Computers in Learning Situations

Computers are common in the learning situations of today. They come in as early as in kindergartens, and they are used in a wide range of ways, from typing and drawing, to teaching. The purpose of this chapter is to give an overview of how computers or computer artefacts have been used to support or provide learning – and we will see that they have mainly played the role of a teacher. The first section discusses the motives for using computer in learning, focusing on computers as teachers. Section two discusses some of the ways computers have been used.

1. The motives

Traditionally there are three major motives behind the use of IT for learning: economical and learning efficiency motives have traditionally played big roles, but also the possibility to bridge distances in time and space. It is however, necessary to extend the concept of distances to also include distances between the ways of study or learning and distances between documents. We believe that an elimination of distances in learning environments, for instance, by forcing learners to study at the same location and time, and use the same material and study it in the same manner mainly have negative effects on learning efficiency. Instead, if distances in the learning situation are allowed and the learners have access to tools that support them to bridge distances, learning efficiency will improve (Broberg, 1997). A more future-oriented motive to the involvement of IT in the learning situation is that IT plays an important role in the working situation of the knowledge worker of tomorrow, with web-based information seeking, computer based refinement of information, etc. Therefore, the learners have to practice their skill in common knowledge work tasks, and IT must be viewed as a natural part.
The classical motives

It is uncontroversial to use computers in a traditional learning or teaching situation, when the purpose is to prepare the learners for a future in which computers have become common in all kinds of situations.

Ever since the birth of the computer in the 1940s, and even before, people have been fascinated by the thought of using computers or intelligent machines to provide teaching. This way of using computers has been more criticised than the other uses. This is understandable; at least from a teacher perspective when to replace the human teacher with a computer – “can a computer do my job?”.

Through the years the motives to use computerised teachers have been mainly three: cost efficiency, learning efficiency, and the possibility to bridge distances. At a workshop in Linköping in March 1996, three invited speakers – Beverly Woolf, Susanne Lajoie, and Valerie Shute – discussed the motives for the industry to use computer-based learning environments. Shute presented a top-ten list of reasons why industry should be interested in ITS (Shute, 1996). The main arguments in this list and the motives that the workshop focused on, are the arguments of effectiveness regarding both to the costs, and to the level of knowledge.

Cost efficiency

**Definition:** The cost efficiency of learning can be defined as the quotient of the knowledge acquired and the total money invested.

One huge cost for companies and other organisations is the cost for further education and competence development of the employees. At the Linköping workshop, Woolf discussed how much companies and governmental organisations in America spend at training employees (Woolf, 1996):

- IBM spends $2 billion yearly on training, including $1 billion for employee salaries;
- AT&T spends $700 million yearly on training;
- the US military spends $20 billion on training.

These three examples give an idea of the amount of money involved in this business. Naturally, there is a great interest from companies and organisations to decrease these costs. But even though the organisations want to cut the costs for education and training of the employees, I believe that in most cases they are not willing to let the competence level drop (the outcome from the educational process). The costs should be reduced, while keeping the quality of the outcome.
So, what are the different costs in more detail, for the education in a company? Some of them are rather obvious even for a financial novice. The normal situation is that persons to be educated, must be removed from the production during education. Unproductive employees are obviously a cost for the company. One other cost is due to the fact that individuals often have to be sent away for the education, implying extra costs for the companies for travels and living. But, the most obvious costs are those that are related to the teachers, housings, and equipment. I believe that the motivation most of these individuals have for the learning task, decrease when they have to leave their normal setting. There are also other factors that affect individuals in this kind of situation:

- learning is context sensitive – there are indication in the psychological literature that people tend to remember better if the “memorisation environment” is the same as the “recall environment” (Anderson, Reder, & Simon, not-published);

- cognitive overhead – in travelling away from home, there are so many factors that differ from the normal situation, like the situation to stay in a hotel, using local transports, etc. All these things are an extra cognitive burden for the learners in the learning situation and distract them.

