how teaching and learning may be interpreted and modelled as cybernetic processes of control and communication. The self-adaptive keyboard instructor (SAKI) (Pask, 1960; 1982) was an early embodiment of Pask's ideas. SAKI was an adaptive teaching machine that optimised the rate of learning of a trainee keyboard operator by learning about and modelling the learner. Difficulty levels of tasks were made contingent on a learner's performance. As performance improved the rate of presentation of stimuli increased and cue signals for how to perform the task were delayed, eventually serving a detailed "knowledge of results" function. Training times were typically one-half to two-thirds those obtained by conventional methods. An early SAKI used to train card punch operators is shown in Plate 1.

Later came the course assembly system and tutorial environment (CASTE), designed to support the learning of complex academic subject matter, bodies of conceptual knowledge and associated procedural skills for problem solving and model building. CASTE embodied Pask's conversation theory approach to learning and teaching, where transactions between learner and teacher are construed as questions and answers about conceptual knowledge ("why" questions and concept definitions) or as questions and answers about procedural knowledge ("how" questions and demonstrations). An entailment structure representation was used to show relations between concepts. Particular concepts were modelled and demonstrated using a modelling

Kybernetes,
Vol. 30 No. 5/6, 2001, pp. 807-818.

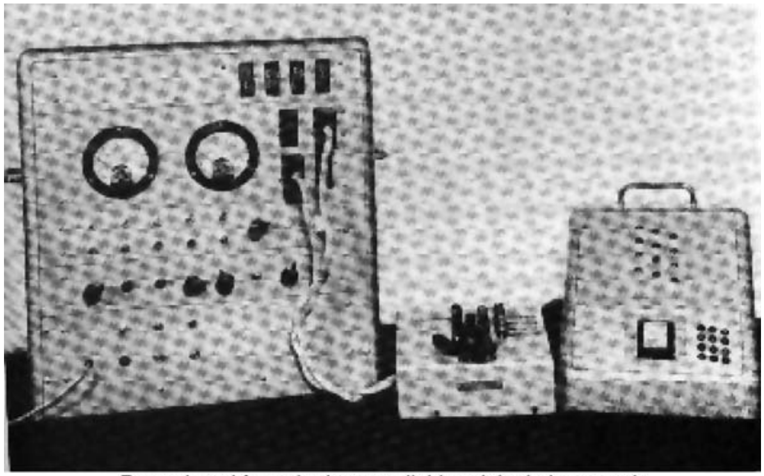

Plate 1.
Early SAKI used for training card punch operators

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facility. A subsystem, belief and opinion sampling system (BOSS) was used to elicit subjective probability measures of a learner's uncertainty about subject matter content and about his or her choice of learning route (see Figure 1). CASTE transactions also included summative assessments of conceptual understanding and performance, which formed the basis for conversational exchanges with the learner about his or her learning strategy and its effectiveness (Pask and Scott, 1973; Scott, n.d.).

The Byzantium system described in this paper is a contemporary example of an adaptive, conversational system in the tradition of SAKI and CASTE. The developers (Patel and Kinshuk) initially approached their work in a fairly

