Journal of Courseware Engineering, Vol. 2. pp. 22-33, Fall 1999

Challenges for Design: Seeing Learners as Knowledge Workers Acting in Physical – Virtual Environments

Marcelo Milrad
LIST Group
The Institute for Media Technology, Jönköping Sweden

Anders Broberg and Thomas Pederson
Department. Of Computing Science
Umeå University, Umeå, Sweden

ABSTRACT – *Traditionally, behaviouristic models have been used for the design of many interactive learning environments. In contrast, we propose a pedagogical model based on social constructivism and phenomenography, which we believe is more adequate when, for instance, information seeking and the use of the WWW are natural components in the learning situation. To see learners as persons who continuously alter their conceptions and ideas by working with data, information and knowledge, i.e. to see learners as knowledge workers, corresponds well with social constructivism and phenomenography. Frequently, the design of interactive learning systems focuses exclusively on computers and the virtual environments they provide, excluding the physical environment. We believe that the design of learning environments based on a combination of physical and virtual artefacts will enhance the learning experience. In this paper we present our efforts in exploring the implication of two learning theories, phenomenography and social constructivism, for the design of learning environments that combine physical and virtual (computer-based) media.*

INTRODUCTION

There is general agreement as we approach the next century and next millennium that our society is changing into a knowledge and information society. The world is constantly evolving now at a faster pace than ever before, creating the challenge for individuals and organisations to deal with changes and for schools and universities to prepare people for changes. There is trend indicating that the amount of people working with knowledge and refinement of data and information is increasing (ERT, 1997). More and more of the labourers can be categorised as knowledge workers, hence knowledge workers is a group of workers who is growing in size and importance. Scientists, stockbrokers and journalists are examples of knowledge workers of today.

The shift from manufacturing-based work to information-based and technologically rich work generates new requirements and demands for "life long learning“ – for individuals, groups, as well as for corporations. Furthermore, there is an ongoing shift from the view of education as a non-recurring investment, to a view on learning as a life-long process. In these, learning becomes an active process of discovery based on intrinsic motivation rather than on the consumption of facts (Marton et al., 1986). Therefore there is a growing need to support new ways of learning.

The previous notions of a divided lifetime-education followed by work are no longer tenable. Professional activity has become so knowledge-intensive and fluid in content that learning has become an integral and inseparable part of "adult" work activities. In the information society, learning is to be considered as a new form of labour (Fischer, 1999; ERT, 1997; Cochinaux & de Woot, 1995). Professional work can no longer simply proceeds from a fixed educational background; rather, education must be smoothly incorporated as part of work activities fostering growth and exploration. Similarly, children require educational tools and environments whose primary aim is to help cultivate the desire to learn and create, and not to simply communicate subject matter divorced from meaningful and personalised activity (Milrad, 1999).

There now exists a need for computational environments to support "new" frameworks for education such as:

- lifelong learning,
- integration of working and learning,
- learning on demand,
- authentic problems,
- self-directed learning,
- information contextualised to the task at hand,
- collaborative learning,
- organisational learning.

Interactive learning environments (ILEs) are having an increasing role in teaching and learning and are likely to play an important role in the future (Wasson, 1997). In particular those tools that encourage and enhance discovery, creativity, thinking and expression are very much needed. Equally, from the technological point of view, developing new tools for all kind of learners forces technologists and designers to think about the creation of new solutions, without pre-conceptions and not merely based around text or the PC**.** The fact is that many tasks traditionally performed in physical environments are now done in virtual (electronic) environments, or they have been altered to fit to the new premises of emerging physical-virtual environments (Pederson, 1999).

Current and emerging technological advances in Information and Communication Technology (ICT) make it possible to develop interactive learning environments to support all the above mentioned types of learning. Historically, behaviouristic models have been used for the design of many interactive learning environments, in spite of the fact they have been rejected in traditional education. This is to some degree caused by the nature of computers and the ease to implement behaviouristic models. Even if one accepts that the behaviouristic model works quite well for memorising facts, and also in some sense procedural knowledge acquisition, it has some major drawbacks (Broberg, 1997).

In this paper, we present a pedagogical framework for the design of learning environments that combine physical and computational media. We do this by discussing and putting together some theories about learning from the field of pedagogy with ideas from computing science and information science. This paper consists of four sections. The first section presents issues related to life-long learning and knowledge work. In section two we give a brief pedagogical perspective regarding those issues related to the design of interactive learning environments. In the third section, technical aspects of interactive learning environments are discussed. The focus in this section is on the integration of physical and virtual environments. The fourth section concludes the article by discussing the implications and consequences for the design of interactive learning environments from seeing the learner as a knowledge worker.

