The architecture of technology-assisted problem-solving packages for engineering

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ABSTRACT: Efforts to incorporate interactive multimedia simulations in the teaching of mechanical engineering at the University Tenaga Nasional (UNITEN), Kajang, Malaysia, has been initiated. In this article, the author presents an innovative approach based on the principle of Computer Aided Learning (CAL) to design and implement integrated packages known as Technology Assisted Problem Solving (TAPS) packages. The ultimate aim of TAPS packages is to coach students in a step-by-step approach to learn and solve engineering mechanics problems. In this article, the author first illustrates the architecture and key concepts of the TAPS packages followed by their contributing technologies.

INTRODUCTION

Various technologies are coming together to alter the methods used to teach students in the technical field. Multimedia has the potential to create high-quality learning environments [1]. The key elements of multiple media and user control over the delivery of information and level of interactivity can be used to enhance the learning process through the creation of integrated learning environments.

In the context of introductory courses, such as engineering mechanics, which requires students to read and understand engineering structures, such an interactive system can indeed facilitate and accelerate the learning curve by putting the entry-level transfer of information at the disposal of the student. The student can be provided with opportunities to control the pace of delivery, including the option to stop and replay portions of the lecture that seem unclear.

Although one may say that the textbook is there to serve this purpose, experience shows that most students are unable to carry this out, whether for reasons of time, motivation, ability to absorb new information from a printed medium, or others. In any case, a textbook is a mono-medium that has great difficulty in presenting moving or evolving processes.

According to Cairncross and Mannion, the design of a multimedia system must be based on the needs and interests of learners [2]. Interactivity in learning applications merits more detailed investigation and the issue of how best to design learning activities that engage the learner needs to be addressed.

In order to address these issues, an innovative approach based on the principle of Computer Aided Learning (CAL) to design and implement integrated packages known as Technology Assisted Problem Solving (TAPS) Packages is presented here.

The theory and principles of CAL has been well defined in ref. [3]. The preliminary work consist of an architecture to develop a TAPS package to facilitate and assist mainly engineering students in the hope that they will be able to comprehend and gain a better understanding of the subject matter.

TAPS: A NEW APPROACH TO LEARNING, VISUALISING AND PROBLEM SOLVING IN ENGINEERING

TAPS packages are specialised computer programs developed to work as standalone (PC-based) or with Web servers that can supplement student learning, and facilitate revision, laboratory experiments and self-study. In this article, the term *TAPS* is used to represent interactive multimedia CAL in which the student is engaged with a computer tutor in the problem-solving task of the subject matter. TAPS packages offer similar pedagogic values as an experienced human tutor, with the added advantage of guiding students to solve engineering problems in a more flexible mode, ie students have the freedom to work on the problem at their own pace, repeat all or certain steps, spend more time at each or particular step until they are able to understand, and solve the problem. The objective of these TAPS packages is to improve students' understanding of the selected engineering problems by guiding and presenting the problem-solving steps accordingly. The ultimate goal is to instil a sense of independent learning, encourage critical thinking and promote deep learning. TAPS packages include the use of computers to provide most aspects of instruction that a classroom instructor could provide, such as tutorials, questioning, feedback contingent on answers, analysis and testing.

TAPS packages also employ a variety of multimedia elements, such as text, 2D animated and still graphics, 3D animated and still geometric models, audio, video and animations, stereoscopic images, and simple artificial intelligence

techniques to develop individualised computer-based learning environments in which the student and computer tutor can have a flexibility that closely resembles what actually occurs when a student and a human tutor communicate with each other. Such suppleness is important because without it, the package cannot be fully adaptive to the individual student's ongoing learning and problem-solving needs during instruction.

KEY CONCEPTS IN A TAPS PACKAGE

There are a number of key concepts that can be applied in the development of a TAPS package. Some of these are similar to Intelligent Tutoring Systems (ITSs) whereby a computer tutoring system incorporates aspects of intelligence, particularly an assessment model (used to monitor the performance of students), and domain knowledge representation. In a TAPS package, these concepts can be divided into three main categories, namely: learning scenarios, knowledge representation and assessment modelling.

A learning scenario is a situation in which the student's learning takes place. When implementing a TAPS package, the criterion for determining the most appropriate learning scenario is based on the interaction required between the student and the computer. The learning scenario selected will therefore be dependent on the type of information to be delivered to the student during the tutoring session, the amount of knowledge the student is expected to gain from completing the problem-solving tutorials and, to a certain extent, on the knowledge base of the TAPS package.