These two factors affect learners negatively, but on the other hand, one can never exclude “Hawthorn effects” (Asplund, 1987) that may be positive for the learning outcome, (more about learning effects in the section Learning efficiency, page 24). If it is true that learners’ learning ability is negatively affected, a major drawback with this way of performing further education is the lowered quality of the outcome.

What can be done to cut these costs, without giving up on the quality? As I see it, there are three things to start with: the production loss, the travelling costs, and the motivation. Keeping individuals partly in production during the education, will cut the costs and can also affect the motivation. There are two possible ways: either people take their work to the place for the education, or they are educated at their ordinary work site. To decrease the travelling cost, and at the same time avoid the problem of loss of motivation due to the travel, the latter alternative is better. If one is to educate people “at their work”, one must send teachers to the learners. In some cases this is possible, when there are enough individuals to be educated in the same subject at each site, but often the learners are spread over a large area. Then, it will not be cost effective to send human teachers to each site. It is in this kind of situation it becomes interesting to replace or complement the human teacher with computers, because it has been shown to be more cost effective. At the workshop in Linköping, Woolf discussed cost benefits with
computer-based learning environments, using Federal Express as one of many examples. By replacing the traditional way of teaching with a computer-based learning environment, they saved $150 million over 3 years; the investment cost was $40 million (Woolf, 1996).

With my experience from the academic world, I can identify some other significant costs for the organisations. One example is the costs for the administration of the course material, for updating and distributing it. In traditional education these costs are large and there is a general interest to decrease them. Some of these costs have to do with the kind of media used. I believe that it would be more optimal if one had a central storing device with the latest editions and revision, where the learners could fetch the course material. Instead, the normal situation is that the course administrators send all printed material to the learners. One possibility is to use the WWW and the Internet as the medium for the course material, and as a basis for the learning environment.

**Learning efficiency**

**Definition:** Learning efficiency can be defined as the quotient of the knowledge acquired and the total time invested by learners.

To appreciate the gain in terms of economy, and the benefits of attempting to bridge the distance, I do not find as hard as to evaluate the pedagogical advantages. The concept of efficiency of learning has two aspects: time, and the level of knowledge. Both of them are important in a learning environment, but also in a larger perspective of educational system. If one could prove that learners studying in a computer-based learning environment can learn the same things that learners in normal learning environments do, but faster, it would be great. If it takes less time to train or educate employees, organisations can reduce their costs for education, because people would be unproductive during a shorter period. It would not necessarily give the same economical benefits, if one could prove or show results which indicate a higher level of knowledge as the outcome, but both kinds of results might lead to great changes in the educational system, and have consequences for society.

Some researchers believe that both of these effects are possible to achieve, and that they have results to prove it. What are the arguments and results that they base their claims on?

In the *Handbook of Research on Educational Communications and Technology*, Shute and Psotka give a survey of six computerised learning environments, which are evaluated with respect to the learning efficiency (Shute & Psotka, 1994). The six systems are: LISP-Tutor, Smithtown, Sherlock I, Statlady, Pascal ITS (Bridge), and Geometry Tutor.
At the Linköping workshop in 1996, Shute discussed results from the evaluation of two other learning environments (Shute, 1996):

- Algebra Tutor
- Flight Engineering Tutor

All these eight learning environments indicate the same positive results, a high learning efficiency with computerised learning environments. Most of the results are about learning efficiency regarding to the time reduction. Pascal ITS (Bridge) shortens the time that the learners spend with the learning environment to 1/3 compared to a classroom-situated learning environment. Smithtown shows results of 1/2 of the time compared to the classroom situation. Some results show that computerised learning environments have positive effects on the level of knowledge. Learners that have used the Algebra Tutor outperform the control group with 15% on standardised tests, and with as much as 100% on tests targeting the objectives such as authentic math problem solving.

_Bridging the distance_

Many different techniques have been developed and used, with a purpose to bridge distances in time and space. Telephone, answering machine, video, videoconference, radio, and television, are some of them. Modern infrastructure and computers have a great potential to bridge distances of various kinds and there are many attempts in this direction. Before discussing how computer technologies can bridge distances, I want to clarify what I mean with distance in a learning situation, by pointing out four different types of distances.

