EXPLORING THE STATE OF THE ART: SURVEYING THE RESEARCH LANDSCAPE

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ABSTRACT
This paper presents a high level review of the fields and techniques that researchers and practitioners can draw upon to extend learning technology state of the art. The paper begins by describing some of the disciplines that researchers can use to inform the design of their systems. This is followed by an overview of one of the key research approaches: development through engineering. A key aspect to engineering is considered to be evaluation. The importance of the engineering and practitioner case study is also outlined. The final section addresses the issue of technology standards and how they can influence the design and implementation of systems. It is concluded that there is no single 'grand theory' of CBT system design. Instead there are number of different disciplines and methodologies that can be used together to create usable and successful educational systems.

KEYWORDS
CBT software design, research approaches, methodology, software engineering, case studies.

INTRODUCTION

The development of educational software occurs through a cycle of dissemination, evaluation and improvement. This process can be broadly described as 'development through engineering'. The first section of the paper outlines a number of disciplines that can be used inform the design and development of computer-based training systems. The next section describes the engineering process. During the process details of systems are published to allow other researchers to review and evaluate innovations. The evaluation activity is an important one, enabling existing systems to be improved and new systems to be proposed and developed.

The two final sections briefly explore the importance of case studies and learning technology standards. Case studies play an important role in communicating how technologies can be used within a particular situation. The final section discusses increasing influence of educational technology standards such as the SCORM and IMS and the role they can play in the development of CBT systems.

Throughout this paper a small number references to earlier CBLIS research papers are made. These references represent the different research approaches that can be adopted to further extend our knowledge of how to design, build and apply CBT systems.

DISCIPLINES

CBT system design and implementation, like other forms of engineering is, by its nature, interdisciplinary. Engineers need to have understanding design and development approaches, know how to determine whether their artefacts are successful, and have a comprehensive appreciation of the needs of end users. This section presents a snapshot of some of the disciplines that are key to the development of effective CBT systems. It should also be noted that a developer (or development team) should have a full appreciation of the discipline that their system intends to *teach* and an understanding of the set of educational practices that a discipline adopts.

Educational Psychology

Educational psychology is the study of learning and teaching. Like many academic disciplines, educational psychology has a number of schools of thought. These broadly include a behaviourist perspective, a cognitive perspective, a social cognitive perspective and a constructivist perspective (see Brousseau & Carrier, 2003). Adhering to one or the other school can substantially influence the way that education is offered to students, and how learning technologies are designed and applied. Computer technology may present learning problems to students in the form of quizzes or may attempt to engage students in exercises that intend to enable students to use their previous knowledge to help create new knowledge.

Two fundamental questions of this area of study include 'what helps people to learn?' and 'how do people learn?' From the educators perspective an important subjects is instructional design. Instructional design concerns how learning material can be efficiently presented to learners. One approach to instructional design is to divide learning material into sets of discrete learning objectives which in turn can direct the creation of learning material and assessments. Learning objectives can be mapped to Bloom's famous taxonomy (Bloom, 1956). This taxonomy has, in turn, influenced the design of contemporary educational systems (see Fursenko et. al, 2005).

Each learner is unique. Educational psychology also explores how to address differences between individuals such as whether learners are perceived to use particular learning styles or have particular educational needs. One notable area of difference is motivation. Motivation is considered to play a significant role in predicting educational success. A number of theories and models of motivation have been presented which go some way to explaining its influence (Weiner, 1992).

There exists substantial interplay between the fields of educational technology and educational psychology. It must be stated that whilst the technology and presentation approaches may change, the central issues of presentation effectiveness and student engagement continue to remain paramount.

Interaction Design

A successful CBT system must be usable. The discipline of Interaction Design (formerly HCI) describes approaches and techniques that can be adopted to create 'easy to use' and 'easy to understand' systems. Interaction Design does not constrain itself to desktop systems but extends the notions of usability to mobile and ubiquitous devices. Methodologies for the design of usable systems include paper prototyping and the application of expert heuristics to ensure that usability issues are discovered during the early stages of system development.