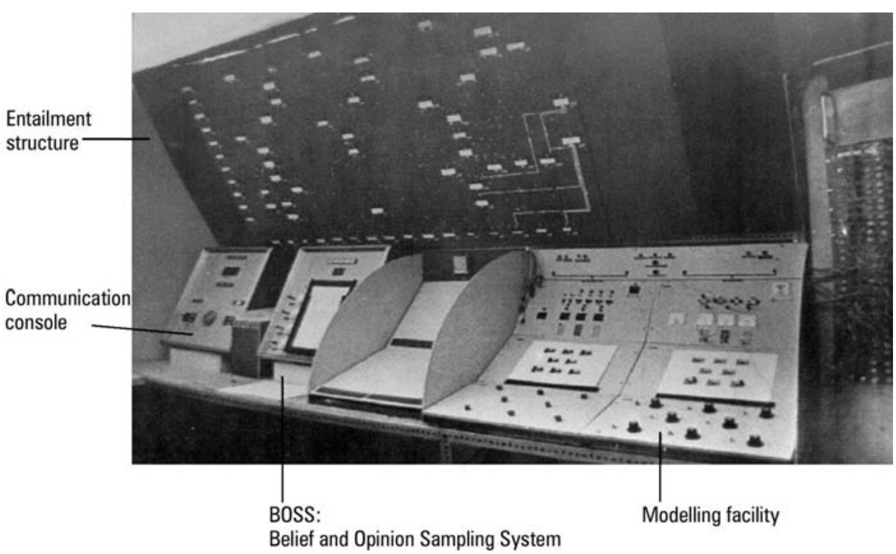

Figure 1.
CASTE

pragmatic way and were gratified later to discover that their own theoretical formulations of good practice accorded well with those expounded by Pask and his colleagues. The paper is based on the experience of the design, development and implementation of intelligent tutoring tools (ITTs) developed by the Byzantium project, a consortium funded under the Teaching and Learning Technology Programme (TLTP) of the Higher Education Funding Councils of the United Kingdom. The consortium was made up of De Montfort University (Lead Institution), Liverpool John Moores University and the Universities of Huddersfield, Middlesex, Plymouth and Teesside. Outside the consortium universities, the ITTs are actively used in learning and teaching by the University of Glasgow and the University of Hertfordshire, while being available as supplementary learning resource at a number of institutions of Higher and Further Education. For detailed description of the structure and functionality of the ITTs, see Patel and Kinshuk (1997a).

The discussion in this paper is based around those domains, where the reality is represented as numeric models that are directly manipulated to determine various outcomes. These are second order in nature as the practitioners work with concepts that are already abstracted to a numeric form of representation, whether it is money, miles, calories or kilometres. For example, engineers deal with abstract mathematical measures such as current, force and gravity while accountants deal with social and economic realities expressed in monetary terms. Perhaps it is the second order nature of the domains, with a greater call on cognitive skills, which makes them more difficult to grasp initially.

A major part of learning in any domain requires a learner to understand the relationships among its concepts (Pask, 1975). In the case of a numeric domain this translates into working with a set of variables representing the relevant concepts. The learner needs to understand how these variables are inter-related, recognise those that have an initial value and therefore act as independent variables within the given problem space, determine one or more possible sequences of resolving dependent variables, and take valid steps to resolve them by employing forward or backward chaining as required to attain the sub-goals on the way to the overall solution.

The elementary operations performed on individual variables are relatively straight forward and performing them on a set of variables in an appropriate sequence helps in forming procedures by clustering elementary operations and pushing them to a subconscious level. It is the procedural knowledge that is critical and separates an expert from a novice. Therefore, in terms of designing learning and teaching systems, it is apparent that these domains favour an implementation of some form of cognitive apprenticeship-based learning involving learner-system conversation.

Phases of cognitive skill acquisition

VanLehn (1996) suggests that Fitts' categorisation of the three phases of motor skill acquisition (early, intermediate and late) also aptly described the course of cognitive skill acquisition. In the early phase, dominated by information acquiring activities, the learner is trying to understand the domain concepts without yet attempting to apply the acquired knowledge. The primary focus is on expository instructional material. The intermediate phase begins when the learner turns the attention to solving problems, mostly after studying a few solved problems. Though the learner may go back to the expository material as and when needed, the primary focus is on solving the problems. At the intermediate phase, the learner removes misconceptions and acquires any missing conceptions while also acquiring heuristic and experiential knowledge to expedite problem solving. At the end of this phase, the learner can solve problems without conceptual errors though they may still commit unintended errors or slips (Norman, 1988), generally indicative of the lack of attention arising from increased confidence. The slips may remain undetected as the learner may not have adequately developed a sense of judgement about the overall solution and may not "feel" that something is not quite right! During the late phase, the learners improve in accuracy and speed through practice. Their understanding of the domain and their basic approach to solving the problems do not change significantly at this stage.

This three-phase distinction, though an idealisation – as the boundaries between the phases may not be sharp and clear – is quite useful for learning resource designers as it indicates the need for three categories of resources to match the three phases of cognitive skill acquisition as given below:

(1) *Expository material.* Expository material may contain hyperlinks to facilitate movement between hierarchically, semantically or laterally connected notions.

(2) *Formative assessment.* Formative assessment material has immediate and dynamic feedback at each step of attempted solution. The immediate feedback ensures that the learner's error is corrected as soon as it occurs and there is no danger of rehearsing an incorrect conception. The dynamic feedback provides concrete contextual guidance rather than generic advice. The learner is freed from the cognitive load of worrying about a chain of sub-goals and is offered greater and better interactivity with the learning resource.

(3) *Summative assessment.* The final category is based on summative assessment to enable free application of knowledge gained by the learner, allowing any slips and errors. A delayed feedback after completion of one or more summative problems can then be provided for the learner to inspect.