In general, most computer-based tutoring packages are implemented using one of the three learning scenario categories. The most common learning scenario category to be implemented is the explanation of theoretical concepts to the student. In this scenario, the TAPS package must convey predefined knowledge to a student in ways that maximises his/her understanding of the concepts being taught. This is the simplest learning scenario to implement as the main challenge of developing the TAPS package is ensuring that more precise information is presented at the correct level of detail for students to comprehend and learn.

The second learning scenario that is commonly employed in computer-based tutoring packages is the simulation of real-world tasks on a computer. These tasks include the detailed operation of a specific component or the simulation of the process that the student is expected to perform in the future. In any event, the learning scenario must deal with simulating the appropriate real-world properties as accurately as possible on the computer. This is a difficult requirement to implement successfully as the TAPS package must both simulate the process as realistically as possible, as well as have the pedagogic ability to explain the process to the student in the best possible way.

In general, the most difficult learning scenario category to be implemented in a computer-based tutoring package is the discovery of knowledge through investigation and exploration. In this third learning scenario, the student is required to participate actively in the learning experience by manipulating the package and observing the direct response to the student's actions.

The knowledge representation component of a computer-based tutoring package can be divided into two categories, namely:

domain knowledge and pedagogical knowledge [4]. Domain knowledge involves issues in the representation of knowledge and refers to the facts, figures and interrelationships between various objects in the domain. Pedagogical knowledge is the sequence of instructions that a computer tutor uses to carry out various tasks in operating a system. Therefore, pedagogical knowledge involves the finding of techniques to solve particular problems. The knowledge components of computer-based tutoring packages contain definite information content and structure, as well as procedures for accessing and utilising the information [5].

In terms of domain knowledge, one of the major limitations with conventional computer-based tutoring packages is that they have a poor structure of knowledge of their domain in the database. The tutoring session typically consists of the presentation of information, problems with which to test the student's knowledge, answers to these problems and, at best, pre-specified branches based on the student's results obtained in the test.

Rickel noted numerous disadvantages with these computer-based tutoring (CBT) packages as summarised below:

- The CBT package is unable to adapt to the requirements of the student;
- There are no facilities with which to assess the student's true misunderstandings;
- The pre-specified branches prevent the CBT package from handling unanticipated answers;
- Pre-specified answers leave the CBT package with no criteria for judging student responses other than correct or incorrect [6].

If human tutors are expected to possess a great deal of domain competence, then this should be the ultimate challenge for TAPS packages.

DOMAIN KNOWLEDGE

The domain knowledge component of a TAPS package should incorporate the necessary information so as to correct the above limitations. This implies that the TAPS package should contain an extensive knowledge database and have the ability to filter out the course material that is not directly relevant to the student. In addition, the TAPS package should have the ability to interact with the student in the same manner as a human tutor. Interaction is perhaps the most difficult part of TAPS package design. A good TAPS package should be able to answer course-related questions asked by the student, as well as present summaries and overviews whenever these are required. Furthermore, the TAPS package should know when and how to present the student with information and be able to determine immediately whether the student has understood this information or not. A good TAPS package should constantly monitor the student and have the ability to automatically offer explanations to match the student's current level of understanding.

The domain knowledge component of a good TAPS package requires a great deal of intelligence and effort to implement successfully. In general, it is for this reason that to date, no computer-based tutoring package has been commercially developed and fully accepted by learning institutions. Even if such packages exist, these packages may be used only for a short period of time. Therefore, it will probably take many

years of research in the field of Artificial Intelligence (AI) before an intelligent computer-based tutoring package could be successfully developed. Currently, when developing a TAPS package, it is necessary to compromise on various aspects of the domain knowledge component in order to ensure that a simplified advanced computer-based tutoring package can be physically realised [7].

PEDAGOGICAL KNOWLEDGE

Pedagogical knowledge is an essential component of a TAPS package. Although the domain knowledge component is responsible for filtering useful information from the vast knowledge base, the pedagogical knowledge part is responsible for relating this information to the student. The pedagogical knowledge component decides how to interact with the student, when to interrupt the student and how to address the student while he/she is using the tutoring package.

Although the pedagogical knowledge component is burdened with many responsibilities, the most important of these is determining a strategy to deal with a student's errors. Since students are seldom consistent, a computer tutor cannot simply provide correct answers to a student's mistake. When a student makes a mistake, the TAPS package must select between ignoring the error, pointing it out, correcting it or somehow guiding the student towards recognising the error and correcting it without the explicit help of the computer tutor.

There are numerous trade-offs in correcting a student explicitly, trying to entrap the student into discovering the error without the help of the computer tutor, or simply allowing the student to view the consequences of any mistakes made.

