

Information technologies *in teacher education*

Issues and experiences for countries in transition

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Supporting Teachers and Learners to Design Powerful Learning Environments

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Abstract

Recent developments in instructional design often involve open educational systems or open learning systems. In these modularised learning systems the learner decides what, when, how, with what, where, and at what pace to learn. Not only the control of the learning is to the learner, but also the designing of his learning environment. Learners' roles differ, but also teachers have to change their roles from instructor to guide. Information support systems have to be built in order to inform the learner about possibilities to learn. Teachers' roles have developed during times in which learning environments gradually differed. Learning environments can be discerned historically into three broad categories and related roles for teachers. The first category stems from developments in behaviouristic approaches to teaching, like programmed instruction and ruled-instruction. Learning is heavily controlled by the environment that sets conditions and parameters for action. The role of media and technology is separated from the role of the teacher. They are operating apart from each other. The second category of learning environments has been influenced by cognitive learning theory. More emphasis is put on aspects of adaptive instruction and on knowledge representations as a condition for learning. Teachers adapt technology and are collaborating with technology in order to optimise learning outcomes. The role of technology in instruction and the role of the teacher are integrated. The third, most recent, category comprises constructive beliefs and ideas about learning and instruction. Technology is not controlling learning any more but

plays a supportive role, informing and advising the learner. The teacher's role is integrated in this supportive function, also by advising and meta-cognitively supporting the learner. In some instances the role of the teacher is amplified by technology. Teacher and technology are collaborating in supporting the learner in achieving learning outcomes that were not possible before. In this sense, technology not only supports the learner but also supports the teacher to play an effective and affective role in knowledge acquisition and knowledge construction and in practice of skill in the learner. This contribution describes research directed to the roles of teachers and students in designing powerful learning environments.

1. Learning and the evolution of apprenticeship

1.1 Apprenticeship: From central paradigm to decline

Recently there has been a growing interest in the characteristics of the task environment of the learner, its physical as well as cognitive characteristics. Traditionally, this environment consisted of teacher(s) and learners. In ancient times, learning was provided by the master who teaches the novice learner by introducing him experiences and ideas in an environment that was almost identical to the real context of performing a job. In medieval times in Europe the so-called guild system was very prominent as a vocational-training system. Learners learned professional skills by interacting with real tools also used by experts. They gradually became experts themselves through a process in which the control of the master faded. This form of apprenticeship learning has almost now disappeared in Western educational systems. It has become a small part of the curriculum of vocational-training systems, at the end of the formal training within schools. Within these systems emphasis is laid on the acquisition of basic skills and also of cognitive skills that are supposed to transfer to other situations, in particular the job context. There is no dyadic interaction of master as teacher and learner anymore. Less collaborative learning takes place. Instruction is to be given by a teacher for a class of 20 to 30 learners or even more. Learning research therefore concentrated on the conditions that make effective learning possible within these environments, e.g., instructional strategies to be used by the teacher, communication between teacher and learners, and interaction between learners.

1.2 Technological facilitation of apprenticeship learning

Before the technological revolution came to be an important impetus within the field of learning and instruction, theories of instructional design were assumed to pertain to instruction presented to groups of learners through means such as lectures, demonstrations, and texts. A limited form of communication, almost always one-way, was permitted due to technological inadequacies and constraints. But quite recently, great progress has been made in the computation and storage capacity of technological aids and this has a positive effect on designing intelligent learning environments. Yet, the main goals

to accomplish are still to promote the relevant cognitive processes and also to promote their immediate use in context. Maybe due to a nostalgic tendency to the good old times there is a growing interest in apprenticeship learning (e.g. Resnick, 1987; Collins, Brown & Newman, 1989; Brown, Collins & Duguid, 1989). Their perspective work on apprenticeship learning originates from cognitive-anthropological studies by Scribner, Rogoff and Lave (in Rogoff & Lave, 1984). They later stated that effective learning has to be situated in a context similar to the one in which the skills will be used, that learner and master or coach have to be active participants in this intellectual enterprise, and that cognitive processes are to be externalized and displayed for reflection. Success depends on the instantiation of these design features of apprenticeship in an intelligent learning environment. Learning environments can thus become effective instructional environments if the purpose of the design is to facilitate the cognitive processes by letting the learner solve authentic problems within the deMed learning environment. In this way it is possible to create what Montague (1988) calls a working environment or functional context for learning.