A practical application of this categorisation can be found in the Byzantium ITTs. The first screen in all the ITTs offers a menu shown in Figure 2. The learner selects "Basic concepts" for expository material, "Interactive mode" for formative assessment and "Assignment mode" for summative assessment. The

Figure 2.
Menu on the first screen of the ITT

fourth option, "View marked work" is selected for inspection of marked assignments and provides feedback on the attempted solution for each assignment problem.

While the discussion so far is based on the phases of cognitive skill acquisition as idealised distinct categories, the continuum between the early and intermediate phase is perhaps better captured in the functionality oriented cognitive apprenticeship framework suggested by Collins *et al.* (1989). The framework requires that the following functionality should be present in a tutoring system:

- The learners can study task-solving patterns of experts to develop their own cognitive model of the domain (modelling). The ITTs provide a "Basic concepts" mode presenting textual/graphical explanations and solved examples. The same material is also available through the Help button in the interactive learning mode.
- The learners can solve tasks on their own by consulting a tutorial component (coaching). The ITTs offer qualitatively better coaching through interactive guidance and dynamic feedback while a learner is attempting to solve a problem.
- The tutoring activity of the system is adaptive; it is gradually reduced with the learner's improving performances and problem solving (fading). The ITTs provide help "by exception" and the tutoring activity is triggered by an illegal or incorrect attempt. With the improvement in performance there is less tutoring intervention.

The next section briefly discusses the cognitive apprenticeship-based learning environment provided by the Byzantium ITTs and how their design implements various aspects of conversation theory (CT) (Pask, 1975).

An implementation of a cognitive apprenticeship-based learning environment

With well-designed learning resources employing granular interfaces, it is possible to learn from much simpler interactions as the learning tasks are decomposed into smaller components and the perspective shift is enabled through the user interface (Patel and Kinshuk, 1997b). There is no need for the system to engage in complex inferencing about user knowledge as the system can provide a simple correct/incorrect feedback at a coarser grain size. Where necessary, the system can advise the learner to use a fine-grained interface for more detailed interaction, as shown under "Interactive messages" in Figure 3.

In terms of the CT, the granular interfaces represent the entailment structures at different levels facilitating a more detailed conversation to take place between the learner and the system. This is analogous to a natural language request by a teacher, "I don't think that is correct! Can you show me how you got that answer?", but is more efficient from a learner's viewpoint as the request comes with an appropriate entailment structure in the form of a fine-grained interface.

Figure 4 shows a problem space in the capital investment appraisal ITT. The proposed investment into a project can be evaluated using one or more of the four techniques, each of which can be selected by one of the pushbuttons on top of the panel on the left-hand side. The learner is given some information, shown in blue, which is sufficient to solve the problem. The derived values entered by the learner are shown in black. The learner is using the third technique of evaluation, namely net present value (NPV) and is attempting the