**Distance in space** – the space between persons involved in the learning situation. This is one of two classical definitions of distance when one is talking about distance education, a learning situation where the involved persons are spread over a large area. The other classical definition of distance has to do with time.

**Distance in time** – the time when persons involved want to study varies from person to person, and especially if the distances in space are huge enough to involve more than one time zone. The time when each individual has the opportunity to study may also differ from day to day. Preferably, everyone should be able to study when it suits them best. This way to perform education causes a distance in time between learners, and also between learners and the course administration, which in turn causes communication problems.
Distance in the way to study – there are differences in how persons prefer to perform their studies: what each individual studies, in which order they study things, etc, see the discussion in section Learning styles of chapter 4, Perspectives on Learning and Knowledge. This causes one kind of distance in the way to study. There is another kind of distance, too, between the individual’s preferred way to study and the way(s) offered by the learning environment. Preferably, all learners should have the possibility to study in their own way. At the same time, it would be good for them to have the opportunity to have meaningful, fruitful discussions with other persons studying the same topic. The more one allows the learners to study in their own personal way, the more the distances between the learners increase, and so the need for bridging the distance, will increase, too.

Distance to relevant material – how easy or hard it is to access and get relevant material to study. At first, this looks like a distance in space, but it is more than that. This kind of distance has more to do with different “costs” to get the material: the time it takes, the skills you need, etc. This includes linguistic distances like: language, length, author, etc. Learners or readers, often take these factors under consideration when they choose which documents to discard and which to read, (Wilson, 1993). For example, persons tend to choose material written in their own native language, material that is short, constructed by well-accepted persons, and exclude material in languages they do not master.

To summarise the concept of distance in the context of learning, distance is a complex concept with at least four dimensions, with dependencies among the dimensions. There is a strong dependency between the distances of space and time, and also between the distances of time and way to study. For all dimensions there are many advantages related to the ability to manage large distances. Hence, it is not an optimal solution to minimise the distance in each of the four dimensions. At the same time, distances are difficult to manage both for the learners and for the administrators. Instead, one should allow situations with great distances, but give the involved persons support to manage the problems that are related to it – bridging the distance.

I believe that many people conceive the traditional learning situation, the classroom way to teach, as a learning situation without any distances, or a situation where one attempts to eliminate all kinds of distances. One gathers all involved person in one location (the classroom), and all persons are there at the same time. With this move the distance in time and space are minimised, but how is it with the other two distances? Usually, persons use the same course material (which is chosen by the teacher), and they all study following the same plan (which is constructed by the teacher). At first blush
this solution seems optimal: all four dimensions of distance are minimised, but for whom is it optimal? With this way of doing it, with learners tightly controlled by the course administration the outcome is not good, and costs are high. To eliminate the distances by force, is not such a good idea. I find it hard to see any situation where it would not be better for the quality of learning to accept and bridge the distances instead of eliminating them by force. So what can be done to bridge the distance?

Through the years, there has always been a discussion about different techniques to bridge the distance\(^4\), and many educational institutions and organisations have worked with distance education. The University of Umeå has a long experience of distance education, using many different techniques and models to bridge the distance. Bååth (1989) summarises some of these experiences. Let us return to the question what computers and computer-based communication do to bridge distances. There are many possibilities. The purpose of the following is to clarify and discuss the basic ideas behind computers as a distance bridging technology.

\[\text{Figure 4. Every learner has a computer.}\]

The simplest case is that all learners have access to a computer, at their work place and/or at home, on which educational software is installed. In some sense, this educational software works as a teacher. It can be used in many ways, from a modest complement to the human teacher, to a complete replacement of the human teacher. With this solution, one has bridged the distance of time, by giving the learners the opportunity to study when it suits them best. This solution also offers the learners the possibility to study at

\(^4\) In this area there has always been great expectations as to what the newest technology and inventions can do.
home or at work, thus bridging the distance of space. Still there are many problems that this solution does not address, for example the distance between people studying the same thing, and the distance to relevant material.

