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Self-regulation and computer based learning*

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In recent years, interest in self-regulated learning has risen considerably. While self-regulatory activities are controlled cognitively, they encompass more than the monitoring of cognitive activities. Motivational and emotional processes are also important in learning and they too need to be regulated. At the same time, multimedia computer programs and the Internet have come to play an important role in present day's learning environments. The question therefore arises as to what extent these new technologies facilitate the acquisition and improvement of self-regulated learning strategies. In the present article, we first explore the field of self-regulated learning and then try to come up with an answer to the question posed.
Key words*: Self-regulated learning, metacognition, self-regulation, new technologies.*

En los últimos años, el interés por el aprendizaje autorregulado se ha desarrollado considerablemente. Aunque las actividades autorreguladas son controladas cognitivamente, abarcan más que el control de las actividades cognitivas. Los procesos motivacionales y emocionales también son importantes en el aprendizaje y también requieren ser controlados. Al mismo tiempo los programas multimedia e Internet han logrado un papel importante en los entornos de aprendizaje y se presenta la pregunta de si las nuevas tecnologías facilitan la adquisición y el perfeccionamiento de las estrategias autorregulativas. En este artículo exploramos primero el campo de aprendizaje autorregulado y después tratamos de dar una respuesta a la pregunta planteada.
Palabras clave*: aprendizaje autorregulado, metacognición, autorregulación, nuevas tecnologías.*

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In writing about a specific topic, one of the most difficult problems seems to be to find an appropriate frame of reference and an adequate level of analysis. Although cognitive psychology has helped us greatly in understanding how individuals perceive, think, learn and solve problems, it has reduced man to an information processing machine – a computer. We therefore need a larger frame of reference, a frame that acknowledges that individuals have feelings and motivation, that they are conscious of themselves, that they plan their actions in order to pursue goals that they themselves have set, and that they invest effort in doing so.

Self-regulation refers to activities in which individuals engage while trying to achieve specific goals. Self-regulatory activities become particularly important when obstacles arise in the course of the pursuit of goals and additional investment of effort is required. Self-regulatory activities are directed at performances in very diverse areas (see Boekaerts, Pintrich & Zeidner, 2000, for a recent overview), but the focus of this paper is on self-regulatory activities in learning processes.

Cognitive psychology defines learning as the acquisition of knowledge, but a broader, perhaps more appropriate definition would hold that learning comprises all activities that increase an individual's knowledge and understanding of the world and that help him to develop skills which he uses to interact meaningfully and successfully with his environment.

Self-regulation in learning and instruction has attracted a considerable amount of interest in recent years. At the same time, computers have come to play an important role in today's learning environments. With the advent of the new Information and Communication Technology (ICT), computer programs have become more complex and it can be argued that the high degree of complexity at least requires and possibly affords a higher degree of self-regulation.

The present article will first discuss the concepts of metacognition and self-regulation and will then turn to the question to what extent the new ICT will require or even facilitate the acquisition and maintenance of self-regulatory skills in learning processes. It is not, however, intended to give a systematic, exhaustive overview of the literature on computer-based learning.

Self-regulation and metacognition

There is some affinity between the terms self-regulation and metacognition. However, as Brown (1987) pointed out quite a while ago, the term metacognition is far from being used unequivocally. According to Flavell (1971), metacognitive knowledge refers to persons, tasks, and strategies. Knowledge about persons may further be subdivided into intraindividual, interindividual and universal knowledge. Intraindividual knowledge refers to one's own personality characteristics and is related to beliefs people have about themselves which include those beliefs that Bandura (1997) has called self-efficacy beliefs. Interpersonal knowledge encompasses knowledge about differences in people while universal knowledge refers to knowledge and beliefs that are common in a specific culture. Of particular interest in this context are naive psychological assumptions or subjective theories about learning and thinking. Other authors have termed the latter kind of knowledge epistemological beliefs, and it is well-known that dysfunctional epistemological beliefs may make successful goal pursual difficult, if not impossible (Schoenfeld, 1985). A student who believes that only a highly gifted person will be able to cope with mathematics will have enormous difficulties surviving in his math class if he happens to consider himself not to be highly gifted.