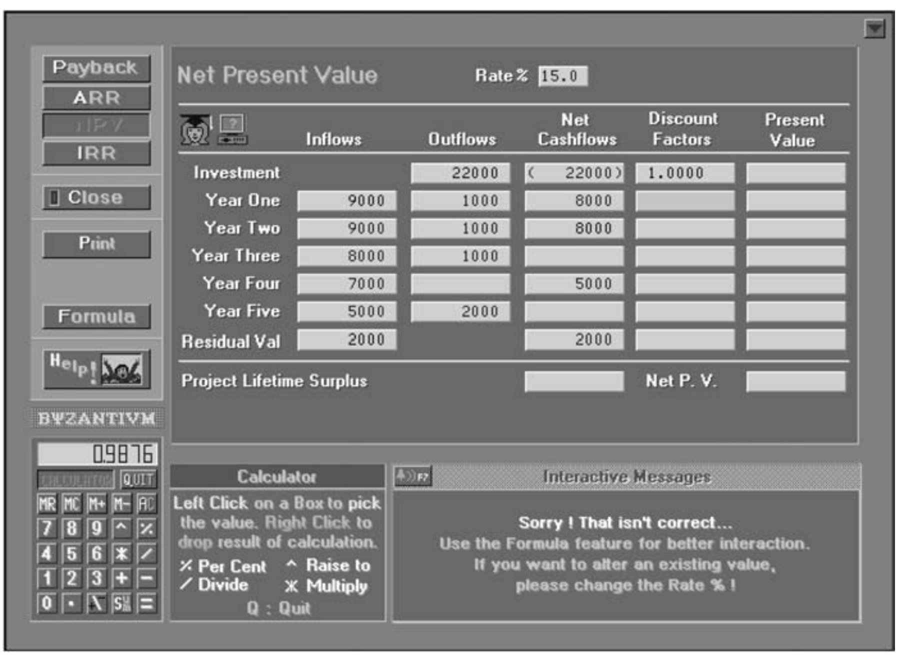

Figure 3.
A fine-grained interface for more detailed interaction

discount factor for end of year 1. The value of the discount factor attempted by the learner was incorrect so the interactive message advises the use of the Formula feature. The feature employs a fine-grained interface, shown in Figure 4, called up using the "Formula" pushbutton on the left-hand side panel.

The ITTs have "just-in-time" scaffolding and "built-in" fading as demonstrated by the following attributes:

- The system does not force a learner to use a rigid sequence of data entry or a specific path to solution when multiple paths are possible (the scope for such multiple paths depends on the subject matter; for example, it is very limited in the screens shown here). Though the expert solution records its own path to the solution, the system recognises all the alternative valid paths to solution and alters its guidance in line with the path chosen by the learner. The system thus facilitates the preferences of serialist and holist learners who may prefer to view the situation from different perspectives. When the learner has not already carried out any action to warrant the application of a different relationship, the system provides guidance based on its own route to solution. However, the learner can choose to disagree and take an alternative (but valid) route to solution, satisfying a quite important requirement of the CT that conversation includes agreement including the vital agreement to disagree.
- The system offers scaffolding only when the learner demonstrates a need for it through an erroneous action. This strategy maintains a

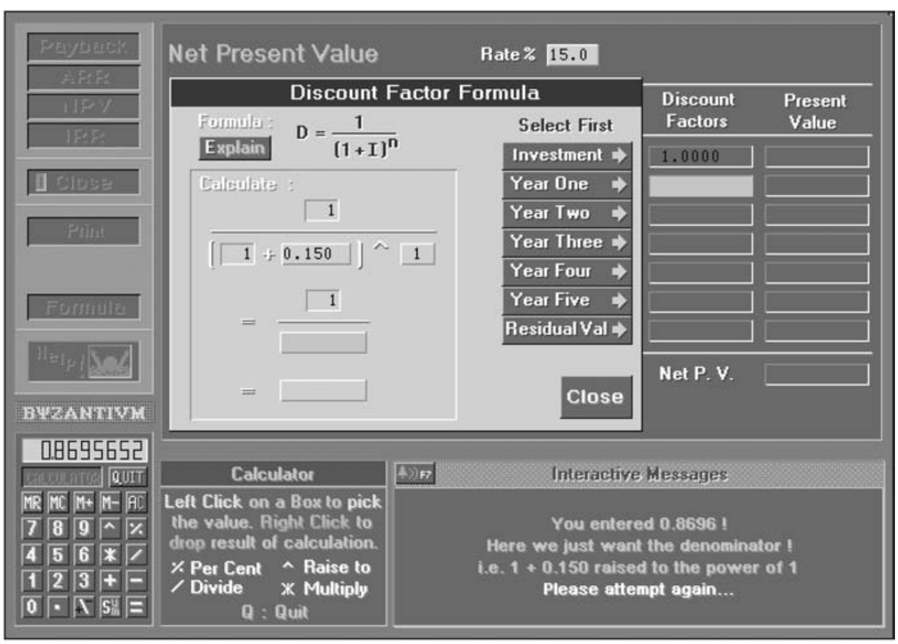

Figure 4.
A problem space in the capital investment appraisal ITT

smooth normal flow of conversation through matching of learner and system responses that is expanded to include feedback on learner action in case of a mismatch.

- If the attempted value cannot be obtained directly from the given information and that already derived by the learner, the system suggests that the learner should attempt an intermediate step. This feedback helps in clearing any misconceptions and in acquiring any missing conceptions. If the learner has performed some mental operations and attempted a correct value, the system does not insist that the intermediate step must be carried out first.
- If the attempted value is incorrect at the first attempt, the system merely notifies that it was incorrect and allows re-examination. The frequency of this, the first level of feedback, has been observed to diminish to almost zero with the increase in learning and then rise again due to the slips arising from overconfidence and increased cognitive load as the learner attempts to tackle a larger chunk of problem by performing several mental operations.
- On the second incorrect attempt, the system advises a possible correct relationship to use. This, the second level of feedback, is the workhorse of intermediate phase of cognitive skill acquisition as it indicates misconceptions and helps in getting rid of them with the immediate feedback. Even at this stage, the system does not enforce its route to solution and the learner is at liberty to follow an alternate route to solution.
- On the third incorrect attempt, the system shows the calculation using the actual data. This level of feedback has been observed only at the initial stage of the intermediate phase as the learner is still grasping the various domain concepts by placing them in relation to each other.

