Intelligent Tutoring of Domain Skills: The Need and A Solution

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Abstract

The task-oriented disciplines require acquisition of physical and cognitive skills, besides the domain's conceptual knowledge to get ready for challenges of real work environment. Traditional academic practices tend to emphasize facts acquisition and fail to provide adequate learning of cognitive skills required in the day-to-day application of these facts in real life, requiring the learners to subsequently acquire these through experiential learning at the work place and thus delaying the productive use of domain knowledge. On the other hand, learning only in the real work environment makes the learner competence too situated to the particular context in which learning takes place and the learners frequently lack the ability to generalize or even distinguish between the concrete and abstract aspects their knowledge, reducing the scope of immediate productive use of their competence in different situations that may not be completely identical to their place of learning. This paper describes an intelligent tutoring system, developed under the Byzantium project, which attempts to bridge this gap and aims to facilitate acquisition of cognitive skills to go with the learning of a domain's concepts

Keywords: Cognitive apprenticeship, Cognitive skills, Domain competence, Intelligent tutoring, Software tutors

Introduction

The disciplines, which are predominantly task-oriented, require the acquisition of basic skills and domain knowledge before applying them to real world problems (Kinshuk & Patel, 1996). This paper discusses the need to learn practical skills and reviews the *tutorial* and *situated* learning approaches. The paper then provides an overview of the approach adopted by the Byzantium project (a consortium of six UK Universities) for designing intelligent tutoring system for learning numeric disciplines.

Jamous & Peloille (1970) argued that professional knowledge includes (a) technical elements that can be mastered and communicated in the form of rules, and (b) indeterminate elements that escape rules and are attributed to the 'virtualities' of the producers. The professional knowledge can therefore be seen as made up of the technical skills and judgement. Johnson-Laird (1988) explained that learning occurs when, as a result of experience, one is able to do something one could not do before or is able to do it better. Initially the learners have to be attentive to all the parts of their performance but gradually, they need to monitor only the trickier parts. The ability to automatically carry out as many basic performances as possible, therefore, ensures that the memory does not get overloaded with only the mechanical aspects of the problem under consideration. Learners in any discipline need competence acquired through practice and the support for this view is reflected in the academic practice of tutorials following a lecture.

Whereas the apprenticeship model allows different rate of progression based on the student's learning efficiency over a range of skills, the current tutorial model based on human instructor is time bound and therefore quite constrained in adequately addressing the issue of natural differences among students in their working patterns, preferences and abilities. If computers can be used in an interactive manner for the tutorial purpose, they can greatly help in relieving this bottleneck as computer labs can easily be made available for needy students outside the scheduled tutorial sessions.

Logic based analytical disciplines (such as philosophy, economics and so on) have a major focus on the domain's conceptual knowledge whereas task-oriented disciplines (such as medicine, engineering and so on) principally rely on skill based competence that embeds two constituents: physical skills related to the procedural tasks; and cognitive skills that surround the efficient "carrying out" of these procedural tasks. Although both physical and cognitive skills demand a great deal of training and practice to achieve competence, physical skills benefit from external visibility as it is possible for the learners to visualize the processes and learn through direct observations.

Cognitive skills, on the other hand, demand a more sophisticated learning process as most of the processes involved in cognitive skills run inside a human mind and can not directly be seen by the learner. For example, entering the data in a spreadsheet model in a short time with less mistakes requires physical skills which can be obtained by observing a master practitioner who would exhibit better eye and hand co-ordination; more efficient use of a combination of mouse and keyboard; and selection of the quickest ways to perform the required tasks from the various methods available to suit users at different levels of expertise. However, the judgment that a particular data appears problematic and may indicate error in coding some key information etc. requires mental alertness that can be attributed to cognitive skills. For task-oriented disciplines, the application of cognitive skills is of critical importance in real life situations.

How Situated are Domain Knowledge and Skills

Considering the predominantly practical dimension of the task-oriented professions, it may be natural to assume that learning in an academic institution (non-contextual learning) can only be inferior through apprenticeship in a real work environment (contextual learning). Real work environments, however, provide a very narrow and overly situated learning of the tasks, severely limiting the acquisition of generalized knowledge and skills that may be applicable to a much wider area of practice. Such a core of domain knowledge and skills relatively easily transfers within a profession so that an auditor in a chemical industry is more readily re-oriented to work in public transport sector than, say, a butcher or a barber seeking a change in occupation.