KNOWLEDGE WORK

"The manual worker is yesterday…. The basic capital resource, the fundamental investment, but also the cost centre for a developed economy is knowledge worker who puts to work what he has learned in systematic education, that is, concepts, ideas and theories, rather than the man who puts to work manual skill or muscle."

Drucker (1973)

Peter Drucker describes the group of knowledge workers as growing in size and importance. Then, what does it mean to be a knowledge worker? The working situation of a knowledge worker implies an active role and requires cognitive effort. Just like craftsmen are affected physically by their work and their working objects, knowledge workers are affected cognitively by their work and their working objects (Kidd, 1994). As will be discussed later in this paper, the working environment is dynamic and since it is heavily affected by the development of information technology, it is continuously evolving. This set up requirements on the knowledge workers to be open-minded and willing to adapt to the new situation. Therefore, learning becomes a natural process in the working situation for knowledge workers.

Even if many of the tools and working objects for knowledge work are situated in the physical world, the amount of virtual (computer-based) tools that modern knowledge workers use using in their work is increasing. Today's computer technology does not provide the kind of support knowledge workers need: it is rather huge and inflexible computer systems are still dominating. We can identify many reasons for this.

One reason is that the history of computers reveals a view of them as an automaton aimed at making things easier and more efficient. In many traditional situations where computers are involved, we can identify a so-called factory metaphor, but also in other situations, e.g. learning situations where teaching is based on an instructional approach. Traditional teaching, a lecture-styled teaching in a classroom, is an example of such a situation, where teachers are active and learners are rather passive. Also, there are many computer-based learning environments, which build on the same approach.

We believe that one of the reasons why these approaches and metaphors are so widespread, is the focusing on the artefact – *and computers are good at processing huge amounts of information*. Instead, with a focus on the kind of work we actually do with computers, a kind of work where we collect, process, and communicate knowledge – we would have a different history of metaphors. History also indicates the existence of such metaphors, where the users have more control over the working situation, as in the case with craftsmanship – a knowledge worker metaphor.

"A memex is a device in which an individual stores his books, records, and communication, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory"

Bush (1945)

Vannevar Bush's idea from the late 1930s about an artefact he called Memex[1], is an example of such an approach. The purpose of the Memex was that it should be a tool for scientists, and other people working with information. Much of a scientist's work can be described as establishing focus, collecting information, processing the information, and communicating it. One characteristic of such a working situation is information overload (Wilson, 1993). As we see it, one of the main ideas behind the Memex was to make it easier for scientists to manage information overload.

A few years ago, the most revered among cognitive artefacts were systems using artificial intelligence techniques, which many thought were even destined to supplant human decision makers in a number of complex diagnostic activities. Our attention was riveted on intelligent systems, interfaces, menus and control over systems by users. Now emphasis is shifting towards areas like computer-mediated communication (CMC), computer-supported cooperative work (CSCW), and virtual reality (VR) as media (Mantovani, 1996). We believe we are witnesses to the start of a new approach towards the design of more adaptive learning/working environments in order to fulfill the requirements for supporting knowledge workers.

PEDAGOGICAL ISSUES

What kind of pedagogical framework has the ability to cope with the educational requirements that arise from this increasingly important group of labourers? A point of departure for this paper is a view on learning based on the following definition: "Learning, is an active, constructive, cognitive and social process where the learner strategically manages available cognitive, physical, and social resources to create new knowledge by interacting with information in the environment and integrating it with information already stored in memory" (Shuell, 1988). Furthermore, we assume that learning can be characterised by having the following features:

[1] The Memex was a forerunner to more modern artefacts such as hypertext and hypermedia. Bush presented his concept of the Memex in his 1945 Atlantic Monthly article *As We May Think* (Bush, 1945). We do not think that Bush expected that it would take more than half a century for his ideas to be implemented. Tim Berners-Lee's invention of the WorldWideWeb is very much an implementation of Bush's ideas – the first proposal for the "web" is dated to the early 1990s (Berners-Lee, 1990).

Learning is embedded: Learning will take place in a situation – we learn out in the real world where the knowledge and skills are needed to solve problems. As Brown et al. (1989) says: "We must, therefore, attempt to use the intelligence in the learning environments to reflect and support the learner's or user's active creation or co-production, in situ, of idiosyncratic, hidden models and concepts, whose textures are developed between the learner/user and the situating activity in which the technology is embedded."