Other authors have suggested dividing metacognitive knowledge into declarative, procedural, and conditional knowledge (Paris *et al.*, 1983; Schmitt & Newby, 1986) where conditional knowledge points to the circumstances for which a specific cognitive strategy, given a specific goal, is particularly suitable. There seems to be, however, some consensus that metacognition basically has two features: knowledge about oneself and self-regulation of cognitive activities or cognitive monitoring (Borkowski *et al.*, 1990; Flavell, 1971, 1979; Hacker, 1998a; Paris & Winograd, 1990).

Schraw & Dennison (1994) developed a 52-item inventory to assess metacognitive awareness, distinguishing between knowledge of cognition and regulation of cognition. Self-regulation of cognitions as a metacognitive process includes the development of a plan on how to go about acquiring knowledge in a given domain or to solve a specific problem, and the execution, monitoring and evaluation of this plan (see e.g. Brown, Bransford, Ferara & Campione, 1983). Schoenfeld (1985) systematically studied the problem-solving activities of his mathematics students by analyzing their video-based protocols. In doing so, he used a scheme that included the following steps: 1. read the problem, 2. analyze the problem (encode), 3. explore (the problem space), 4. (design a) plan, 5. implement (the plan) and 6. verify (the correctness of the solution). Artzt & Armour-Thomas (1992) slightly augmented the Schoenfeld scheme and used it as a framework for protocol analysis of mathematical problem- solving. They found it to be a useful device for the study of the interplay of cognitive and metacognitive activities students engage in when they solve mathematical problems.

Kluwe (1982) took a closer look at metacognitive self-regulation; he distinguishes between executive monitoring and executive regulation. The term «executive monitoring» describes metacognitive processes that are used to assess ongoing cognitive activities. Identification is a metacognitive strategy to characterize this activity with regard to its content, while checking aims to assess its quality. Evaluation refers to the evaluation of the results of checking. Finally, executive monitoring comprises preview strategies.

The term «executive» regulation describes the regulation of the ongoing cognitive activities. Regulation of cognitive capacity deals primarily with the cognitive effort a person is willing to invest in pursuing a given goal or how he wants to distribute his efforts to various parts of his information processing. Regulation of the object has to do with how people direct their attention to different aspects of the task they are doing. Regulation of intensity basically refers to how persistent a person is in her goal pursuing activities. Regulation of speed pertains to the question whether specific processing activities should be added - which would reduce speed - or deleted - which would increase speed.

Although students acquire metacognitive strategies in the course of their academic careers, these strategies may also explicitly be taught (Derry & Murphy, 1986). Interestingly, some of the studies that may be cited in favor of this assertion were conducted in an instructional setting that Collins and his co-workers called «situated learning» (Brown, Collins & Duguid, 1989), or more specifically, «cognitive apprenticeship» (Collins, Brown & Newman, 1989). They present three studies that, in their opinion, are examples of teaching the crafts of reading, writing, and mathematics in a cognitive apprenticeship manner: the work of Palinscar and Brown (1988) on the use of reciprocal teaching to enhance reading comprehension, Scardamalia and Bereiter's (1985) article on the procedural facilitation of writing, and the publications by Lampert (1985) and Schoenfeld (1985) in the field of mathematics.

Students do indeed benefit from this kind of instructional setting. Palincsar & Brown (1988), for example, aimed to improve students' monitoring of text comprehension. Students were therefore instructed to (1) summarize paragraphs, (2) to ask questions about each paragraph, (3) to clarify ambiguities, and (4) to make predictions about succeeding paragraphs. The training was done in a reciprocal teaching setting, i.e. teachers and students took turns in actually doing the teaching.

