A more open curriculum and a new organization of education are needed to take full advantage of the opportunities and avoid some of the difficulties when using expert systems in education.

This paper summarises experiences from a number of projects where students use expert systems or try to develop expert systems of their own in different knowledge areas in school. Results from different projects show that the students are motivated and stimulated when going deeper into a given knowledge area, they seek knowledge inside and outside the school, from teachers and others. However, school resources as well as the curriculum and time itself often constrain the exploration of new areas of knowledge. On the other hand it could be difficult stopping students and persuading them to return to their normal school work. Demands are imposed on teachers which often require an increase in their knowledge and skills if they are to have full control over the learning process. Most fundamentally there is a lack of clear strategies as to how students should 'attack' new areas of knowledge.

INTRODUCTION

The purpose of educational aids is to improve and make more efficient the teaching-learning process. Computers as a type of educational aid are also intended to fulfil this purpose even though they have sometimes been wrongly used, i.e. where the sole purpose has been to replace the teacher. Good pedagogical use of computers must be based on modern theories about knowledge and learning.

Larsen (1986, 1989) is a modern theorist working with computer-aided learning. The transfer of knowledge can, according to him, be characterised as a process with three phases. The first consists of a transformation of the teacher’s (expert) personal knowledge into information in the form of definitions, formulations, explanations etc. The second phase involves a transmission of this information to the students while the third phase deals with the retransformation of this information into the personal knowledge of the student.

Computer programs for educational purposes often focus excessively on phase two, the transmission of information to the student and also on the student being able to reproduce this information in its original form. This is in accordance with older educational learning theories where the student is regarded as an empty box that needs to be stuffed with information. The student’s acquisition of knowledge according to these theories occurs of its own accord.

Modern theories regarding the transfer of knowledge draw a firm distinction between information and knowledge. Information can be transferred whilst personal knowledge can only be developed by the student himself. In an active process the information is transformed into knowledge, digested and integrated with the knowledge that the student already has.

In all probability powerful pedagogical benefits can be gained if the computer can be used to stimulate the student’s activity in phase three or if the student can be put into the teacher’s (expert) role in phase one.

A knowledge engineer trying to develop an expert system within a given area, can often contribute to increasing the expert’s awareness of his own knowledge. Specifications, definitions, explanations etc. prompted by the knowledge engineer’s questions bring this about.

The expert finds himself in the first phase while the knowledge engineer transfers information from phase two into knowledge in a computer model as in phase three. Thereafter the model is compared and modified in accordance with the expert’s knowledge and views. It perhaps isn’t so strange that the knowledge engineer gradually becomes some sort of expert within the area.

Another learning theory that can be used in pedagogical software builds on the apprentice model (Collins 1987). The trainee studies first how the expert carries out a skilled task and then tries increasingly difficult tasks while the expert monitors and answers the trainee’s questions.

The projects outlined below on the use of expert systems in education are in line with modern learning theories.

READY TO USE SYSTEMS

Gradually more and more expert systems are being developed for different purposes in our societies. Within different areas these can be used to supplement traditional teaching material in normal education. In a textbook, knowledge is presented on the basis of a certain system, which can usually be searched in a predetermined way. In a knowledge system, searching is done through a dialogue that can lead in many different directions. In addition a knowledge system can be easily updated with new rules.

The pedagogical benefits are that the building up of knowledge within an area (phase three) is made easier if up-to-date information is made available to students as opposed to the repetition of the same information over and over again.

Ready to use systems are of special interest for different forms of vocational training. Unfortunately industrial systems can seldom be used in education since the knowledge itself might reveal details of key processes in

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Another very comprehensive system in diagnosing and treating various fish diseases in connection with fish breeding ‘ESOP’ is planned at the University of Tromsø (Akselsa 1990). In this the students first study different cases that are typical in some respect and then try to solve their own problems with the support and help of the system. The students can also get their own solutions evaluated by the in-built intelligence of the system. Students are then put in the role of a veterinary surgeon and through a hypermedia technique have access to advanced graphics and different video sequences. Intelligent tutoring systems (ITS) systems are a further refinement of traditional tutoring systems, which often aim at automating education within a knowledge area. Tutoring systems are often based on traditional teaching models following a fixed sequence of phases. Gradually however, the term ITS has been broadened today to cover almost all kinds of software where AI techniques are used. The pedagogical ambition has been raised and there are now suggestions that the concept should be changed to Intelligent Learning Environment (ILE systems).