Next logical step is to connect these computers in a network so that each of them has a connection to every other computer, including the course administrator’s. It is with this step that the large benefits come regarding the bridging of the distance. In some sense every computer connected to the network is situated at the same location. Now we have an infrastructure that gives us the opportunity to add a communication system with which the learners can communicate with each other and with the course administrator. Electronic mail systems and computer-based conference systems have the facility to bridge the distance of time and space. The learning situation becomes like a virtual classroom.

The next logical step to take is to use distributed hypermedia such as the WWW, as the basis for the learning environment. This step has both administrative and pedagogical benefits. I believe that this together with a communication facility, has the possibility to bridge the distance in the way to study. At the same time it encourages the learners to focus on internal factors of motivation and relevance, which means that it is a good platform to implement a learning environment based on a pedagogical model like the one the phenomenological approach is pleading for. The use of distributed hypermedia helps the course administrator to update and distribute course information, course material, etc., but it also gives the possibility to bridge the distance to other relevant material. The WWW has the power to be used
both as a digital library in which the learners can search for relevant material, and as a medium for the learners to communicate ideas.

IT is a natural part of a working environment

The language, the art of writing, the concept of books, the printing press, the telegraph, telephone, radio, television, the personal computer (PC), Internet and recently the WWW are all examples of artefacts and IT that help people to share and to communicate knowledge through space and time. The introduction and acceptance of each of these new ITs has also altered our society in numerous ways. Therefore, it is not too much to say that IT and the culture that emerge when people use it, are important factors in shaping our society. These tools are designed with the intention to support knowledge sharing and communication, as well as the usage culture which humans connect to these artefacts.

As we move from a material industry-based society to an immaterial knowledge-based society (Drucker, 1993; ERT, 1997), it is reasonable to expect that IT will play an even more important role than before. Each new IT innovation will have greater impact on society than in the industrial era, since information and knowledge are the hard currency. According to Janlert (1995) one of the major changes with the introduction of new IT is the continuous process of knowledge reorganisation. With this in mind it is safe to claim that IT must be a natural part of a learning environment of tomorrow.

2. Kinds of computer-based learning environments

Skinner, Pavlov, and Piaget all played important roles as founders of theories of learning. Skinner’s and Pavlov’s ideas about the way we learn things, based on the stimulus-response concept, were one source of inspiration for programmed learning or programmed instruction. Those theories have been used as the foundation for the design of the first generation of computer-based learning environments. Using this pedagogical model a huge industry of learning grew up during the early 1960s.
The first generation – programmed learning

Computer Assisted Instruction systems (CAI) are a kind of interactive learning environment based on programmed learning, which became common in the period from the mid of the 60s to the early 70s. Still, many projects are based on behaviouristic ideas (Broberg, 1997). This seems strange since these ideas and all what they stand for have been almost completely rejected in traditional classroom learning environments. At the same time, there is a very simple explanation: two of the major advantages with programmed learning are the possibility of self-administration of a course and the simplicity of implementing a computer-based learning environment with a behaviouristic control mechanism, (see Figure 6). Therefore, it is not hard to see the possibilities to make it serve as a basis for computer-based learning environments.

The second generation – intelligent tutoring systems

Even if one can get positive results with regard to learning in the first generation of computer based learning environments, there is much one can do to speed up the process of learning. One of the major drawbacks of the CAI environments is the lack of individualisation. The learning situation is
one-to-one, but all learners are still running through the course in the same order. Below, we present three examples of ideas that have been exploited in attempts to improve performance:

- multiple paths through the curriculum;
- present the material in different ways;
- analyse the errors that the learners do.