After a three-week training period, students' reading comprehension scores improved from 15 % correct (pre-test) to 85 % correct (directly after the training). Even after a period of six months, students from the experimental group averaged 60 % correct, and it took only one day of renewed reciprocal teaching to bring them back to their 85 % correct level. Also, effects generalised from the experimental to classroom setting, and there was a clear and reliable transfer to laboratory tasks that differed in surface features from the training task.

Evidently, it is important to provide students with the opportunity to observe a competent model and to actively engage in the activities to be learned with the possibility for correction by the model. What seems to be decisive, however, is that in all of these studies, modeling includes the explicit use of metacognitive self-regulation that is then being trained in the coaching phase. And although there are some relatively domain-general metacognitive self-regulation strategies (Davidson & Sternberg, 1998), engaging in a specific learning task also requires domain-specific metacognitive self-regulation. This has been demonstrated for reading and text comprehension by García *et al.* (1998), Hacker (1998b), Maki (1998), and Otero (1998), for writing by Sitko (1998) and for mathematics by Carr & Biddelecombs (1998), de Corte *et al.* (2000) and Schoenfeld (1992).

Self-regulation

While metacognitive activities refer to the self-regulation of cognitive processes, not all self-regulatory activities aim at cognitive processes. Self-regulated learning is more than the regulation of one's own cognitive activities, it also involves motivational and emotional aspects (Zeidner, Boekaerts & Pintrich, 2000).

As is evidenced in the Handbook of Self-Regulation recently edited by Boekaerts, Pintrich & Zeidner (2000), self-regulation is not only employed in monitoring one's learning processes (Boekarts & Niemivirta, 2000; Pintrich, 2000; Rheinberg, Vollmeyer & Rollett, 2000; Schunk Ertmer, 2000; de Corte, Verschaffel & Op't Eynde, 2000; Weinstein, Husman & Dierking, 2000), it also plays an important role in managing social activities (Jackson, Mackenzie & Hobfoll, 2000; Vancouver, 2000) and in coping with stress and in taking care of one's health (Maes & Gebhardt, 2000; Brownlee, Leventhal & Leventhal, 2000; Endler & Kocovski, 2000; Creer, 2000).

Self-regulated learners have been described as students who «seek challenges and overcome obstacles sometimes with persistence and sometimes with inventive problem solving. They set realistic goals and utilize a battery of resources. They approach academic tasks with confidence and purpose. The combination of positive expectations, motivation, and diverse strategies for problem solving are the virtues of self-regulated learns» (Paris & Byrnes, 1989, p. 169). It is the balance between cognitive skills, metacognitive skills, and motivational styles that characterizes the skilled learner (Short & Weissberg-Benchell, 1989).

As far as the acquisition of self-regulatory strategies is concerned, there is clear evidence that it is difficult to acquire cognitive and metacognitive strategies at the same time. Kanfer and Ackerman (1989) ran a number of experiments designed to show how Air Force personnel learned in a real-time computer simulation to land planes (cognitive strategy) and to monitor their learning processes (metacognitive strategy). They found that giving their subjects the task to monitor their own learning made it more difficult for them to acquire the plane landing skills. From their experiment it may be concluded that monitoring tasks should not be introduced before the learner has passed the declarative state of skill learning and has come to a point where he is ready to proceduralize these skills. The execution of skills that have not become proceduralized requires a substantial amount of mental or information-processing capacity. This is also true for monitoring one's own learning processes. Executing non-proceduralized skills and monitoring activities at the same time will therefore lead to cognitive overload, which in turn will inhibit the acquisition of the skill to be learned.