The difference between the ITS systems and the others that have been commented on above is relatively small. APLUSIX (Nicaud et al., 1990) is a system where students learn to factorise polynomials and solve systems of equations. The system provides the student with two learning modes, the learning-by-examples mode and the learning-by-doing mode. The student can choose between three levels of expertise (learner profiles).

What we have learned about the impact on education of specially developed systems like those presented above is not very much. Work within different projects is at present mostly directed to the development of the system itself. One important observation is that systems deepen the educational process in a given area. Of course, this is good per se but it does often create a problem as regards the competence of the teacher and the time needed to become sufficiently ‘at home’ within an area of knowledge.

The knowledge engineer by studying and interviewing experts should be able to formulate rules governing the knowledge and place it into the system. Experience from people working as knowledge engineers is that they learn a lot in their target area whether they succeed in building a good system or not.

This last observation has led to the idea that students should learn a knowledge area by building up themselves a smaller knowledge-based system. At the beginning the students are knowledge engineers but in the process become experts.

EDUCATIONAL SYSTEMS

Building special expert systems for teaching can sometimes be more difficult than building a system for industry. The system must contain not only knowledge but be based on a pedagogical idea that is incorporated in an interface that focuses on the needs of the non-expert.

At the university of Uppsala a system called ‘Analyse more’ (Edman & Sundling 1991) is being built. Its aim is to give the school the best available expertise in the area when analysing stationary water. Education in environmental questions becomes increasingly important in the school and much time is devoted to collecting samples from the environment. Analyses of the results are often done on the basis of inadequate knowledge of the area, which in turn can lead to conclusions that are completely incorrect. Expert systems aim at giving more up-to-date, varied, balanced and hopefully ‘correct’ information so that the students’ knowledge is not built on incorrect foundations.

In a number of systems mentioned below, we are trying to use expert knowledge to give advice and comment on the non-expert’s work. The underlying pedagogical ideas are based on the work of Collins and Brown’s apprentice model (Collins 1987).

At the teacher’s training college in Copenhagen, work has been going on (Andreon 1989) for a time with a system for determining water pollution. The students collect biological samples in a number of places along a flowing river. The results are fed into the system and the students are forced to make their own assumptions and make decisions. Only after this does the system provide comments on the student’s work.

Inspired by this work, a system is being developed in Uppsala (Nystrom & Secher 1990) that deals with the decisions taken on different cases regarding political asylum in Sweden. The knowledge in the system is used to criticise and comment on the student’s answers with the student being forced to provide his own arguments. In this way knowledge systems become a critical teacher or a knowledgeable discussion partner.

In addition to this, there are a large number of projects with different goals (ILE) systems. The system provides the student with two learning modes, the learning-by-examples mode and the learning-by-doing mode. The student can choose between three levels of expertise (learner profiles).

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STUDENTS BUILDING THEIR OWN EXPERT SYSTEMS

When building up a knowledge-based (expert) system we often think about the role of different people. In the first instance we have the expert who is the person who can solve problems within a specific area. In addition to possessing expert knowledge he or she can also explain different solutions as well as absorb new knowledge.

The knowledge engineer by studying and interviewing experts should be able to formulate rules governing the knowledge and place it into the system. Experience from people working as knowledge engineers is that they learn a lot in their target area whether they succeed in building a good system or not.

This last observation has led to the idea that students should learn a knowledge area by building up themselves a smaller knowledge-based system. At the beginning the students are knowledge engineers but in the process become experts.

By building a system students are forced to digest the knowledge and structure it in terms of rules and facts. This way of working means that the students must first understand since the computer does not allow ‘knowledge holes’. The building process itself is important and the development environment (expert system shell) must be easy to handle for the students, but not so simple that they do not regard the system as worth developing.

For students the process of building up knowledge in school is continuous. It is natural that a knowledge base is built up successively and that the base is extended and improved over time. This feature of development shells supports the student learning process in a natural way.

Through the DOS Project — a central project studying the computer as a pedagogical aid — a number of teachers have been encouraged to study...
whether it is possible to build expert systems in schools and what the pedagogical implications of that will be.

Several of the participating teachers were from the beginning dubious at allowing the students to build expert systems. Perhaps it was too difficult? Or too demanding in terms of time? Would it really add anything to the educational process?