1.3 Computer-based environments and new contexts for apprenticeships

Pirolli and Greeno (1988) stated that due to current technology, three kinds of computer-based instructional environments have been provided. According to these authors one class of instructional environment "*...involves an exploratory microworld where learners can manipulate objects in a computational system that is designed to embody a set of theoretical principles.*" Another kind of instructional environment "*... involves a sort of apprenticeship in which a teacher first models behaviour and then coaches learners as they work to acquire the skill.*" As learning progresses the influence of the coach is fading and the learner is trying to solve problems independently. A third kind of instructional environment emphasizes "*...collaboration, either among learners or between the learners and the teacher on intellectual goals that they share.*"

Due to these recent possibilities learning knowledge and skills can take place in a relevant environment of their intended use, although this transmission of knowledge and culture is provided at a higher level of aggregation. Realistic environments provide a micro-world for the user in such a way that the principles of apprenticeship learning are pertinent. Highly sophisticated computer and other technological aids simulate job contexts and other real-life situations to enhance learning and to facilitate cognitive functioning. Hence, learning environments are to be studied at the various system levels on which (simulated) contexts can be created. These fictional contexts can serve as discovery worlds where the learner controls the outcome or as instructional environments where the teacher or program control the outcome.

2. The nature of learning environments and their design

2.1 Constructivists learning and access to powerful tools

In her introduction to the book contributed to Robert Glaser, Resnick (1989) argued that current instructional theory comprises three perceptions of human learning: learning being a process of knowledge construction, learning as knowledge-dependent, and learning as tuned to the situation in which it takes place.

The consequence of adopting such a constructive view on learning is that instruction will be instrumental to the support of the construction of knowledge from experience. Functional contexts (Montague, 1988) have to be designed to provide the learner access to tools with which encountered problems can be solved. We already are familiar with learner control in multimedia environments. These environments, developed by highly specialized cognitive engineers, enables the learner to select his own trajectory through the media landscape. But a constructivist approach will offer more to the learner. User-friendly tools from which the learner not only selects his trajectory, but selects the landscape too. These provocative ideas do not match very well with current instructional design theories.

Current instructional design is directed to designing support tools that provides the designer a set of functions for making training development more efficient and making training materials more effective.

2.2 Third-generation instructional systems design

After the first generation of the behaviouristic assembly-line linear instructional design theories and the second generation of cognitively oriented instructional systems design, a third generation emerges: user-centred instructional systems design. In this third generation tools will be developed that can be of functional use for the designer and teacher, but also for the learner himself.

Third-generation Instructional design places the learner much more in focus than traditional instructional design did. It is the learner that controls the learning process and the instructional designer or teacher only set conditions for an effective learning process. If we take for instance new learning technologies, such as computer-assisted learning environments in which multimedia systems have been implemented, than we observe a tendency to let the learner manage the learning process. Formal instruction is albeit set aside.

Recent developments in instructional design involve open educational systems or open learning systems. In these modularized learning systems the learner decides what, when, how, with what, where, and at what pace to learn. Not only the control of the learning is to the learner, but also the designing of his learning environment. Even needs assessment has to do with open learning. Learners who may choose their own way of learning, will also want to know more about their own needs. In other words, they want to assess their own needs and have information about the way these needs can be filled. Teachers have to change their roles from instructor to guide. And even information support systems have to be built in order to inform the learner about possibilities to learn.