In the interactive mode, the learner has to initiate some action before the system offers any guidance. The feedback's purpose is to spur the learners' own self-explanations by pointing out the correct action. At any stage of interactive learning, the learners can refer back to the expository material by using the "Help" pushbutton and do not have to return to the menu and select the "Basic concepts" option. This allows the learners to navigate back and forth between the work they are doing and the textual explanations and solved examples provided in the expository material.

The system requires greater engagement by the learners while giving them a greater control over the learning actions. It harnesses the natural learning capabilities of an intelligent being by giving enough feedback to prevent an impasse. A positive motivational impact from this approach has been observed and many learners have commented that they find it motivating and positively challenging rather than the "patronising" approach seen in some tutoring systems.

Since the learners may experience different levels of difficulty with different topics based on their background and prior exposure to some of the notions, the system offers an almost infinite bank of questions for practice through its capacity to randomly generate problem data. It does not hold problems and solutions but holds the knowledge of the relationships of the concepts. It can, therefore, randomly select some variables as independent variables and assign random values within the programmer specified bounds. On generating the problem data, the system applies its knowledge to derive an expert solution and if all the remaining variables are found to have a legal value in the expert solution, the problem is presented to the learner. In terms of the CT, the system has learnt the relationships from its designer and is now engaged in presenting it to the learner through the entailment structure, matching of responses and graded feedback that advise the learner about the steps to take and relationships to use to arrive at an acceptable response indicating similarity of understanding between the learner and the system. This strategy provides an ample scope for practice at the intermediate phase of cognitive skill acquisition.

Towards the end of the intermediate phase, a teacher may wish to introduce problems in a narrative form for the learner to experience more authentic situations and interpret the data provided in a raw form. The system provides an "Enter your own" problem data option. However, some variables have a fixed value in the interactive mode to prevent misuse of this option for solving the assignment problems with interactive guidance. The problem narration, therefore, needs to be designed around these fixed values. It still offers ample scope of variation and in return for this limitation, the system offers a rich scope of summative assessment that can be computer marked.

The combination of the ITT and the Byzantium Marker software is capable of identifying and giving partial scores for "incorrect interpretation but application of correct method", just like a human tutor marking the work. For more details on the Byzantium intelligent assessment system, please see Patel *et al.* (1998). The computerised marking enables a very fast turnaround and more frequent summative testing can be employed without burdening the tutor. The advantages of such frequent summative testing are threefold:

(1) it motivates the learners in the traditional educational setting to be more attentive to the interactive learning as they are aware that they have to take a test on what they have learned;

(2) such increased attention shortens the intermediate phase of skill acquisition; and

(3) there is a greater amount of and more frequent feedback to support the late phase of skill acquisition.

The objectives of the Byzantium learning environment reflect Collins' (1990) recommendations for constructing robust domain competence. Accordingly, the Byzantium environment aims to facilitate the learners in:

- acquiring the basic domain knowledge which can be used subsequently as a base to integrate all the bits and pieces of knowledge gained from specific situations; and
- applying the basic domain knowledge in abstract and contextual scenarios to generalise the knowledge and skills to be able to apply them in real world situations.

The learning path consists of transition through observation, interactive learning, simple testing, learning and testing involving multiple contexts and/or interpretation of text narrative. The ITT architecture provides a customisation facility for creating appropriate templates as shown in the example from the absorption costing ITT given in Figure 5.

A teacher can specify various parameters to create a replica of simple real world scenarios. The templates can then be used for both structured and non-structured problems. This facility can be used both for providing situated learning through a particular context (say, for those learning costing as a part of workshop management course or those who have a workshop background and desire to acquire business skills) and for helping in generalising the knowledge through multiple contexts.