Many of the teachers were pleasantly surprised at the ease with which the student learned the techniques involved and their eagerness at working in different areas of knowledge. Some enjoyed it so much that they were reluctant to finish and wished to carry on outside school hours. They felt that it was a form of liberation to be able, in the context of highly organised work, to have the opportunity of going as deeply as they wished into a specific area of knowledge.

To be fair, we must recognise that most teachers have been working with expert systems parallel to their own normal teaching. What would actually happen if we were to replace normal teaching in an important part of the student's work with the students building their own expert systems?

One of the teachers in the project replaced traditional teaching in chemical equilibrium with the students building a number of expert systems within the area. Chemical equilibrium is an important part of chemistry education in upper secondary schools. A good understanding of the concept is an absolute prerequisite for further studies in the subject. In this context it might not be out of place to give a short resume of his way of organising the students' work.

The students spend about 20 chemistry lessons during a period of 4-5 weeks in this area. The teacher to a very large extent becomes more of a guide as a result of reducing the instructional phase. During this time the students also carry out two experiments. The following phases can be distinguished:

- The scope and content of the system. In this first phase, it is important to delimit the area of work. The teacher must show that it is more important and interesting to work deeply as opposed to working more broadly in the system. Knowledge is fed in from textbooks, experiments and other sources in the school.
- Expert groups. The students form into small groups of experts consisting of three to four students. The aim is that the group should work together to develop a structure and illustrate this in terms of a dialogue tree. It is important that all the members of the groups understand and agree on the structure.
- The students are the knowledge engineers. In this phase the structure is implemented in an expert system shell. In connection with this work the students always discover unrealistic expectations and 'holes' in their knowledge; something that the expert shell does not allow. It is also important to make sure that the students start by building a small prototype and develop the system in stages. All too often the students are forced to go back to the source material to deepen their knowledge.
- Presenting the systems. Every system must be presented and criticised by the other students. Our experiences show that the questions 'Why?', 'How does this come about?', 'Is it correct?' deal with chemistry rather than computer techniques. Viewpoints and suggestions for improvement become an important part of the discussion.
- Evaluating the student's knowledge. The students undergo a normal test in chemistry where some of the last tasks can be chosen from a number of questions that are connected to what they have been working on while building up the system. The questions they can choose from are intended to test their understanding of different concepts and are formulated in such a way so that they could not be recognised as being standard problems in the textbook. These questions are therefore often regarded by the students as very difficult. Their results from tests in October 1990 were clearly better than those achieved by the parallel group who had not been working with expert systems shells.

The teachers summarised the results of the work as follows. The main goals of the project had been achieved. The students had obtained better quality and knowledge within their area as compared with a more traditional approach. The quality improvements arose from the students acquiring a personal model of the concept of chemical equilibrium. As a teacher one does not know in detail what this model looks like because it is not the same for all students. Some groups experienced great difficulties with what they thought was highly abstract theory; suddenly there were shouts of triumph 'EUREKA!' — they had found their own working model of chemical equilibrium.

**SUMMARY OF EXPERIENCES**

The overriding impression from using expert systems in schools is positive. However, there are of course a number of problems. (Our experiences from using pedagogical expert systems are limited as most of the systems are still under development.)

Work with ready-to-use expert systems particularly as students build their own systems is time consuming.

In the near future well-developed techniques will shorten the time spent on handling the expert system shell. Thus most of the time will be spent on students developing their understanding of the knowledge area. In education today this time is often underestimated. This has been proved to be the case as students face different individual problems requiring varying amounts of time when building up their working knowledge. *Time is needed to develop understanding.*

The systems often go quite deeply into a knowledge area. This requires extra material so that the teacher can adequately be prepared. Very few teachers dare to go together with their students into such uncharted waters.

The organisational environment that exists in schools does not encourage teachers to try something new. The evaluation system puts a premium on
superficial knowledge. There is no incentive to go more deeply into different areas especially when this is not necessary when evaluating the students' knowledge.

The project has also demonstrated that we really lack good strategies for approaching and processing new knowledge areas. The schools have for a long time worked with areas of knowledge that have been relatively static and well structured. Rapid development in our society means that new knowledge becomes highly relevant and that teachers will find themselves in a situation where they must structure this to be able to present it to their students. Studying an area of knowledge in ordinary school work and building up an expert system are processes with very great similarities.

Within the project we have commissioned different pedagogical institutes to try to get answers to the following questions: 'How do we approach a new area of knowledge?', 'Are there strategies, and if so what are they and what implications do they have in terms of this work?'.

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