It is also a well-known fact that academic non-contextual learning has failed to produce skills needed in real work environment, prompting skills assessment by professional associations. Schools have facilitated the organisation and conveying of large amount of conceptual and factual knowledge, ignoring the ground realities. Stinson & Milter (1996) have noted that in business disciplines, schools have become too theoretical and are out of touch with business realities, thus producing narrow-minded technicians and graduates who do not have a realistic understanding of business world. Other disciplines have experienced similar situations.

While there are various aspects of learning that are strongly situated and the learning process progressively develops through activity, there are also many aspects of learning, especially the core knowledge, that may be relatively weakly situated and more general in nature. The activity for progressing this type of learning, therefore, need not be carried out in the real work environment. Rather, a simulated work environment such as practice tutorial or simulated training environment may prove to be cheap and safe alternative to hands-on training in real work environment. Such simulated environment can provide the necessary context for adaptation, enrichment and refinement by facilitating learning in the form of observation, imitation, feedback and evaluation.

An intelligent tutoring system can be very useful to provide more effective learning by representing the domain content at suitable granularity and providing interactive guidance to the learner. The possibility of decomposing a large task (connected by progressive links) and the need only for the context of the sub task in learning, makes it possible to learn from much simpler interactions.

Cognitive Apprenticeship Framework

To address the need of intelligent tutoring with focus on cognitive skills acquisition, the Byzantium ITS applies cognitive apprenticeship framework (Collins, Brown & Newman, 1989). Under this framework, a learner typically starts the learning process by observing a particular task in the system as it would be carried out by the master (or subject expert) and then tries to imitate the task. If the results of the trial are not satisfactory, the system assists the learner in finding the areas of mistakes and sub-optimalities. If necessary, the learner can again observe the master's approach.

Once the learner has successfully imitated the task, the system provides opportunity to repeat the task in different scenarios so that the learner can get mastery in the task.

The repetition process also facilitates the abstraction of the concepts related to the task and helps the learner to apply the abstracted concepts in situated scenarios.

An educational system that adopts cognitive apprenticeship framework demonstrates the following characteristics (Berryman, 1997).

i. It supports learning of concepts, facts and procedures of a subject.

ii. It supports "tricks of the trade", that is, the problem-solving strategies that experts pick up with experience.

iii. It supports cognitive management strategies - goal setting, strategic planning, monitoring, evaluation, and revision.

iv. It supports various learning strategies - help in knowing how to learn, including exploring new fields, getting more knowledge in a familiar subject, and re-configuring knowledge already possessed.

v. It gives learners chance to observe, engage in, invent, or discover expert strategies in context. For that purpose, it offers hints, feedback, and reminders, provide "scaffolding" - supports for learners as they learn to carry out tasks, and "fades" - gradually hands over control of the learning process to the learner with their learning process.

vi. It supports development of multiple skills in the learner, which are required for expert performance. For this purpose, it facilitates sequencing of increasingly complex tasks, increasingly diverse problem-solving situations and an environment where learners get a feeling of overall problem scenario before attempting the problem.

vii. It provides the necessary context for the use of the domain context and facilitates the technological, social, time and motivational characteristics of real world situations where what is being learner will be used to.

The above characteristics are embedded in the architecture of Byzantium ITS.

The Architecture of Byzantium ITS

The Byzantium Intelligent tutoring system (ITS) supports the following main tasks in learning:

Observation - for acquisition of the concepts

Simple imitation - skills acquisition through articulation of the concepts

Advanced imitation - for generalisation and abstraction of already acquired concepts and for acquisition of skills of applying concepts in different contexts

Contextual observation - for deeper learning after imitation process results into the identification of gaps in learner's current understanding of the domain knowledge

Interpretation of real life problems - for acquiring competence in interpreting raw data in a narrative form as encountered in real life situations

Mastery in skills - for repetitive training

Assessment - for measurement of overall progress

The tutoring system operates in three main phases:

1. Basic concepts observation phase, which supports the above mentioned task (i);
2. Interactive skills acquisition phase, which supports tasks (ii) to (vi); and
3. Assessment phase, which supports task *(vii)*.

The following sections describe the architecture of the Byzantium ITS in detail. As explained earlier, four intelligent tutoring modules are developed using this environment. The rest of the paper uses these modules as examples.