In the next generation of computer-based learning environments many of these ideas were implemented, by experimenting with implementation of intelligent behaviour in the computer systems – Intelligent Computer Assistant Instruction systems, (ICAI), and Intelligent Tutoring Systems (ITS) as they also were called. In 1973, Hartley and Sleeman outlined the basic requirements of ITS environments (Shute & Psotka, 1994):

- Knowledge of the domain (the expert model)
- Knowledge of the learner (the student model)
- Knowledge of teaching strategies (tutor)

The above discussion indicates that there are major differences between ITS and its predecessor CAI: the ITS analyses the learner’s erroneous behaviour, and it models the learner’s state of knowledge. The way the learners work with these ITS environments is quite similar to the way they worked with the CAI environments. The model of the learners, that is, what the learner knows and does not know, and the model of how teachers act in different situations, are used by the system to accelerate the learning, an acceleration made possible by an individualisation or adaptation to the learner’s behaviour. A learner in such environments learns mainly by solving problems chosen by the tutor to promote efficient learning (Broberg, 1997)5.

The third generation – cognitive tools

The ITS approach has many good results to show, although it has also been criticised for a long period. Much of the criticism has concerned the possibilities to trace learners’ state of knowledge. The cognitive tools approach to ILEs started as a strong criticism of ITS, attacking the student modelling approach, as well as the pedagogical basis. Cognitive tools (discussed in chapter 2 on page 14) are artefacts that amplify, support, and unburden the user cognitively, and have the ability to affect the task, and the user’s state of knowledge. The cognitive tools approach has its pedagogic

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5 See (Barr & Feigenbaum, 1982a) for more examples of ICAI systems like WHY, SCHOLAR, etc.
base in constructivistic ideas of knowledge and learning, where the learners are considered to be active knowledge constructors.

What practical results are there, so far, in the area of computer-based cognitive tools supporting learning? According to Jonassen, not many of the tools constructed over the years, have been designed with the purpose of supporting learning. Although computer-based learning environments is and always has been an active area of research, it has not resulted in as many available products as one would wish. Due to this and the fact that cognitive tools is a rather new approach to computer-based learning environments there are not many cognitive tools for supporting the learning process. The examples of cognitive tools that the area presents vary in character. (Kommers, Jonassen, & Mayes, 1992), distinguish five categories of cognitive tools: semantic networking tools, expert systems, hypermedia, co-operative learning environments, and micro-worlds.

Semantic networking – a semantic network is a representational scheme for concepts ordered hierarchically or by associations. The basic idea behind this category of tools is that by creating, processing, and observing semantic nets (which many think are close to the way we actually store concepts), it is possible to learn. Concept-mapping is another term for this category of tools. Lanzing discusses many aspects of the use of concept-mapping (Lanzing, 1996), emphasising that concept-mapping tools can be used in a variety of situations and for different kinds of knowledge work, of which learning is one.

Expert systems – a term that is often used as a synonym for knowledge-based systems. The representational scheme for knowledge that these systems use is commonly a form of rule-based representation; i.e. the database consist of if-then statements. As the name suggests, expert systems are commonly used to model the knowledge and behaviour of experts, e.g. systems for medical diagnose like MYCIN (Barr & Feigenbaum, 1982b). “Knowledge engineer” is a common term used for the category of persons working with constructing and maintaining the knowledge databases in an expert system. It is quite obvious that the kind of work that knowledge engineers do is a form of knowledge work. The idea of expert systems as cognitive tools for learning, is to put learners on an equal footing with knowledge engineers, but the idea does not stop there. It also involves learners working with the knowledge database or the expert system, to extract and use the knowledge in it.
Hypermedia — is a form of media where documents have a non-linear structure, contrary to the basically linear structure that ordinary text documents have. The difference in structure between these two kinds of documents is mostly related to the kind of media. Janlert uses the term medium-space and domain-space to distinguish between structures that are related to the representational medium and the content respectively (Janlert, 1995). A hypermedium document consists of a number of nodes that can be viewed as containers storing information; these nodes are linked to other nodes, i.e. the document is a network of linked information. The link facility gives the opportunity to express relations between pieces of information. It is also via these links that most of the traversing of a hypermedia document is done. This usually implies that there are multiple ways of traversing the document, and not a single path through it, as is normally the case with ordinary text documents. An additional perspective on hypermedia is that a hypermedium document can be viewed as a scheme for knowledge representation, with the nodes describing concepts, and the links expressing relations between the concepts. This gives a representational scheme close to semantic nets and concept-mapping. Today, the WWW is the best known and established form of hypermedia.