Learning (and knowing) is a constructive process: As indicated by the fact that learning is embedded, we should view learning as a constructive process rather than a passive absorption of facts and rules. The view that the learner should acquire the expert's knowledge does not necessarily acknowledge this constructive perspective. Knowledge and skills are gained and regained over and over in an on-going process between the learner and situations in which the knowledge and skills are required. The central notion is that understanding and learning are active, constructive, generative processes such as assimilation, augmentation, and self-reorganisation.

Learning is a social process: Several researchers e.g., (Kearsley, 1994), point out that learning is a social process; it happens in collaboration between people or together with technology. This is especially true in complex domains. So when introducing technology the view should be shifted from seeing it as a cognitive delivery system to seeing it as means to support collaborative conversations about a topic (Brown,1989). The central notion is that learning is enculturation, the process by which learners become collaborative meaning-makers among a group defined by common practices, language, use of tools, values, beliefs, and so on (Lave & Wenger, 1991; Wasson, 1996).

Knowledge is very much a question of understanding phenomena: The field of pedagogy traditionally takes a positivistic and quantitative view on knowledge (Marton, 1986). Phenomenography in contrast takes quite a different view – knowledge is understandings of phenomena, and learning is viewed as a process where these understandings are changed; this is a central principle (Marton, 1986). Other important characteristics are the analysis of the outcome of the learning process in qualitative terms, the move of focus from the "teacher-side" to the "learner-side" of the learning situation and the view on learning as a generative process, which is constantly going on.

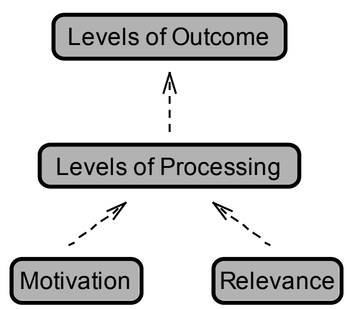

Figure 1. The functional relations known from the phenomenographic research about "How We Learn" (Marton, 1986).

The kind of motivation, and the kind of relevance of the topic, are two important factors that affect the level of processing. Internal motivation factors and internal relevance lead to a depth-directed level of processing which in turn implicates a better understanding or higher level of outcome. These relationships are almost functional, see Figure 1.

NEW WAYS OF LEARNING AND TEACHING

"The notation of 'intelligent machines' for teaching purposes can be traced back to 1926 when Pressey built an instructional machine teeming with multiple-choice questions and answers submitted by the teachers. It delivered questions, then provided immediate feedback to each learner"

Shute & Psotka (1994: 2)

The knowledge explosion requires professionals to engage in lifelong learning if they intend to stay current – let alone evolve, advance, and remain competitive – in their profession. Therefore, lifelong-learning skill development is imperative if people are expected to learn over the full expanse of their professional lives. In order to better prepare for lifelong learning activities, learners must be exposed to learning activities that require them to take on and develop many of the responsibilities normally afforded to educators. To achieve this requires moving away from a view of learning that is controlled outside the individual – by a teacher, trainer, instructional designer, or subject matter expert – to a view of learning that is internally controlled by the individual.

The role of the teacher/instructor is coming more to be seen as mentor or guide facilitating and playing an essential role in this process. Current and emerging trends in education are increasingly moving towards learner-centered approaches. In these, learning becomes an active process of discovery and participation based on self-motivation rather than on more passive acquaintance of facts and rules (Sfard, 1998). From this perspective, learning can be considered as a dynamic process in which the learner actively "constructs" new knowledge as he or she is engaged and immersed in a learning activity (Papert, 1993). The theory of constructivism is at the core of the movement to shift the center of instruction away from delivery in order to allow the learner to actively direct and choose a personal learning path.

As mentioned above, IT will play an important role as a tool for supporting knowledge workers in the learning situations of tomorrow. *How* and *why* should we use information technology (IT) in learning environments? These are two relevant questions to ask in this context. In this section we discuss these two questions putting our main focus on the "how question", although the "why question" is first briefly discussed.

Why

Traditionally there are three major motives behind the use of IT for learning: economical and efficiency motives have traditionally played a big role, and also the possibility to bridge distances in time and space. It is 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 for the learners' situation. Instead, if distances in the learning situation are allowed and the learners have access to tools that support them to bridge distances, then it becomes a more fruitful learning situation (Broberg, 1997). Consequently IT plays a very important role for supporting the learning process and must be viewed as a natural part of the learning environment.

How

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.