Observation - Acquisition of the Conceptual Knowledge

The domain competence acquisition in the Byzantium ITS takes place in several stages. First of all, the learners grasp the understanding of domain concepts with the help of textual, graphical and other multimedia based explanations in *Basic Concepts* part of the modules. The explanations are divided into sub-topics to break down the complexity of the concepts. Besides providing the knowledge of concepts, the explanations also include numeric examples to give a concrete dimension to these abstract concepts. For example, figure 1 shows a Basic Concepts screen for the concept of discount factors in the Capital Investment Appraisal module. Examples besides the actual relationships ensure that the learners would grasp the contextual use of the relationships. This stage of the Byzantium ITS requires the intelligent tutoring modules to use suitable combinations of various multimedia techniques (such as pictures,

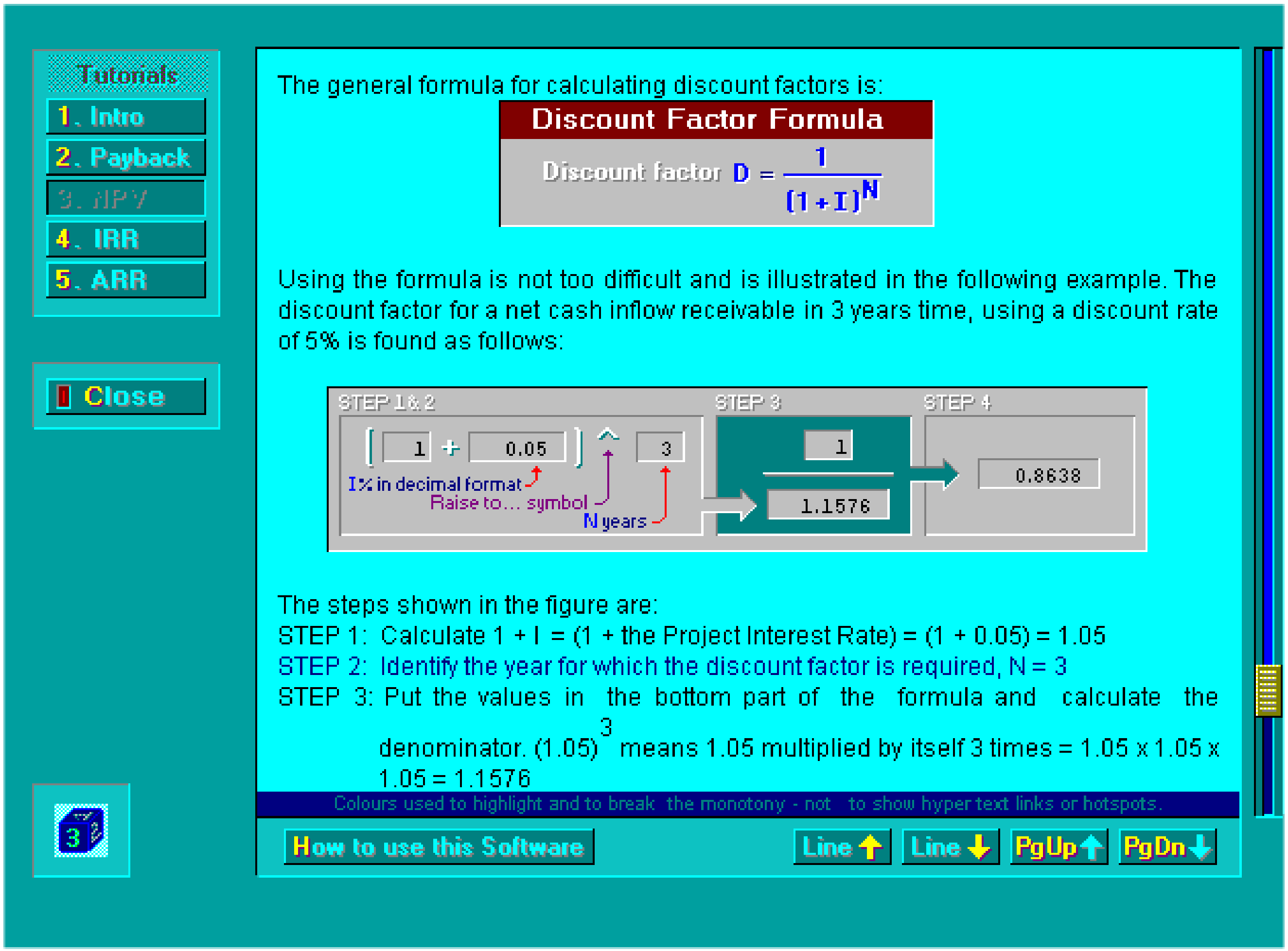

Figure 1. Example of *Basic Concepts* screen from Capital Investment Appraisal package

animations and so on) and hyper-links to various related topics for better observation