Cognitive Psychology

Cognitive Psychology concerns the study of mental processes. These include the study of memory, attention, language and problem solving (Eysenck & Keane, 1995). Ideas from cognitive psychology are adopted within the fields of Educational Psychology and Interaction Design. Interaction Design contains a number of design principles that are drawn directly from cognitive psychology. A fundamental understanding is that users (students or tutors) have bounded rationality (or limited processing capacity). Two simple principles of interactive systems include: avoid the use of gratuitous animation since these may direct attention away from key facts; do not design a system that forces a learner to remember a series of complicated operations, thus putting strain on the user's short-term working memory.

The research processes used by cognitive science, a sister discipline to cognitive psychology, are also influential. When considering the area of language processing researchers may draw rough 'box and arrow' models. These models can be explored either through direct experimentation using real subjects to test the validity of their systems, or through the construction of computer simulations. The act of constructing simulations may add evidence and may enable theoretical assumptions to be expanded. Again, we step towards the idea of engineering or building systems.

Social Sciences
CBT systems are designed by people and for people. CBT software may be designed for a learner working alone, perhaps reviewing learning material or taking a test. Alternatively CBT software could be used by groups of users. New technology may be able to facilitate new forms of communication. The social sciences, such as traditional psychology and sociology provide researchers with methodological tools to further understand the impact of new technologies amongst a group of students. Qualitative research approaches offer researchers to ability to capture rich data sets that may inform the design and construction of educational tools.

Software Engineering and Computer Science
Understanding Computer Science (CS) and Software Engineering (SE) is necessary to successfully build effective CBT systems. These interrelated disciplines inform designers what may and may not be technically possible. SE describes software construction techniques, such as Test Driven Development and phased implementation. CS, on the other hand describes programming languages, database systems, communication protocols and software architectures.

DEVELOPMENT THROUGH ENGINEERING

The word engineering often makes us consider physical artefacts such as bridges, roads and trains. These familiar constructions may have been *built by engineers* using the *process* of engineering. The word *engineering* originates from the Latin word *ingenium*. This means that an engineer is, in essence, someone who constructs useful devices or systems. CBT systems can be built or *engineered* by instructional designers, software developers and educators. Developing and deploying a successful CBT system is considered to be intrinsically an *engineering* exercise.

There are two main ‘development through engineering’ approaches. The first technique can be described as simply a *description* of a new technology. The second technique may also describe a technology but combine description with *evaluation*. Within the academic community description primarily occurs through publication. A formal publication through an academic journal or conference may detail how a particular system has been designed and argue that a particular technology may allow a new form of educational practice to be established. This is evident with discussions surrounding the notion of 'm-learning' (mobile e-learning), or concepts such as digitally recording lectures allowing students to play them back during exam preparation. Publication of engineered systems allows the authors to describe a technology and also the problems that have occurred during the *process* of engineering. These experiences are read by other practitioners and engineers who in-turn can add their own ideas to develop alternatives enabling create stronger, better and more usable educational systems to be created.

As suggested earlier, learning technologies are subject to the forces of improvement and enhancement through evaluation activities. Evaluation is the process of determining whether systems satisfy all the requirements they have been designed to satisfy. In the context of computer-based learning, a fundamental question might be, ‘does this technology enable students to learn a particular principle?’ There are a large number of corollary questions that might be asked, such as ‘do the students and the tutors enjoy using a particular technology?’ or ‘is a technology cost effective to use?’ and ‘can a technology be easily deployed within a class room?’

A number of different approaches can be used to answer these questions. One strategy is to adopt qualitative methods such as those used by Pasek & Wright, (2005) who used journals, interviews and meetings with a small number of participants to explore what teaching strategies teachers adopt when using physics simulations. The results from the research yielded a collection of qualitative statements about what may influence the adoption of simulation, and an understanding that collaboration between individual teachers may allow for the development of teaching strategies.

7A different approach is to use a quantitative approach. Zacharia & Evagorou (2005) used a traditional laboratory study comprising of a large number of undergraduate students to determine whether there is any difference of students understanding when using real versus simulated (or virtual) laboratory instrumentation. This research attempts to answer a profound question regarding the efficacy of a particular educational approach and has resonance with several of the disciplines described in the earlier section. In this case, the virtual instrumentation enhanced the students understanding of a particular electrical rule, but like with any quantitative study, replication is necessary to further substantiate the finding and explore experimental variables such as the particular set of virtual instruments that were tested.