THE ASSESSMENT MODEL

The assessment model is a dynamic model of the student's knowledge and capabilities that is maintained and constantly updated by the computer-based package. Its purpose is to evaluate and account for the student's actions and responses. Human tutors do an excellent work on moderating students' answers in the context of their assumed level of understanding and past learning behaviour, thus effectively adapting their instruction to students' competences and abilities. Although adaptation to students is almost second nature for human tutors, it is an extremely difficult characteristic to implement in a TAPS package.

The function of the assessment model is to provide the student with feedback by comparing the student's actions to those prescribed by the TAPS package. This feedback is used to inform the student which actions are correct and which are incorrect. In this way, the student receives tuition while interacting with the TAPS package.

Conventional (classroom) assessment could occur through a variety of methods, for example quizzes, examinations, oral tests or homework. However, the most common technique used to assess the student in computer-based tutoring package is the assessment of the number of correct and incorrect answers upon completion of a course topic. Adaptation to the student's level of understanding is usually limited to the presentation of pre-specified course material based on the student's responses to the questions of the test. Most available conventional computer tutoring packages do not have the ability to keep track of the student's insufficient knowledge, except at a very

basic level. For current tutoring packages, the assessment model will have to be greatly simplified so that it may be practically realised.

The student assessment model represents an overview of the student's capability levels. There are a number of fundamental rules that should be adhered to when developing an assessment model in a TAPS package. These can be summarised as follows:

- The model must be able to represent knowledge, concepts and skills;
- The model must include knowledge that the student has acquired, and which the student has been exposed to and shown some understanding;
- The model must be able to represent the student's misconceptions;
- The model must be able to include a history of the student's problem-solving performance.

CONTRIBUTING TECHNOLOGIES

There are various technologies that have – and will – contribute significantly in the development of TAPS packages now and in the future. It is assumed that with the current level of progress in the field of computer hardware and software, most of these contributing technologies could dramatically change the environment of TAPS packages. Although computer hardware is a contributing technology in itself, technologies that are of greatest interest are those of multimedia and Virtual Reality (VR). Each of these is briefly described below.

MULTIMEDIA

Cairncross and Mannion described three main attributes of multimedia applications, ie multiple media, interactivity and delivery control [2]. These attributes can be further shown with their sub-functions or properties as shown in Figure 1.
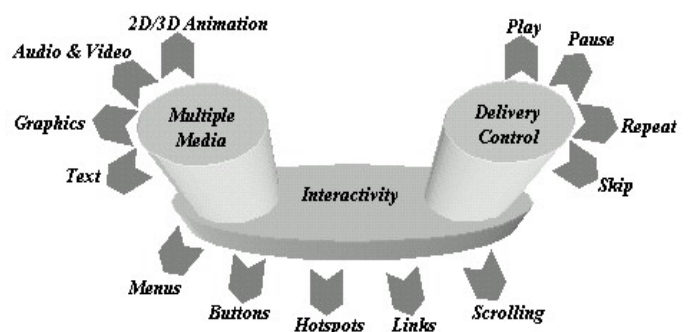

Figure 1: Key attributes model of multimedia.

According to this model, a given piece of information could be delivered using one or more media element. For example, an image can be used to illustrate a text-based description. The information originally presented on screen can be supplemented by the use of audio, video and pop-up boxes. Thus, multimedia has the ability to support multiple representations of the same piece of information in a variety of formats.

The non-linearity offered by many interactive multimedia learning applications provides a learner/user with greater navigational freedom. Users may go to any section in a multimedia tutorial and in any order [2]. Dynamic media such

as video and audio can be controlled, ie pausing, playing and repeating clips.

Another attribute is interactivity. Interactivity in multimedia-assisted learning applications should go further than simply allowing a user to choose his/her path, and pointing and clicking at various menus and buttons. Most multimedia applications provide some interactivity in that it responds to user instructions. What makes the difference, even in simple educational software, is whether the software allows the user to work at his/her own pace, in the order desired, repeating sequences at the user's will, manipulate virtual objects on screen, and the simulation of experiments or industrial processes [2].

VIRTUAL REALITY

Virtual Reality (VR) is a remarkable technology that allows three-dimensional artificial worlds to be created on a computer. What makes this technology unique is that it is possible to move about and interact within these artificial worlds in a way that allows all navigational and manipulative movements made by the user to be emulated in this computer-generated environment [8]. This is accomplished using immersive VR input devices, such as the Head Mounted Display (HMD) and data glove. Using this equipment, the user believes that he/she is actually immersed in this artificial world.