INTERACTIVE LEARNING ENVIRONMENTS TODAY

Today there is a lively debate in this field. More or less, this debate can be traced back to four questions concerning the pedagogical issues of interactive learning environment:

- level of learner-control;
- individual or collaborative learning;
- the view on learning and knowledge;
- what can more sophisticated user interfaces and presentation techniques (like multimedia and virtual reality) contribute with?

Learner Centred Design

The design of ILEs should be guided by contemporaries' educational and learning theories. Learner Centred Design (LCD) is concerned with the nature of the active learning process, the unique qualities of diverse individual learners, and motivational factors. Therefore, constructing interactive learning environments that truly address the needs of learners is a challenge: while learners are also users, and thus the principles of user-centred design apply, learners additionally have a set of unique needs that should be addressed in software as defined by Soloway et al. (1996):

- *Growth* – At the core of education is the growth of the learner; promoting the development of expertise must be the primary goal of educational software. Rather than just support "doing" tasks, software designed for learners must support "learning while doing."
- *Diversity* – Developmental differences, cultural differences, and gender differences play a major role in the suitability of materials for learners. To be usable by all learners, a range of software tools that address these differences must be available.
- *Motivation* – In contrast to software developed for professionals, the student's initial interest and continuing engagement cannot be taken for granted. (pp. 1-2)

Developing an in-depth understanding of learners' unique needs and interests at the cognitive, organisational, and socio-cultural levels is a first step in designing meaningful and productive technologies for learning. According to Soloway & Guzdial (1998), the development of a design model that places the learner at the centre and situates the learning process within the larger educational context is the key to this process. The outcome of this approach will result in the identification of design features and associated learning conditions that will make significant contributions to the design of effective learning environments.

A further aspect to be considered in learner-centred design is the perspective of life-long learning. In its current use, the notion of learners is limited to school populations. Yet we need to recognise that learning is not just for students in classrooms but professionals are (or should be) constantly learning too. Moreover, when the professional is acting as a learner, that person is susceptible to all the challenges faced by students. How does one design systems for lifelong learning which can be of use to a learner over a lifetime?

THE IMPACT OF INFORMATION TECHNOLOGY ON KNOWLEDGE WORK CONDITIONS

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 World-Wide-Web (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 foolhardy to say that IT and the culture that emerge when people use it, are important factors in shaping our society. From now on we will refer to the term IT to denote both hardware and software artefacts. 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 believe 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. Thus, if we want to know something about the future knowledge work situation, it is almost necessary to try to design new kinds of IT and applications.

According to Janlert (1995) one of the major changes with the introduction of new IT is the continuous process of knowledge reorganisation. As a result of this process some old kind of knowledge becomes irrelevant, some new kind of knowledge becomes relevant. This fact is obviously very important for teachers to be aware of and it would be useful to have at least a notion of under what conditions the learners´ acquired knowledge will be applied. In other words, educators should strive towards being able to answer the following question: *What kind of knowledge and skills will be important in the future?* In the following section we will briefly look into some trends in the field of human-computer interaction. The purpose of this part is to provide a technical perspective in order to understand how these technologies will impact the way we think about the design ILEs.

The End of the Desktop PC era – Some Trends in User Interface Development

The design of user interfaces (UI) – the interaction layer between human and machine – has impact on both IT development and IT culture. UIs reveal the nature and possible utility of computer artefacts to the users, and have major influence on the culture around its usage. Artefacts are what they seem to be, based on the look-and-feel of the UI (Norman, 1988). As we focus in the design of learning environments as focus, we can note four interesting UI development directions that might have big impact on the way of performing knowledge work in the future, trends proclaiming that:

- future human-computer interaction takes place everywhere rather than in one specific place
- future virtual (computer-based) environments are more tactile and spatially oriented
- future IT will be more closely connected to our perception and cognition
- future physical and virtual knowledge work environments will become more integrated

The mentioned above issues will be discussed in further details in the next section.

Future Human-Computer Interaction Takes Place Everywhere

When the personal computer (PC) was introduced in the beginning of the 1980's, it rapidly became a tool among other tools placed on the knowledge worker's desktop. The utility of this tool has continuously expanded to encompass both old and new working tasks to the extent that it is now more or less not possible anymore to efficiently perform knowledge work without it. On the other hand the way the user interface looks has not changed so much in the last years in spite of the development of new interaction devices. Most knowledge workers have the PC situated on a corner of a desktop, and all functionality of this tool – that is, the virtual environment – is accessed through a single screen, a keyboard and a mouse which together does not really make full use of our human perceptual capabilities. Also, the simplistic interaction model which is hard coded into the operating systems of PCs is perhaps no longer suitable to handle the wide range of tasks that a modern PC system can support (Gentner et al., 1997).