2.3 Learning landscapes

In the third generation of instructional design needs assessment is integrated with open learning (or open instruction) systems. To fulfil this need, designers have to create educational or learning landscapes in which learners can stroll through the use of many learning tools. We may think of real landscapes in schools, companies or community colleges in which teachers in another role, as guide or facilitator, can inform learners and give them advice. We may also think of artificial landscapes in which learners learn in partnership with the learning technologies. Recently developed distributed intelligent technologies afford the learner a partnership with results greatly dependent on joint effort. The partnership with computer technologies and tools is very real in this respect. It entails according to Salomon, Perkins and Globerson (1991) three major ingredients one finds in human partnership: (a) a complementary division of labour that (b) becomes interdependent and that (c) develops over time. An interesting point, indicated by these authors, is that even novice learners might gain from certain computer tools that support cognitive processes. Novice learners might engage in cognitive activities out of their reach without the technological partnership in traditional educational environments. Current computer simulation within multimedia systems allows the construction of a simulated reality in which learners do not need to commit anything to memory. This kind of systems let the learner engage in intellectual activities at a level that transcends the limitations of his own cognitive system.

2.4 New roles for teachers

For teachers, new roles emerge in this era of new information and communication technologies. Simons (1991) describes different roles for teachers facing new challenges of learning and instruction. Challenges that are related to not only new developments of information and communication technology, but also to new insights in learning and instruction, and especially in the transfer of learning. The first role of teachers Simons distinguishes, is teacher as external monitor. The teacher monitors the learning process and makes explicit the decisions that have to be made by the learner in order to optimize the learning outcomes. The second role is teacher as expert model. In this role, teachers demonstrates domain specific problem solving and thinking skills, with a clear emphasis on the process of reaching outcomes and not on the outcome only. The third role is directed to meta-cognitive aspects of intellectual functioning. The teacher has the role of meta-cognitive guide that stimulates reflection and articulation of thinking and regulation processes. The fourth role comprises scaffolding. During the first phases of the instructional and learning process the teacher is the one who is in charge but gradually this influence fades and the learner is taking over the responsibility. The fifth role is directed to goal setting, to gaining self-confidence and to promoting motivation and self-control and consequently to attributing success and failure.

2.5 New roles and new learning environments

These new roles develop during times that learning environments gradually differ. To be short, learning environments can be discerned historically into three broad categories and related roles for teachers.

The first category stems from developments in behaviouristic approaches to teaching, such as programmed instruction and rule-instruction. Learning is heavily controlled by the environment that sets conditions and parameters for action. The role of media and technology is separated from the role of the teacher. They are operating apart from each other.

The second category of learning environments has been influenced by cognitive learning theory. More emphasis is put on aspects of adaptive instruction and on knowledge representations as a condition for learning. Teachers adapt technology and are collaborating with technology in order to optimize learning outcomes. The role of technology in instruction and the role of the teacher are integrated.

The third, recent, category comprises constructivistic beliefs and ideas about learning and instruction. Technology is not controlling learning any more but plays a supportive role, informing and advising the learner. The teacher's role is integrated in this supportive function, also by advising and meta-cognitively supporting the learner. In some instances the role of the teacher is amplified by technology. Teacher and technology are collaborating in supporting the learner in achieving learning outcomes that were not possible before. In this sense, technology not only supports the learner but also supports the teacher to play an effective and affective role in knowledge acquisition and knowledge construction and in practice of skill in the learner.

3. Supporting learning and instruction

3.1 Cognitive technologies

Above we described three aspects of supporting learners and teachers in learning environments. These are, (a) supporting the learning process by supporting the student in the acquisition and construction of knowledge and the practice of skill, (b) supporting the teacher as a designer of powerful learning environments, and (c) supporting the student as a designer of his own learning environment. A means to accomplish such a supportive function is the application of tools that facilitate these three functions of support. The tools or as we prefer to call them, cognitive tools or in a generic sense cognitive technology, are mechanisms or devices to promote, support, and facilitate knowledge acquisition and construction, and the practice of skill.