Feedback from independent evaluation of the ITTs

In an independent evaluation exercise carried out at the University of Glasgow, Stoner and Harvey (1999) found the results indicating that students'

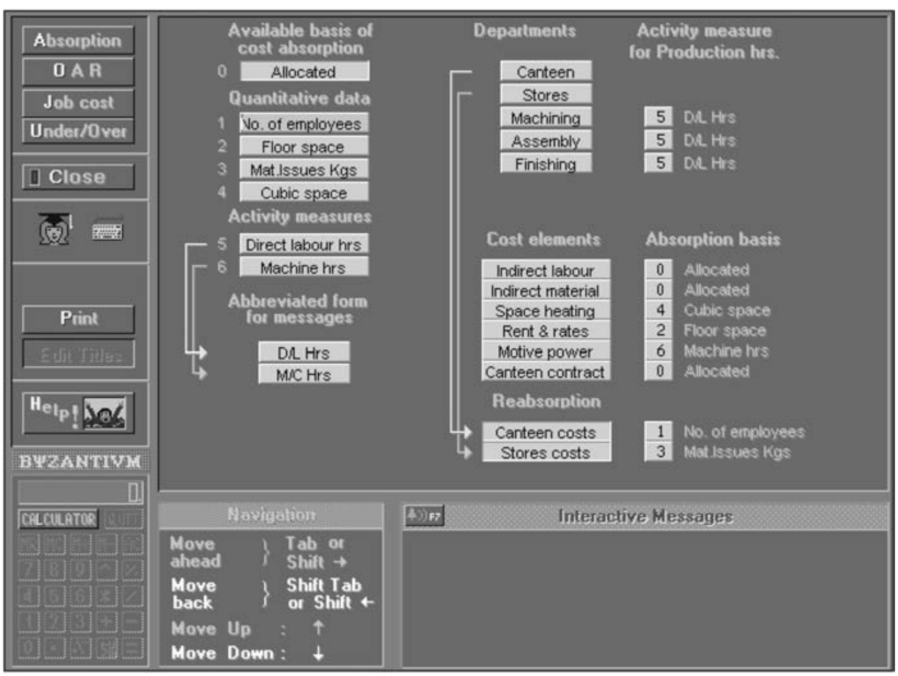

Figure 5.
Absorption costing ITT

performance had improved statistically significantly over the period since learning technology materials were introduced and that this improvement appeared to be mainly reflected in the students' ability to complete numeric questions, the area addressed by the ITTs. Interestingly, their evaluation involved the Byzantium ITTs, another widely used traditional computer-based learning package and human teachers. It was based on a comparison of the examination performances over a period of three years. Their approach is, perhaps, better able to capture the improved long-term retention enabled through the cognitive apprenticeship-based learning (Kinshuk *et al.*, 2000). In terms of subjective opinions, their student feedback focus groups made the following observations while indicating their preference:

> Byzantium was useful because you could go over bits you were unsure about. It was better than a book because it was interactive. With the interactive questions you tend to pay more attention than you would to a book.

> Prefer Byzantium because the other package waffles on about what you already know and provides no incentives to pay attention to what it says. Byzantium offers instant feedback, is more involving and you can do as many questions as you like.

Of the two computer-based learning systems, 71 per cent students showed a preference for Byzantium material while 8 per cent indicated no particular preference. The students wanted more tutoring systems, similar to Byzantium material, for other topics and were positive about computer-aided learning (CAL) in general, observing that it was good to use CAL if the tutoring software was good.

Way forward

The success of the stand-alone ITTs has opened the way to at least two very exciting possibilities:

(1) It is possible to implement process modelling by monitoring the learner's actions on the integrated calculator within the ITT to offer much better diagnostics in case the learner wants to query, "What did I do wrong?". Process modelling is exciting because it provides a window into the cognitive processes taking place in a learner's head and which are invisible to a human teacher.

(2) It is now possible to create intelligent tutoring applications (ITAs) over the Web, using the same underlying methodology but written in Java or other such platform independent language suitable for the Web. With the help of suitable authoring tools and a modular software structure, the Web permits the tutoring modules to be created, held and accessed in a structured manner across vast distances. With the appropriate structuring parameters, the ITAs created by different teachers build up to a large inventory of accessible knowledge that can be utilised by all the teachers in various configurations of single or multiple ITAs to create a hyper-ITS. If the system can acquire the knowledge base from a teacher through an interactive dialogue, then it would be possible for

any teacher to produce the ITAs for any numeric discipline relatively easily. For more details on the proposed extension of the ITT methodology to the Web, please see Kinshuk *et al.* (1999).

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