Ubiquitous Computing

The question arises: Should it not be possible to create a UI to the virtual environment so that knowledge workers can perform computer-supported activities over a larger area, say the whole office or classroom? Or perhaps, even without any limitations regarding physical location? Humans are not "designed" to act in front of a small square-like window manipulating objects with only one or two physical input devices. The vision of Ubiquitous Computing (Weiser, 1991) is an attempt to develop environments where the ordinary PC normally situated on the knowledge workers desktop is replaced with a set of smaller computers. These computers are deliberately spread out in the physical surroundings and have more or less specialised UIs designed for the particular tasks that they are intended to support. However, the ubiquitous computers can keep each other informed through a network, so that sensor and HCI communication mechanisms implemented in one computer might accidentally be utilised by another computer if necessary. Recent technology development, like for instance standards for local wireless data communication ([Bluetooth], 1999), has dramatically increased the possibilities for implementing this vision.

Wearable Computing

The fact that computer hardware continuously becomes smaller has evoked another related vision; that of Wearable Computing (Mann, 1997). Computational support has become so valuable and important that some of us almost feel handicapped without it. So far, most computers have been too large to be always carried around, but we are very fast approaching a threshold where this limitation is no longer present. Many people today carry digital watches, cellular phones and so called personal digital assistants. Soon, the functionality of these small devices — and they will become even smaller, even knitted into our clothing or placed in jewellery (Resnick et.al, 1998) – will expand to encompass support for tasks that we currently perform using our desktop PCs. As if this would not be enough, these devices will of course also support activities that today's PCs cannot, including activities not yet thought of.

Future Virtual (computer-based) Environments are more Tactile and Spatially Oriented

There is, of course, more to ubiquitous computing than just the distribution of computers. Advances in the development of digital motion tracking, positioning, and identification systems enable new kinds of human-computer interaction, which facilitate the 'ubiquitousness' of computers. By keeping track of physical objects (computers, 'digitally dead' objects, or users) computer systems can interpret ongoing activities in a far more delicate way than what is possible today, where the only input data the PC gets is from the mouse and keyboard. The physical environment suddenly itself becomes the UI, opening up for a more physical working-style where our spatial cognition and tactile perception skills, in a quite straight-forward way, can be utilised for HCI (Fitzmaurice et al., 1995; Ishii et al., 1997).

Future Computer Technology will be more Closely Connected to Our Perceptive and Cognitive Skills

Our dependency of IT in everyday life will continue to increase. If the vision of wearable computing becomes reality this dependency will become even more evident. "Ehr, sorry, please wait, I forgot to turn on my automatic language translator…" might be heard in the initiating phase of international phone calls in the future. The automatic translator functionality might be a network service or implemented in the wearable phone. Nevertheless it is invoked in no time and works everywhere since it is assessable through the always-with-you wearable phone. Although automatic speech recognition development has not yet reached the ability to realise the above mentioned scenario, it can serve as an example of computer-augmented perception and cognition. Another example would be to get a special pair of spectacles when at the supermarket, showing optional information about any goods you happen to lay your eyes on. If you are allergic to some specific ingredients, food containing dangerous substances might generate a warning message on your spectacle display if you place it in your shopping cart. Augmented Reality (Feiner et al., 1993) technology like this is currently expensive but will, just like any other computer hardware, eventually become affordable for everyday use.

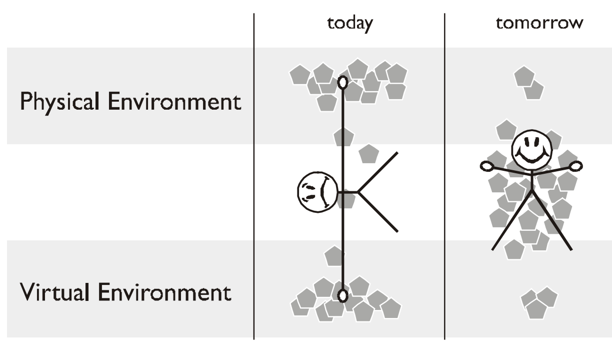

Figure 2. Vision and goal: Artefacts that are both physical and virtual at the same time (Pederson, 1999).