3.2 Cognitive learning tools

In the book about cognitive tools for learning, Jonassen (1992) introduced tools as "... *extensions of human beings that partially differentiate humans from lower order species of animals.*" Tools have been designed for various purposes and to serve an impressive number of functions. Jonassen writes that it is the irony of education that only few tools have been designed to optimize the process of education, by facilitating learning. Learning tools are a special kind of educational tools. Educational tools are meant to facilitate the whole process of education on the level of organisation or classroom. Cognitive learning tools are specially designed to promote and support the acquisition and construction of knowledge and the practice of skill of the individual learner. These

cognitive tools are to be differentiated from task-specific tools and have to be generalizable tools that can facilitate cognitive processing (Jonassen, 1992). Jonassen sets limits by characterising cognitive tools. They can be regarded internal or external to the learner. Internal by for instance cognitive or meta-cognitive learning strategies. External by "... *cognitive tools as both mental and computational devices that support, guide, and extend the thinking processes of their users.*" The tools to be described here are computer-based devices and other environments, external to the learner, that extend the knowledge acquisition and construction and skill-practice processes of the individual learner. The teacher can apply these tools in order to design powerful learning environments, but on the other hand, the learner himself, in a constructivistic sense, can apply these tools too. In both cases, the tools promote and facilitate the acquisition and construction and the practice of skill.

3.3 Cognitive tools and the application of cognition

The support of the cognitive tool to the process of thinking and other cognitive processes, domain-dependent as well domain-independent processes, is also emphasized by Kozma (1992): "*By supporting processing and compensating for limits of the system, a cognitive tool can amplify cognition. In this role the computer extends the learner's thought processes by providing an external model of internal cognitive processes. In turn, by making these internal processes more public and available for examination and reflection, the computer can help the learner improve on these cognitive processes. (...) Thus, not only may the cognitive tool aid in the learning of the particular knowledge domain to which it is applied, it may contribute to the development of general purpose learning skills and strategies.*"

3.4 Functionality perspectives

In utilizing cognitive tools, formal instruction is albeit set aside, in favour of task performance. Mayes (1992), therefore, stresses the action oriented nature of using tools: "... *essentially comprehension tasks which require a learner to analyse material at a deeper level than would normally follow from a simple instruction to learn' Deep learning results as a kind of by-product of using cognitive tools task, as it does from any such analytical search for meaning.*"

The functionality of cognitive tools can be compared to the functionality Montague (1988) referred to in describing the cognitive-based learning environments. These environments, in his view, provide a functional context model for instruction. The main purpose of learning environments is to offer the learner a functional context that enables him to use what is acquired. Montague (1988): "*The design of the learning environment thus may include clever combinations of various means for representing tasks and information to students, for eliciting appropriate thought and planning to carry out actions, for assessing errors in thought and planning and correcting them. I take the view that the task of the designer is to provide the student with necessary tools and conditions for learning. That is to say, the student needs to learn the appropriate language and concepts to use to understand situations in which what is learned is used and how to operate in them.*"

In sum, cognitive tools provide the learner a cognitive technology external to him, to support knowledge acquisition and construction and practice of skill, by facilitating and optimising cognitive processes underlying knowledge acquisition and construction and practice of skills. Deliberately planned or not, this cognitive technology is made up of knowledge about cognitive processes and conveyed to the learner by means of external devices or models. We follow Kozma by saying that the cognitive tool supports the learner in acquiring domain knowledge but also "..., it may contribute to the development of general purpose learning skills and strategies. " In some instances we prefer to use the word technology instead of tool because of its generic meaning. Obviously, the teacher plays the role as facilitator by creating conditions for optimal application of these tools, either indirectly by letting the learner deploy the tools or directly by letting the learning environment deploy the tools. As said before, in both cases the aim is to promote cognitive processes in the learner.