Currently the modules, which were developed under Byzantium environment, only use text and static pictures due to the limitations of non-multimedia laboratories where they were going to be used.

Simple Imitation - Articulation of Concepts

After acquiring concepts and representations of procedural knowledge in *Basic Concepts* stage of the system, learners are presented with a problem space that structures the problems progressively into its conceptual components to introduce simpler concepts first. At this stage, the learners encounter with various problems, which are teacher-created in order to ensure that though the problems are not based on real life contexts, they are covering aspects that are useful to solve most of the real life problems at later stages. The system categorises these problems in increasing complexity and presents them to the learners according to learners' current domain competence level as informed by the learner model.

The problem space in the Byzantium environment attempts to address the whole problem in a single model to present the full view of the problem to the learners. But where it becomes necessary, model progression of the problem is based on model segments that are self sufficient (e.g. alternative decision paths, different techniques based on same initial data and so on) or those that provide a logical basis for aggregation to a coarser grained representation in the following model(s). The teacher assigns values to some of the conceptual components in a consistent network of several conceptual components. The number of assigned conceptual components must be sufficient to address the whole problem because at this stage, learners are not expected to solve open-ended problems. The learners have to derive the values associated with the remaining and dependent values by applying the conceptual and procedural knowledge acquired from the *Basic Concepts* stage. Figure