Future Physical And Virtual Knowledge Work Environments Will Become More Integrated

Many knowledge work activities traditionally performed in physical environments are now done in virtual (electronic) environments, or they have been altered to fit to the new premises of emerging physical-virtual environments. Since the physical environment facilitates certain knowledge work activities (e. g. reading extensive amounts of text), and the virtual environment facilitates other (e. g. the distribution of information), people tend to choose and switch between these complementing environments depending on the task at hand (Arias et al., 1997). However, this alternating behaviour involves bridging the physical-virtual environment gap implying additional costs for the knowledge worker. Our research on physical-virtual environments aims to make these two environments more homogeneous. Our approach is to give knowledge workers technical and conceptual support in overcoming the physical-virtual environment gap by introducing physical-virtual artefacts (Figure 2).

CONCLUSIONS

To be able to meet the challenges for the design of tomorrow's learning environments we propose a pedagogical framework based on a knowledge work approach to learning. This framework has its base in five cornerstones:

- Knowledge work tasks are those that most likely many people will be doing in the future
- There is a continuous knowledge reorganisation in the society partly caused by the use of new technologies
- People in the future will become more and more IT-augmented
- The use of computers for learning purposes is still in its infancy
- It reasonable to adopt phenomenography and social constructivism, as a pedagogical base for the design of interactive learning environments

Knowledge Work Tasks Are The Tasks Of The Future

As we mentioned in the introduction to this paper, there is a trend in the society, which directly and indirectly has a major impact for the educational system. The base for this trend is that more and more of labour has to do with knowledge and refinement of data and information. Consequently, more and more of the labourers can be categorised as knowledge workers.

Knowledge Reorganisation: The view of work and what kind of knowledge and competence which regarded as important to master, is constantly drifting. IT has come to play an important role in the working situation for knowledge workers and its influence will probably increase when the physical and virtual environments begin to merge. Part of this is the fact that the use of IT in our society is one of the sources for the reorganisation of knowledge.

IT-augmented: In fact, we have to take *future* information technology into consideration because it will have a major influence on the conditions for future knowledge work and learning. Information access everywhere, through new 'physical' devices with computational power, will contribute to bridge the gap between the physical and virtual worlds. New tools will be so close to our cognition and perception that they almost become part of our personalities. These new computerised environments will complement and eventually replace the desktop PC as provider of cognitive tools. All these aspects will cause a new knowledge reorganisation that should not be ignored.

The Way We Use Computers: Using IT for learning has a long tradition but we need new ways of doing it Mainly because many of the traditional approaches of involving IT in learning situations do not meet the requirements of future more dynamic physical-virtual learning environments. A futuristic learning environment should include elements where learners can put the topic into a context and relate it to things, situations, and events that are relevant to them – promote active learning. One such element for instance, could be an open hypertext environment; *open* meaning that there are possibilities to search for information external to the course material, possibilities like those offered by the World-Wide-Web. It would also be open in a wider meaning, letting the learner view how other people (learners and teachers) have worked with the topic. Learning in such environment demands much support from the system, in order to help the learners to manage the new kind of learning situation. This support could be of the kind of: to establish goals, to manage goals, to manage the in-stream of information, searching for relevant information, etc.

Pedagogical Base: The design of ILEs should be guided by educational and learning theory**.** We believe one possible approach for design is the knowledge worker approach. From this perspective, learners are viewed as knowledge workers acting both in the physical and the virtual world. This corresponds very well with the phenemonographic and social constructivistic ideas about learning and knowledge.
Implications for the Design: What are the design implications from seeing the learner as a knowledge worker acting in a physical-virtual environment? Below, we introduce a table, which summarises how the implications are related to the cornerstones (Table 1). In the following discussion, the numbers in the text refer to the implications shown in

Table **1**.

Our society demands lifelong learning (4) on a labour market dominated by people performing knowledge work. These learners are active knowledge constructors (5), using an open and dynamic set of information sources (8) which not only contribute in changing their professional abilities but also their attitudes. Learning is an inevitable part of knowledge work (3). If we want to understand this emerging learning situation it is necessary to see the learner as a knowledge worker (1) and to adopt a phenomenographic and social constructivistic view and on knowledge (2; 6).

Information technology is already today an important part of knowledge work environments (9) and with emerging new user interfaces and interaction design models (11) that integrate the physical and virtual environment, elements of IT will be even more tangible and ubiquitous (12). This also implies that learners have constant access to virtual cognitive tools (14; 10), a fact that should be considered in the pedagogical context because IT has historically had big influence on the continuous process of knowledge reorganisation (15). Because of the nature of knowledge work, being a highly personal activity, knowledge workers will demand a flexible and customisable working environment (13) consisting of an increasing amount of cognitive tools (16).