3.5 Cognitive tools as agents of constructivism

The view presented here about cognitive technology expresses the distinction drawn by Salomon, Perkins, and Globerson (1991) between cognitive effects with and of information processing technologies. New technologies can be applied to solve problems, e.g. arithmetic problems, but this technology can also be applied to learn to solve problems. Jonassen (1992), in his discussion about the nature of cognitive tools, refers to the distinction with and of technology: "*Cognitive tools represent learning with information processing as opposed to learning of them (Salomon, Perkins & Globerson, in press). Learning with technology amplifies the learner's cognitive processes while using those technologies. Computer-based cognitive tools are in effect cognitive amplification tools that are part of the environment. Environments that employ cognitive tools distribute cognition to the person (Perkins, 1990). Cognitive tools are intelligent resources with which the learner cognitively collaborates in constructing knowledge.*"

Jonassen (1992) defines the following descriptive epistemological system to derive at the constructive nature of cognitive tools. His epistemological system has three dimensions: Engagement (active - passive), Generativity (presentation - creation), and Control (student - teacher/system). He continues by defining the constructive nature of cognitive tools. "*Cognitive tools are constructive because they actively engage learners in creation of knowledge that reflects their comprehension and conception of the information rather than focusing on the presentation of objective knowledge. Cognitive tools are learner controlled, not teacher or technology-driven. Cognitive tools are not designed to reduce information processing, that is, make a task necessarily easier, as has been the goal of instructional design and most instructional technologies. Nor are they 'nertip' tools (Perkins, 1990) that learners use naturally, effortlessly, and effectively. Rather cognitive tools provide an environment and vehicle that often requires learners to think harder about the subject matter domain being studied while generating thoughts that would be difficult without the tool. They are cognitive reflection tools and amplification tools that help learners to construct their own realities using the constructs and processes in the environment on a new content domain.*"

3.6 Research focuses for cognition

In our research three perspectives of cognitive technology are approached, discussed, and experimentally dealt with: (a) to promote and support the learner and his selfregulative power, (b) to facilitate and to create the designs of environments powerful enough to support the learner in the process of knowledge construction and practice of skill, and (c) to support the instructional designer creating landscapes including cognitive tools, from which the learner can select his own trajectory.

The research question central to the activities performed in our current research program about cognitive technology, is: What characteristics do cognitive tools have, under what conditions can they be applied, and what design characteristics can lead to optimally design these tools, in order to promote, support, and facilitate knowledge acquisition and construction, and practice of skill?

4. Research activities

The research carried out within the framework of this program is directed to three areas of study, to concentrate (a) on cognitive tools for the learner and the cognitive effects, (b) on cognitive tools comprising the environment, and (c) on cognitive design tools for the designer to design cognitive tools.

4.1 The learner

4.1.1 *Supporting cognitive processes (funded by University of Twente)*

Projects related to the support of cognitive processes, pertain to the knowledge utilization by employees and by older adults. In both situations, difficulties become apparent in retrieving relevant knowledge and utilize this knowledge in new task situations. Tools have to be developed that facilitates the improvement of the cognitive processes and thereby leading to an effective and efficient utilization of acquired knowledge.

4.1.2 *Generating and testing hypotheses in meaningful problem-solving (funded by University of Twente and by DELTA)*

Exploration or scientific discovery is a learning and instructional approach that is well in line with the conception of the learner as an active agent of knowledge acquisition. A theory has been developed, from Klahr & Dunbar's scientific discovery as dual search', that introduces two search spaces: a hypothesis space and an experiment space. Recent work of De Jong and Van Joolingen led to an extension: hypothesis space is structured into a variable and a relation space, and hypothesis space is divided into a number of regions. Prior knowledge is regarded as the personal configuration of hypothesis space. In the studies to be carried out prior knowledge will be manipulated as its effects on learning behaviour are assessed.

4.1.3 *Promoting conceptualising (funded by Dutch Organization of Pure Research)*

A learner can gradually master a domain by being involved in mental models that increase in sophistication and complexity. This increase pertains to the different levels of

knowledge with which a domain can not only be described but also by which the utilization of domain knowledge can be characterised. Research is directed to encourage learners to fulfil tasks that are designed to support learners to utilize the appropriate knowledge (Goei & Pieters, 1991).