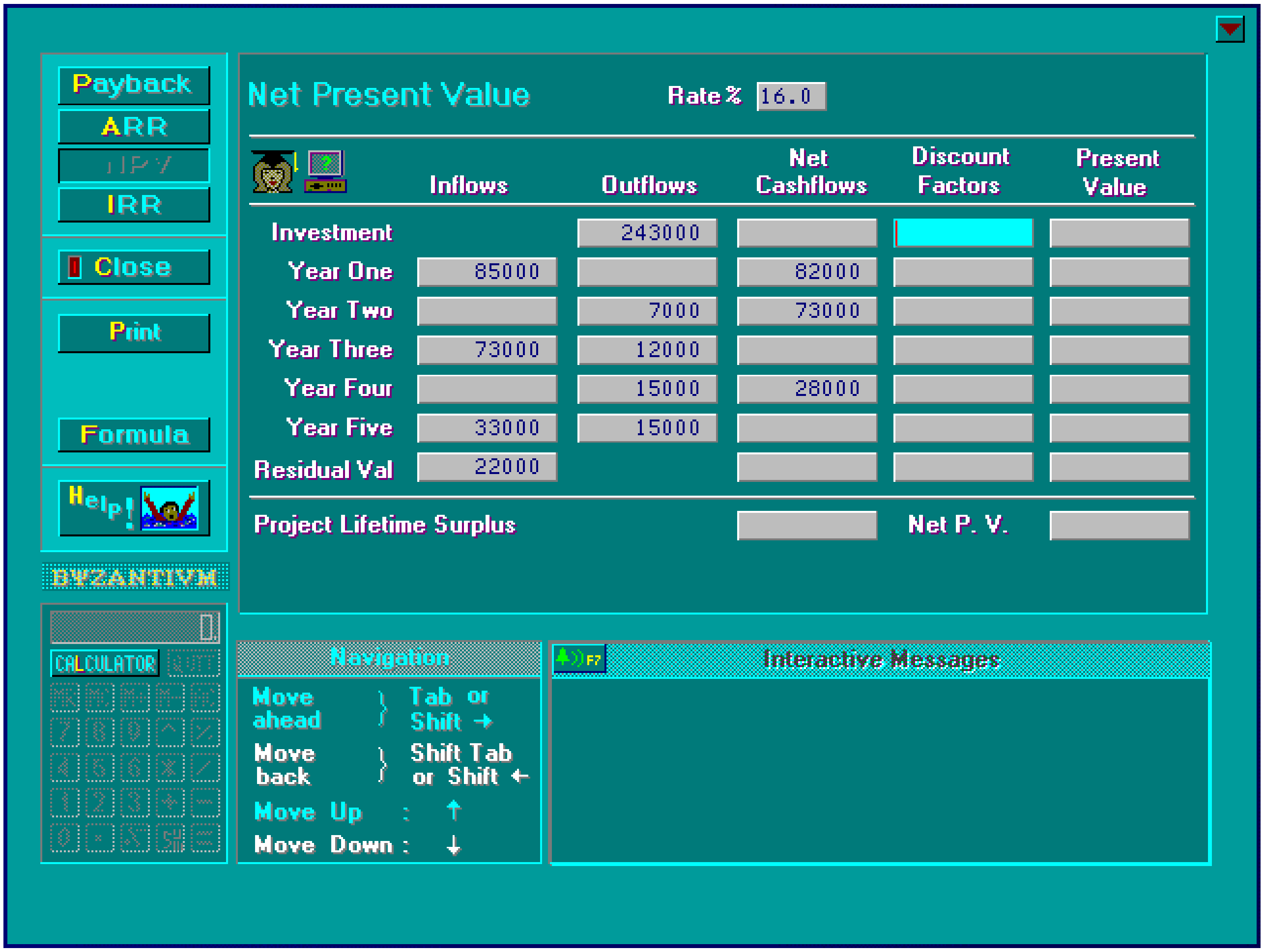

Figure 2. Example of a problem screen from Capital Investment Appraisal package

2 shows an example of one of the four problem screens in the Capital Investment Appraisal module. The screen

shows some values already assigned by the teacher and these values are sufficient to derive rest of the values on the screen (and on other screens related to payback, ARR and IRR techniques, for that matter). The interface of the problem screen uses “fill in the blanks” metaphor by providing some empty and other filled containers related to the domain concepts. Since throughout the schooling process, the learners are extensively exposed to the “fill in the blanks” metaphor, the empty containers are perceived as a challenge and the learners are well motivated to solve the problem.

The learners at this stage are supposed to deal with closed ended problems where the problems are well defined and the only task remaining for the learners is to apply the learnt concepts. The system monitors the learners’ interactions with the system and observes the learners’ problem solving approach. Whenever the learners make mistakes, the system intervenes and recommends the learners either to revisit observation stage for better acquisition of concepts or to go to a fine-grained interface if that is available for the erroneously understood concept. In the fine-grained interface, the learners (and the system) can easily pinpoint the exact place of erroneous or missing knowledge.

For example, if the learner enters an incorrect value for a discount factor (figure 2), the system informs that it is incorrect and advises the learner to use the fine-grained interface shown in figure 3. The fine-grained interface can be called up using the ‘Formula’ button on the control panel. If the learner still has difficulty in understanding the concept of discount factor, the system provides a fine-grained descriptive explanation with an example as shown in figure 4, accessible through the 'Explain' button. The tutoring on the finer details is necessary until the learners internalise these concepts and are able to process them more efficiently in their minds. Beyond this point, it causes boredom if they are forced to use the fine-grained interface. The Byzantium ITS therefore does not force the use of the fine-grained interface as a routine. It only recommend the learner to use the fine-grained interface when the learner has difficulty in problem solving at coarser level, although the learner can use the fine-grained interface explicitly even without system's recommendation.

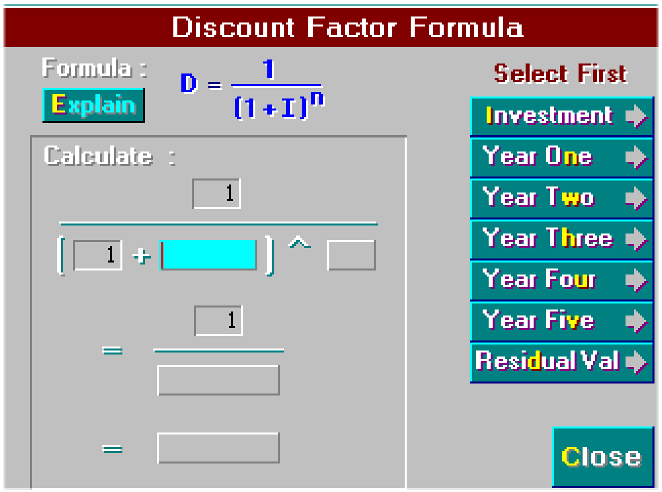

Figure 3 Fine-grained interface for discount factor in Capital Investment Appraisal package