The basic idea of hypertext as a cognitive tool is the assumption of a close mapping between the structure of the author’s state of knowledge and the structure of the produced hypermedia document. Tool-use can involve constructing, processing, and reading hypertext:

- when hypertext authoring is used to support learning it becomes very similar to semantic nets and concept-mapping – the document captures the learner’s understanding of the topic as a concretisation of the personal knowledge creation process;
- when processing of hypertext (the learners add links, for instance) is used to support learning, it should give positive effects of active reading;
- learning is believed to be better promoted by reading pre-produced hypermedia documents than ordinary linear documents, Egan et al. carried out an experiment that strengthens this hypothesis ⁶. This presupposes that the reading environment supports the reader in overcoming the specific problems that readers of hypermedia documents face (McKnight, Dillon, & Richardson, 1993).

Hypermedia is a rather complex concept. In hypermedia literature such as (Conklin, 1987; McKnight et al., 1993; Nielsen, 1995; Woodhead, 1990), many more aspects of hypermedia systems are discussed.

**Micro-worlds** – can be viewed as dynamical models of both concrete and abstract concepts from the real world. Many take micro-world to be a synonym for cognitive tool for learning. The idea of micro-worlds is to offer an environment that would be inaccessible for the learner in the normal case, for economical or safety reasons, or for some other reason. Micro-worlds typically involve simulation, manipulation, and testing of hypotheses, but the creation of micro-worlds is also important.

**Co-operative learning environments** – learning is both an individual and a social activity. Co-operative learning environments are focused on the social and group aspects of learning. In a co-operative learning environment, the learners are together with other learners when they work with information. Working together with other learners has positive effects on the learning outcome. The activities in these environments are similar to those in individual environments: creating, processing, and observing. In an environment where several individuals perform something together, there are distances between individuals. Bridging these distances is important for a fruitful collaboration – computers connected into a network, offer good opportunities for bridging distances between individuals.

All the above categories are systems and tools with which one creates, processes, or observes information, no matter if the objects are represented in a semantic net, in an expert system, in hypermedia, or in a micro-world. The main difference between them is whether or not they support collaboration, and the fifth category – co-operative learning environments – covers this aspect, but still the tools that belong to this category basically provide the same kind of activities as the other categories.

One problem that almost all existing systems share is that they tend to be very complex system. In fact, most of these systems consists of a number of smaller and simpler tools. I think that none of the constructors or designers of SemNet (Fisher, Lipson, Patterson, & Faletti, 1997), Bio-World (Lajoie, 1993; Lajoie & Greer, 1995), LOGO (Hoyles & Noss, 1992; Papert, 1980), or any other of the systems that can be counted to the group of cognitive tools for learning, will disagree that the collections of simpler tools these systems consist of are the real cognitive tools. It would be preferable to decompose these rather complex systems into simpler tools, that fit the categorisation of tools, using the nine dimensions of artefacts outlined on page 9. Such a split will give a collection of cognitive tools that are moveable and applicable independent of the representation. Even if this is only a hypothetical idea, it
illustrates the need for a shift of approach in the area of computer-based learning. There are a few examples of computer-based learning environments such as SimCalc (Roschelle & Kaput, 1996; Zeppenfeld, 1996), in which it is possible to identify similar ideas about a set of simpler tools that are possible to combine.

Piaget and ILE

In Piaget’s theory, learning is explained in terms of interaction with the environment, and the learning is driven by our innate tendency to have a balance in the way we represent it and the way it actually is. Therefore, Piaget’s role in the area of interactive learning environments is mostly related to learning environments with a pedagogical model based on learning by simulation, and manipulation of micro-worlds. Papert’s programming language LOGO is an example of a computer-based learning environment based on Piaget’s theories about cognitive development (Hoyles & Noss, 1992; Papert, 1980).