*4.1.4 Promoting to assess knowledge gaps and to adequately choose information
(funded by University of Twente)*

Two major problems users of knowledge support systems, such as on-line documentation or expert systems, often encounter, are related to the compatibility of information presented to the task performed at that very moment: (a) They often do not realize that they need help, and (b) accessing the available help is problematic. Recent research revealed that in many cases learners or performers were not supported by the information nor did they indeed ask for help. The two aspects of the problem can be elaborated: the finding the problem' and the constraining the utilisation'. The first, constructivistic, problem pertains to the inability of the performer to adequately formulate his knowledge need. He is not able to find and define the problem (the difference between what he knows and what he needs to know). In the constructivistic sense, he has difficulty in tracing the bugs in his knowledge base. The cognitive tool to overcome this knowledge problem can be formulated as triggering a cognitive conflict. This tool includes three types: surprise, perplexity, and discoordination. The second, minimalist, problem pertains to the minimal amount of information presented to the learner while performing, and to the moment of information presentation. The amount of information not only pertains to the number of information elements but the content as well, either declarative knowledge, procedural knowledge or conditional knowledge (Pieters & Van der Meij, 1994).

4.2 The environment

4.2.1 Designing hypothesis scratchpads to generate problem-solving and exploratory behaviour (funded by University of Twente and DELTA)

A theory (an extension of Klahr & Dunbar's Dual Space Theory) has been developed (Van Joolingen, 1993) in which exploratory learning is seen as a search through two spaces: an experiment space and a hypothesis space, of which hypothesis space again is divided into a variable and a relation space. The learner's search moves are supposed to be taken place within the learner's personal hypothesis space. A tool has been designed to structure and facilitate this exploratory behaviour, the so-called hypothesis scratchpad (Van Joolingen, 1993; Van Joolingen & De Jong, 1991, 1992). A hypothesis scratchpad is a software tool that provides the learner all necessary elements for composing hypotheses (variables, relations, and conditions). By selecting these elements with a mouse and dragging these to a hypothesis window the learner creates a hypothesis. In this window the learner may save hypotheses and mark them as true or false.

4.3 The designer

4.3.1 Advice systems for designers (funded by DELTA)

In the SMISLE-project (System for Multimedia Integrated Simulation Environments) an Advice System will be developed that comprises all the pedagogical advice an author may need. It intends to provide authors with information that may be helpful for the decision-making process in designing computer-based multimedia simulation learning environments. The SMISLE Advice Module consists of a number of separate, but interconnected modules. The main modules are: the MEASURES module, containing information on the SMISLE instructional measures; the ADVICE RULES module, containing a rule base which can infer hints for using instructional measures on the basis of characteristics of the simulated domain and of the target learner population; the BACKGROUND module, containing background information on exploratory learning with computer simulations; and, a GLOSSARY containing definitions of specific SMISLE terminology. This ADVICE MODULE will be used in a number of studies, as a design tool to be evaluated, and as an experimental tool to provide evidence about the process of designing by the author.

4.3.2 Design tools for complex teaching-learning environments (funded by Organisation for Provision of Labour)

Work simulations can be characterized by their preferred knowledge acquisition processes and the tasks to be performed in order to trigger those processes. The theoretical framework for categorizing and designing work simulations is based upon a framework meant for designing computer simulation. De Jong (1991) distinguishes four major characteristics of computer simulations that can establish a design model for simulations: a formal model, learning objectives, learning processes, and activities. The processes taking place in the simulation have to be based upon a model. In computer simulations a mathematical model will be used. In work simulation a more qualitative version of a model will be implemented. Objectives pertain to the following categories: acquisition of knowledge of the model, practising relevant technical and social skills, and practising knowledge acquisition skills. The learning processes include the following cyclic phases: authentic acting, reflecting, abstracting, and exploring. The activities reveal the essential cognitive processes and activities necessary to fulfil assignments within work simulations. Design tools will be developed based upon this framework (Pieters & Brouwer, 1992).

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