The choice of pedagogic approach that a system may adopt may affect the form of data that can be captured during an evaluation. This can strongly influence the evaluation methodologies that can be selected.

LINKING SCIENCE WITH ENGINEERING

It was suggested that engineering was a *process*, that engineering is something that engineers *do*. An engineer strives to create the best possible solution to a problem whilst understanding that anything that can be built (or engineered) can also be subject to failure. After designing and building a product an engineer may test an artefact to destruction to ensure it performs satisfactorily across *all* operating conditions. If a failure occurs an engineer is likely to determine what has gone wrong and devise a correction, often by making a change to an existing design.

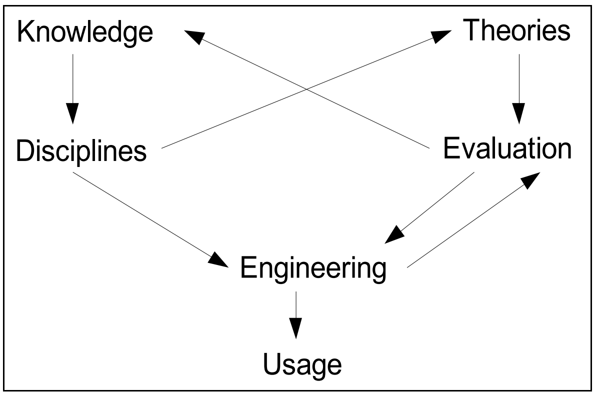

Figure 1. Links between Engineering and CBT

Engineering is connected to science in many ways, but let us consider two. Firstly, engineering can be defined as the *application* of science to achieve something useful. Science, in this context, refers to the research outputs from the disciplines that were outlined earlier. Another connection between science lies with the activity of evaluation. Scientific theories need to be evaluated rigorously before they can be accepted. In the world of engineering, constructed artefacts can be considered, in some senses, to be a physical manifestation of a *theory*. This means that the artefact should perform the same actions that the engineer predicts it should carry out. If a system breaks down, an engineer may use a scientific process to uncover what went wrong. An engineer may construct a series of hypotheses to attempt to explain a failure. When satisfied with a potential explanation an engineer may then attempt to perform an experiment to replicate the failure, to 'add evidence' to the theory why a failure occurred.

Figure 1 illustrates some of the links between the activity of engineering and learning technology. The 'usage' label describes the output of the process – software technology that a student or tutor uses. Domain knowledge is shown to be a significant influence to the engineering process. A loop between the evaluation and engineering activities represents iteration, a key part of the Interaction Design process described by Preece et. al. (2002).

EVALUATING THE PARTS

A CBT system can be a very complex artefact. It may apply knowledge from one or more disciplines, present information in a unique way and require users to engage in a set of potentially difficult learning activities. Due to the number of variables that may effect an evaluation, understanding the system as a whole may become very difficult. To create further insight into the benefits of a system it may be necessary to apply Occam's razor to determine whether the most important or salient aspects of a system can be studied on their own.

A good example of this can be seen in the carried out by Hench (2005). Rather than asking whether on-line or computer presented tests can help the student to learn, Hench asks the important question of whether on-line tests are *equivalent* to traditional proctored tests.

Other evaluation questions attempt to understand how students can best find their way around a training system. Again, rather than attempting to understand whether a whole system can be navigated easily, Shneiderman presents a series of studies that aimed to explore the seemingly simple question of which is easier to navigate: highly categorised or 'deep menus' or wide and 'broad menus' (Shneiderman, 1998).

An example that is more relevant to CBT systems can be seen in the work carried out by Parsons. Parsons attempts to answer the seemingly innocuous question of whether students find long pages that scroll over the bottom of a screen more difficult to read than pages that are presented over a number of discrete pages. Parsons attempts to answer this question through a series of experiments that use reading comprehension tasks (Parsons, 2001), with the underlying understanding that reading efficacy is directly connected to learning efficiency.