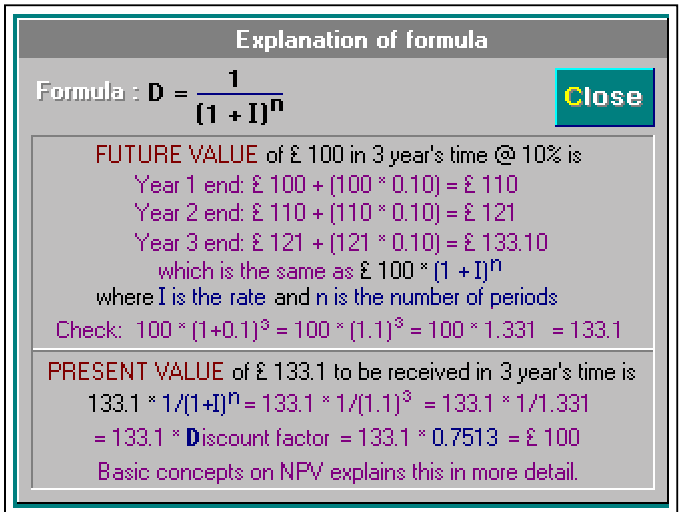

Figure 4. Fine-grained descriptive explanation for discount factor in Capital Investment Appraisal package

Advanced Imitation

This stage is similar in structure with simple imitation stage, but the focus of this stage is more contextual. In this stage, it is assumed that the learner possesses the conceptual knowledge and basic skills of the domain and is ready to apply them in various contexts, but has not yet achieved the competence where these skills can be used for real life problems.

At this stage the learners encounter problems created by teachers presenting different contexts. The teachers are provided with facilities to generate various real life scenarios as templates of problems and the focus remains on application of concepts in different contexts. An example of such facility is available in the Absorption Costing module. The teachers can specify various qualitative and quantitative values to create a replica of real world scenarios. Once they save these scenarios, they can create a number of problems based on any of these scenarios and save the problems for learners' use. The scenarios provide functionality similar to templates available in standard word processors.

Contextual Observation - Bridging the Conceptual gaps

While attempting the problem solving in simple and advanced imitation stages, the gaps and areas of misconception in learners' achieved domain competence are identified. In such situations, it is possible for the learners to refresh the knowledge of the concepts or to bridge the gaps in the conceptual knowledge by returning to the *basic concepts* through the *help* button. The *help* button takes the learners to the relevant part of the observation stage. These subsequent returns to the observation stage are in the form of focused query and therefore provide a deep learning experience. Such revisits of observation stage are not mandatory for the learners. The learners have an equally effective alternative of attempting to 'figure out' the situation from the name tags of the conceptual components employing natural intelligence. The "context based help system" of the Byzantium ITS supports the learners in this process. The learners get a feedback of best suitable relationship in the current context and they at this point can explicitly invoke a "why" window which explains the suitability of recommended relationship with example based on current situation. This process also provides a deeper learning experience. Currently the "why" approach is still being fully developed.

Interpretation of Real Life Problems

This stage is meant to prepare the learners for real life situations where the problems are not clearly stated and interpretation of problem statement (problem formulation) is also a part of problem itself. The learners are supposed to decipher not only various useful information from the available data but also the goal of the problem. Then the learners need to plan the problem solving approach to reach to the solution. In the process, the learners are also supposed to identify the superfluous information (current prototypes lack this feature). This stage requires not only the application of already learnt concepts in different contexts but also to generalise the contextual information to figure out which techniques of domain competence are relevant in particular situations.

The learners at this stage encounter the problems in narrative form. The teacher's model answers for the problems held with the assessment analysis facility of the environment serves as the overall (*remote*) expert model conveying the correct interpretation and the correct method while the module (*local*) expert model tests correctness of the method employed by the learners. The combination of remote and local expert models enables partial scoring for an answer based on correct method but wrong interpretation of given data. Figure 8 shows a screen-shot of the marking of an interpreted problem in marginal costing module.