On the other hand, there are also Desktop Virtual Reality (DVR) applications that do not require expensive hardware equipments to be used. DVR requires a PC or laptop, some specialised hardware such as a 3D graphics card, 3D sound card, a 6D tracker, a joystick, and software that displays and permits navigation in virtual environments such as *Cortona*™ and *Cosmo*™ viewer, and *Macromedia*™ *Shockwave*. The delivery control features of DVR, as shown in Figure 2, are an extension of the key attributes model of multimedia shown in Figure 1. These new features enable the user to move along any direction on the screen, and have the object displayed continuously and updated instantaneously. Therefore, the user could gain a greater understanding of a given problem. In terms of cost, DVR is cheaper than immersive VR systems.
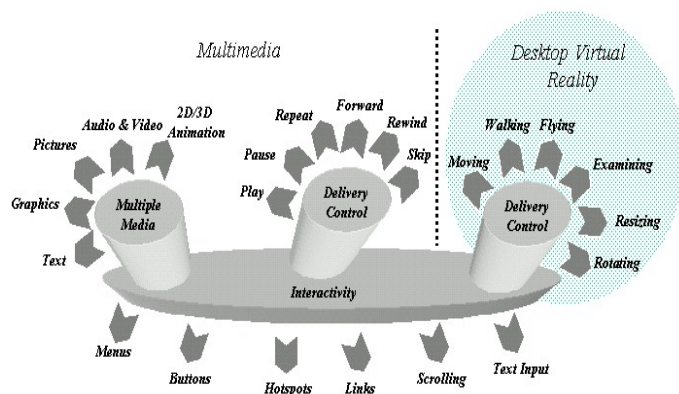

Figure 2: Extended key attributes model of multimedia and DVR.

It can be anticipated that VR will be one of the key technologies to influence TAPS packages in the near future. With constant developments and improvements in the field of computer hardware and software, it will eventually be possible to create immersive VR TAPS packages at an affordable price. Such packages could help students learn and understand better,

ie if an environment responds realistically to various inputs given by the student, then the student can observe exactly how the system functions in reality.

CONCLUSIONS

In conclusion, interactive multimedia CAL has great potential and has been widely used across a wide range of courses to promote learning. However, due to the different nature of each field of study, the degree to which computers can be used in teaching varies greatly.

In this article, the author presents an architecture to design and implement Technology Assisted Problem Solving (TAPS) packages and the contributing technologies. The design of a TAPS package requires various key components to be successfully integrated. These include the appropriate choice of learning scenario, comprehensive domain and pedagogical knowledge components, and a dynamic student assessment model. With these components firmly in place, the TAPS packages should have the ability to present relevant course materials at a level of detail ideally suited to the individual style of learning. In addition, the TAPS packages should be able to constantly assess the capabilities of the student and provide adequate feedback throughout the problem-solving process. A good TAPS package demands a great deal of computer intelligence to be incorporated into the problem-solving package. Presently, it is not possible to represent all the characteristics of a human tutor in TAPS packages. Consequently, it is permissible to compromise on the knowledge representation of a human tutor to a certain extent in order to produce a tutoring and problem-solving package that can teach students in a more effective manner than other existing CAL packages.

ACKNOWLEDGEMENT

REFERENCES

1. Cairncross, S. and Mannion, M., How multimedia functions in engineering. *Engng. Science & Educ. J.*, 8, **3**, 100-107 (1999).
2. Cairncross, S. and Mannion, M., Interactive multimedia and learning: realizing the benefits. *Innovations in Educ. and Teaching Inter.*, 38, **2**, 156-163 (2001).
3. Kinshuk, R., Computer Aided Learning for Entry Accountancy Students. PhD thesis, De Montfort University (1996).
4. Burns, H., Parlett, J.W. and Luckhardt Redfield, C., *Intelligent Tutoring Systems: Evolutions in Design*. Hillsdale: Lawrence Erlbaum Assoc., 1-11 (1991).
5. Chu, R.W., Mitchell, C.M. and Govindaraj, T., Characteristics of an ITS that evolves from the tutor operator's assistant. *Proc. IEEE Inter. Conf. on Systems, Man and Cybernetics*, Cambridge, USA, 778-783 (1989).
6. Rickel, J.W., Intelligent computer aided instruction: a survey organized around system components. *IEEE Trans. on Systems, Man and Cybernetics*, 19, **1**, 40-57 (1989).
7. Manjit, S.S., Development and Applications of Technology Assisted Problem Solving (TAPS) Packages for Engineering. PhD thesis, University of Malaya (2006).
8. Pimentel, K. and Teixeira, K., *Virtual Reality – through the New Looking Glass*. New York: McGraw-Hill (1993).