CBT technology development occasionally requires researchers to 'think outside of the box', or more precisely, 'outside of the virtual learning environment' or 'simulation environment' to answer the more difficult questions. Sometimes the activity of studying parts of a system in isolation can allow us to begin to appreciate some of the more subtle difficulties that users can be faced with.

PRACTITIONER CASE STUDIES

CBT systems are tools. These are often used in conjunction with formal courses and blended with face-to-face teaching. An aspect of the CBT research landscape that sits alongside the engineering research is the notion of a 'case study'.

A case study is familiar to practitioners of medicine, particularly domains such as neuroscience. Case studies are also used within engineering. They can be used to illustrate the successful adoption of a manufacturing or software development process, for example. In the context of CBT systems, a case study can be used to describe how a particular technology can be used within a classroom or laboratory.

As well as describing technology successes or failure, case studies can be used to present individual experiences of educators who use CBT systems 'in the wild'. A case study allows practice experience to be distilled and communicated to peers. These studies represent a dialog that enables the useful aspects of learning technologies to be clearly exposed and problems efficiently presented to an interested audience. In turn, experience can be used to inform system design that can influence the state of the art.

Barker presents some of his experiences whilst teaching and assessing writing skills on two Open University courses (Barker, 2005). The reflections offered allows can fellow practitioners to understand their own experiences in greater depth, perhaps allowing new uses of technology to be discovered that were otherwise unappreciated.

It must be noted that the distinction between a case study and an evaluation study that adopts qualitative techniques can sometimes become blurred. A qualitative evaluation can be described as a rich study of a particular system or group of systems. A case study may represent a concise set of experiences. Case studies have the potential to explore wider issues that a constrained qualitative study may not. A single case study may have limited impact but if combined with others, the argument for the exploration of specific issues regarding the use or design of CBT systems may become stronger.

STANDARDS AND INITIATIVES

Engineers sometimes find themselves solving similar problems. A standard is essentially description of a solution to a problem that others can adopt. One of the advantages of standardisation is that a solution designed for one system may become compatible with others. This, in turn, may allow systems and learning materials to work together in ways that were previously impossible.

In traditional engineering the physical are often described in terms of specifications or industry standards. Components can be used together to form sub-assemblies. Without standardisation an engineer would have to continually change his or her tools. Lack of standards may reduce an engineer's problem solving ability since lower-level problems may have to be solved on many different occasions, increasing the cost of solutions. In recent years, much work has been carried out to develop educational technology standards. This can be seen by the work published by the ADL and IMS initiatives[1]. It is important to state that a standard will only succeed if it is implemented or used by learning technologists. Examples of usable implementations of some international learning technology standards can be seen in work by Douce, (2005) and many other VLE systems such as Blackboard and Moodle[2]. The engineering approach to development enables learning technology standards to be implemented, tested, verified. Any difficulties found during implementation and evaluation can be communicated to standard bodies that can benefit a wider community of learning technologists.

SUMMARY

There is no single model that can describe the development of computer-based learning systems. The development and enhancement of the 'state of the art' relies on both the application of knowledge from other research areas and execution of careful evaluations to determine whether engineered systems solve the problems they set out to solve. Extending 'state of the art' also relies on listening to those who use CBT technology. This may take the form of sets of practitioner case studies or rich qualitative evaluations. If a learning technology makes use of a particular pedagogic approach and it is shown that the users of a particular system learn effectively, it could even be argued that a system may 'adds evidence' or 'adds weight' towards a particular theory.

The computer-based learning research landscape is wide. It encompasses many disciplines and uses a number of different methodological approaches. The field of computer-based learning facilitates:

- The development of new learning technologies by the process of engineering.
- The study of learning and educational theories.
- The running of structured evaluations to determine the effectiveness of learning systems.
- Dividing larger 'innovations' into smaller units that can be studied independently, potentially allowing separate theories or models to be established.
- Informing development and engineering practice (such as human-computer interaction).
- Adding to the body of knowledge of related disciplines.
- Learning about the individual tutor and learners view of particular technologies

[1] http://www.adlnet.gov, http://www.imsproject.org
[2] http://www.blackboard.com, http://www.moodle.org

- Adoption and criticism of standards.

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