Mastery in Skills (Repetitive Training)

Once the learners have successfully imitated the problem solving tasks, the Byzantium ITS provides opportunity to repeat the tasks in different scenarios so that the learners can get mastery in the tasks. The repetition process also facilitates the abstraction of the concepts related to the tasks and helps the learners to apply the abstracted concepts in situated scenarios. The Byzantium ITS supports automatic generation of problems for various predefined scenarios and hence eliminates the need for a large data bank of problems, which would otherwise be needed.

The learners are provided with virtually infinite number of different problems as required for repetitive training. For this purpose, the Byzantium ITS supports a *random question generator* which randomly picks variables for a network of conceptual objects and assigns random values within specified bounds (the generator essentially replaces the teacher's task which was necessary at previous stage, and this facilitates generation of a number of mixed complexity problems) and then derives the solution by applying its knowledge rules. Once the generator determines that the problem with feasible solution is generated, it passes that problem to the learner through the interface. In classroom based scenarios, the random question generator has a unique benefit. It provides different learners with different sets of values for independent conceptual objects even for same predefined contextual scenarios, hence enforcing any peer to peer communications to address the inter-relationships of the concepts.

Assessment (Delayed Feedback)

The assessment stage is meant for assessing the overall progress of the learners' domain competence. This stage serves both self-learning and classroom based learning. In self-learning, the learners can get analysis of their own progress, whereas in classroom based learning, the assessment stage can provide an alternative to traditional assessment methods. Since the focus of learning in the Byzantium ITS is different from traditional academic practices, the criteria for assessment is also different. The focus of assessment is on the acquisition of skills in the application of facts in different contextual and non-contextual scenarios. Emphasis is more on the cognitive skills rather than on mare acquisition of facts by heart or mechanical aspects of the tasks.

There is no immediate help available for the learners in the assessment stage. Learners are supposed to analyse the problems, design a full problem solving plan to reach the solution and provide their full solutions without any help at intermediate stages from the modules. The learners' problem solving approach would be monitored by the system. Once the learners submit their work for marking, the assessment analysis facility provides delayed feedback in two ways.

Comparative analysis of learner's solution with that of expert solution is provided. The analysis is based on the local expert models and overlay type of learner models presented in the intelligent tutoring modules. In case of narrative real life problems, an analysis of the data interpretation by the learner is also presented with the help of remote expert model.

A detailed analysis of learner's problem solving approach including comments on any sub-optimalities is provided. This analysis is made by matching the prioritised conceptual relationships in knowledge base with that of used by the learner.

Important system issues in cognitive skills acquisition

Following section provides details of how the Byzantium ITS supports cognitive skills acquisition by providing suitable interfaces, feedback/messaging mechanisms and other features in the intelligent tutoring modules.

Reducing Cognitive Load through Suitable Interface

The Byzantium ITS recommends that the cognitive load on the learner should not exceed the learner's capabilities. While evaluating the prototype intelligent tutoring modules developed under Byzantium ITS, it was found (Kinshuk, 1996) that the presentation of the problems to the learners has great impact on amount of cognitive load and hence can greatly influence the acquisition of domain competence by the learners. For example, in marginal costing module, only few concepts were involved and these concepts were closely related to each other. The whole problem in marginal costing was displayed on single screen. This facilitated the learner to visually maintain a full picture of the problem and the performance of the learner was found highest in this module.

In other modules such as capital investment appraisal and absorption costing, the number of concepts involved was very large, and the problem questions were spread out into a number of screens by breaking the problems into small parts for ease of learning. It was found in the evaluation study (Kinshuk, 1996) that the multi-screen approach increased the cognitive load on learners as they had to relate the concepts of a particular screen with the screens which were not visible. Though the values of critical concepts were reproduced on the current screen, a novice learner still had to retain a mental map of the concepts in the previous screen(s) to maintain the semantic links and had to move between the screens to refresh these links until the critical concepts were fully grasped. The evaluation study also revealed that the mental linking of various concepts from different screens also resulted in missing or wrong inter-linking of information and hence reduced the performance of the learners.

When the learners fail to grasp the inter-relationships of concepts between screens, some additional help is needed to reduce the cognitive overload. This help may take the form of graphic display of the concepts already presented in the previous screens, or as a concepts map, where the learners can refer and relate the currently presented concepts with previous screens. Some repetition of data from previous screens may also provide better understanding of the conceptual inter-relationships.