		Cornerstones				
	Implications	Pedagogical base	Knowledge work	IT-augmented learners	The use of computers	Knowledge reorganisation
1.	See the learner as a knowledge worker.					
2.	Adopt a phenomenographic view on knowledge.					
3.	Learning is an inevitable part of knowledge work.					
4.	Learning is a life-long process.					
5.	Learners are active knowledge constructors.					
6.	Learning is view as the social construction of knowledge					
7.	Teachers are motivators, relevant guides, and learning environment designers.					
8.	The *course material* is an open and dynamic set of sources.					
9.	Information technology is a natural component of the learning environment.					
10.	Much of the work knowledge workers do is associated with cognitive efforts. Hence, knowledge workers need tools that support cognitive tasks – cognitive tools.					
11.	New design methods are needed for the development of physical-virtual learning environments.					
12.	All physical environments are potential virtual learning environments.					
13.	The working environment for a knowledge worker consists of personal and flexible toolboxes.					
14.	Learners are not digitally naked.					
15.	Teachers should be eager and open-minded enough to alter their competencies based on upcoming knowledge reorganisations.					
16.	There is an open market for cognitive and communicative tools.					

Table 1. Implications for the design of interactive learning environments, when applying the knowledge worker approach. Much of the last decade's writing about interactive learning technologies seems to imply decreasing role for real, physical objects. Learners are portrayed as increasingly virtual creatures, spending their time in virtual laboratories, taking virtual measurements, collaborating within virtual learning communities, and

communicating their results in virtual notebooks and journals. It is strange that those people designing these kind of learning environments are not aware of the need and importance of physical objects in learner's life.

In this paper we have argued that virtual-physical environments can be important artefacts that amplify, support, and unburden the knowledge worker. They have the possibility to affect the task, and the user's state of knowledge. It points to the introduction of new devices and new artefacts for learners to learn with, and to integrate them in a virtual-physical environment. In doing so, virtual-physical environments can remake the surroundings of knowledge workers, enriching their lives by merging a sense of intellectual work with a sense of physical place.

REFERENCES

Arias, E., Eden, H., & Fischer, G. (1997). Enhancing Communication, Facilitating Shared Understanding, and Creating Better Artifacts by Integrating Physical and Computational Media. *Designing Interactive Systems (DIS 97): Processes, Practices, Methods and Techniques Conference Proceedings*. ACM Press.

Barr, A., & Feigenbaum, E. A. (1982b). Application-oriented AI research: Medicine. In A. B. E. A. Feigenbaum (Ed.), *The Handbook of Artificial Intelligence* (1 ed., Vol. 2, pp. 175-222): William Kaufmann, Inc.

[Bluetooth] (1999). Special Interest Group web page *http://www.bluetooth.com*.

Broberg, A. (1997) Cognitive Tools for Learning. Licentiate thesis. Umeå University, report UMINF 97.18.

Cochinaux, P & de Woot P. (1995). Moving Towards a Learning Society. A CRE-ERT Report on European Education.

Drucker, P. F. (1973). Management: Tasks, Responsibility and Practices. New York: Harper & Row.

Drucker, P. (1993). The Post Capitalist Society, Editorial Sudamericana.

Eden, H., Eisenberg, M., Fischer, G., & Repenning, A. (1996) Making Learning a Part of Life. *Communications of the ACM*. Vol 39.No. 4. (40-49).

Enkenberg, Jorma. (1995). Complex Technology-Based Learning Environment. In R. Tennyson & A. Barron (Eds.), *Automating Instructional Design: Computer-Based Development and Delivery Tools* (245-264). NATO ASI Series.

European Round Table of Industrialist (ERT). (1997). Investing in Knowledge: The Integration of Technology in European Education. An ERT publication.

Feiner, S., Macintyre, B., & Seligmann, D. (1993). Knowledge-based augmented reality. In *Communications of the ACM* 36, 7 (Jul. 1993), pp53-62.

Fischer, G. (1999). Lifelong Learning Mindsets. *Proceedings of ICCE 99-New Human Abilities for the Networked Society*- Volume 1, pp.21-30, IOS Press.

Fitzmaurice, G.W., Ishii, H., & Buxton, W. (1995). Bricks: Laying the Foundations for Graspable User Interfaces. In *Proceedings of CHI'95*, ACM Press, pp442-449.

Forrester, J. (1994). Learning through System dynamics as Preparation for the 21st Century. Keynote Address for *Systems Thinking and Dynamic Modeling Conference for K-12 Education*, June 27-29, 1994 at Concord, MA, USA.