Learner-System Interaction

The tutoring strategies in the Byzantium ITS (in the stages where the environment provides immediate feedback to the learners) are applied mainly through the interface since all of the learner's interaction is through the interface, and the application of the tutoring strategies remains dependent on the information inferred about the learner from interactions. The environment supports mixed-initiative approach which also reflects in the interfaces of the modules. The learners can decide their own paths to reach the solution on the basis of their own understanding of what they have learnt. The system then infers from the learner's interactions the information about their level of domain competence and tries to identify gaps still remaining in their grasp of the subject matter. If the learner moves along the chosen path without showing any deficiencies, the system infers that the learner has correct understanding. If the learner finds it difficult to progress further and start making mistakes, the system enters into active mode and advises the learner to go to higher level of granularity where the concepts are deconstructed into their components. At this moment, the mixed-initiative strategy of the system allows the learner to take the decision as to pursue the finer granularity, or return to the original path way. The system inference is of three types.

i. Basic misconceptions, where the calculations related to particular concepts are possible from the data available on the screen, and the learner has used wrong relationships among the concepts.

ii. Missing conceptions, with the help of misconceptions, where the learner has provided wrong calculations related to a particular concept, when it was not possible to do any calculations on that concept without providing calculations related to the intermediate concepts. This misconception arises due to missing knowledge about intermediate relationships.

iii. If the learner provides wrong calculations for some complex concepts, which are in themselves an output of another set of concepts, the system infers this as a misconception and advises the learner to use finer grain knowledge. If the learner pursues finer grain knowledge through the interface, the interface then captures the learner's misconceptions in term of one or more component concepts. The system's advice regarding the misconceptions in component concepts eventually leads to rectification of the misconception of complex concepts.

Additional Features Supporting Cognitive Skills Acquisition

Two more features in the environment are being used to support the acquisition of cognitive skills, but this support is currently in the prototype form and is not fully developed.

Calculator's data ribbon **- visualisation of problem solving history**

When the learners use the online calculator to solve the problems, the attached visual "data ribbon" shows the path tracing of learner's problem solving approach. This is hoped to help the learners in pinpointing the areas of errors by tracing the history. The approach has not been evaluated yet.

Annotations **- generalisation of concepts**

The learners can attach various annotations in free text form at various points in the system. These annotations remain connected to various system parts so that they can be referred in different contexts (in different problems) to get the generalisation of concepts.

Conclusion

This paper presented an ITS for task oriented numeric disciplines with major focus on cognitive skills acquisition. The application of the environment has been tested and found useful for replacing the tutorial part of the current academic curriculum. It is envisaged that the application of this environment would bridge the gap between pure context based skill acquisition in real work environment and pure concept based non-contextual learning in academic environment.

The Cognitive Apprenticeship framework has already been used in simulation based systems, but has now been used for the first time in symbolic representation based systems for numeric disciplines. Since symbolic representation approach is equally valid for disciplines with visual concepts, further research is required to explore that possibility.

References

Berryman S. E. (1997). Designing effective learning environments: Cognitive apprenticeship models. Document no. BI-1 (brief), Institute on Education and the Economy, New York.

Collins A., Brown J. S. & Newman S. E. (1989). Cognitive Apprenticeship : Teaching the crafts of reading, writing and mathematics. Knowing, Learning and Instruction (Ed. Lauren B. Resnick), Lawrence Erlbaum Associates, Hillsdale, N. J., pp453-494.

Jamous H. & Peloille B. Changes in the French university-hospital system. *Professions and Professionalization* (Ed. J. A. Jackson), Cambridge University Press, Cambridge, 1970, pp113.

Johnson-Laird P. (1988). The Computer and the Mind. Second Ed., Fontana press, London.

Kinshuk & Patel A. Intelligent Tutoring Tools - Redesigning ITSs for adequate knowledge transfer emphasis. *Proceedings of 1996 International Conference on Intelligent and Cognitive Systems* (Ed. C. Lucas), 1996, pp221-226.

Patel A. & Kinshuk (1996). "Knowledge characteristics: Reconsidering the design of Intelligent Tutoring Systems", Knowledge Transfer (Ed. A. Behrooz), pAce, London, pp190-197.

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