Gargarian, G. (1996). The Art of Design. In Constructionism in Practice: Designing, Thinking, and Learning in a Digital World, edited by Kafai, Y & Resnick, M, (125-160). Lawrence Erlbaum Associates, Publishers.

Gentner, D., & Nielsen, J. (1997). The Anti-Mac Interface. In *Communications of the ACM*, August 1997/Vol. 39, No 8, pp70-82.

Hoyles, C., & Noss, R. (Eds.). (1992). Learning Mathematics and LOGO. London: The MIT Press.

Ishii, H., & Ullmer, B. (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of CHI'97*, ACM Press, pp234-241.

Janlert, L. -E. (1995). Hemma i Cyberspace. Scandinavian University Press, ISBN 91 88584 06 2.

Kearsley, G. (1994) Explorations in Learning & Instruction: The Theory Into Practice Database. See *http://gvis2.circ.gvu.edu/~kearsley/*.

Kidd, A. (1994). The Mark are on the Knowledge Worker," presented at The Human Factors in Computing Systems (CHI'94), Boston.

Lave, J. & Wenger, E. (1991). Situated Learning: Legitimate Peripheral Participation. Cambridge University Press.

Mann, S. (1997). Wearable computing: A first step toward personal imaging. In *IEEE Computer*, pages 25-31, February 1997.

Mantovani, G. (1996). New Communication Environments: From Everyday to Virtual. Taylor & Francis.

Marton, F., Hounsell, D., & Entwistle, N. (1986) Hur vi lär. (Vol. 1). Kristianstad: Raben & Sjögren.

Milrad, M. (1999). Designing an Interactive Learning Environment to Support Children's Understanding in Complex Domains. Proceedings of ED-MEDIA 99, Seattle, USA, AACE.

Nardi B. (1996). *Context and consciousness: Activity Theory in Human-Computer Interaction*. Cambridge, MA: MIT Press.

Norman, D. A. (1988). The Psychology of Everyday Things. Basic Books, New York.

Papert, S. (1980). *MINDSTORMS: Children, Computers, and Powerful Ideas*. Brighton: The Harvest Press.

Papert, S. (1993). The Children's Machine: Rethinking School in the Age of the Computer. New York: Basic Books.

Pederson, T. (1999). Physical-Virtual instead of Physical or Virtual — Designing Artefacts for Future Knowledge Work Environments. *In Proceedings of HCI International'99*, 8th International Conference on Human-Computer Interaction, Munich, Germany.

Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K., Silverman, B. (1998). Digital Manipulatives: New Toys to Think With. *Proceedings of the CHI '98 conference*. ACM Press.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. Educational Research, 27(2), 4-12.

Shuell, T. (1988) The role of the student in learning from instruction*.* *Contemporary Educational Psychologist* 13, 276-295.

Shute, V. J., & Psotka, J. (1994). Intelligent Tutoring Systems: Past, Present and Future. In D. Jonassen (Ed.), *Handbook of Research on Educational Communications and Technology*: Scholastic Publications.

Soloway, E., Jackson, S., Klein J., Quintana C., Reed J., Spitulnik J., Stratford, S., Studer S., Jul, S., Eng, J., Scala, N. (1996). Learning Theory in Practice: Case Studies of Learner-Centered Design. CHI 96 Conference Proceedings, ACM Press.

Soloway, E., & Guzdial, M. (1998). Designing for Learners. Paper presented at the CHI 98 Learner-Centered Design Workshop, Los Angeles, April 1998.

Spector, M & Davidsen, P.(1997a). Creating Engaging Courseware Using Systems Dynamics. *Computers in Human Behavior*, Volume 13, Number 2 (pp. 127-156).

Wasson, B. (1996). Instructional planning and contemporary theories of learning: Is this a self-contradiction? In P. Brna, A. Paiva & J. Self (Eds.). *Proceedings of the European Conference on Artificial Intelligence in Education*, 23-30, Lisbon: Colibri.Weiser, M. (1991). The Computer for the 21st Century. In *Scientific American*, 1991, 265 (3), pp.94-104.

Wasson, B. (1997). Advanced educational technologies: The learning environment. *Computers in Human Behaviour*, 13(4), 571-594.

Weiser, M. (1991). The Computer for the 21st Century. Scientific American, 1991, 265 (3), pp.94-104.

Wilson, P. (1993). *Some consequences of information overload and rapid conceptual change.* Paper presented at the Information Authority and User Knowledge, Centrum för Biblioteks- och informationsvetenskap och Högskolan i Borås, Sweden.