De Jong & Simons (1990) conducted four studies to find out if students could be trained to become active learners. The training, however, was only partially successful, and they discuss a number of factors that might have impeded active learning. According to the authors, the factors impeding active learning may be subsumed under the following categories: (1) learning conceptions, (2) goals, (3) motivational, volitional and affective factors, (4) the skill of the active learning itself, and (5) regulation skills. Learning conceptions refers to the beliefs students have concerning the process of learning. Only if they believe that learning is a process that they will have to engage in actively will they be inclined to do so. They will also do have to realize that different learning goals (i. e. learning outcomes) necessitate different kinds of learning approaches. Motivational, volitional, and affective deficits may severely hamper the learning process. But even if students do not suffer from any of these deficits, they may lack the knowledge about specific learning strategies. And, finally, they need to know how to plan and to monitor their learning activities.

Somewhat in the same vein, Boekaerts (1995) has argued that in a given learning episode, a student not only has to self-regulate his cognitive activities, but may also have to self-regulate his emotional state and motivational states arising from this. A student's perception of a learning task as challenging will result in a positive emotional state which in turn will motivate him to tackle the task at hand (mastery mode). In contrast, a student whose appraisal of the learning task as being threatening will experience negative emotions which in turn will motivate him to protect his well-being (coping mode) rather than focus his attention on the learning task. In this case, metacognitive and metamotivational activities interfere, thus impeding those processes that are geared at acquiring the knowledge or skill in question. Successful learning requires multiple monitoring which will help the student to achieve a balance between the pursuit of learning goals and ego-protective goals (Boekaerts & Niemivirta, 2000).

According to Winne (1995), self-regulated learning is not only a deliberate and volitional activity. It also contains inherent, non-deliberate features that are grounded in experientially developed knowledge and beliefs, e.g. tacit knowledge and epistemological beliefs. Jehng, Johnson, and Anderson (1993, pp. 23-24) define epistemological beliefs as basic assumptions «about the nature of knowledge and learning ... that establish a context within which intellectual resources are accessed and utilized». Ruthven & Coe (1994) and Schoenfeld (1985) give examples of epistemological beliefs in mathematics, Hammer (1994) studied these beliefs in first year physics students, and Leach *et al.* (2000) investigated the epistemological representations science students develop.

Epistemological beliefs are not the only beliefs that influence a person's learning activities. It also is of great importance whether the learner believes that he will be successful in achieving the goal he is about to pursue or not. Bandura (1986, 1993, 1997) has termed this perceived self-efficacy and defines it as belief «in one's own capabilities to organize and execute the courses of action required to produce given attainments» (Bandura, 1997, p. 3). Students with high self-efficacy beliefs perform better in learning and problem solving tasks (Bouffard-Bourchard, Parent, and Larivée, 1991; Collins, 1982; Schunk, 1989, 1994), are more persistent and invest more effort in their goal-pursual (Bandura & Schunk, 1981; Schunk, 1996), and also employ metacognitive strategies to a higher degree (Wood & Bandura, 1989; Zimmermann & Martinez-Pons, 1990).

In accordance with his social cognitive theory (Bandura, 1986), Bandura argues that self-regulation also encompasses social and motivational skills. Self-regulation in this wider sense is influenced markedly by self-efficacy beliefs (Bandura, 1997). Students with high self-efficacy beliefs are more enduring in their goal pursuits; they do not give up easily and recover rapidly from failure. They show what Renzulli (1986) in his studies of highly gifted students has called task-commitment. Bandura enumerates four sources of self-efficacy beliefs: (1) enactive mastery experience which results from overcoming obstacles through perseverant effort, (2) vicarious experience which is mediated through modeled attainment, (3) verbal persuasion which takes place when significant others express faith in one's capabilities, and (4) physiological and affective states which signal the individual that he is free of stress and negative emotions in his goal pursual activities. There is empirical evidence that self-regulation can be improved through training (Masui & de Corte, 1999), thus bolstering self-efficacy beliefs (Schunk, 1994, 1998). In accordance with Bandura's social cognitive theory, teaching self-regulation using peer modeling has also proven to be successful (Orange, 1999). In studies on the development of self-regulation a shift from other regulation to self-regulation can be observed (Karasavvidis, Pieters, & Plomp, 2000).

Although there are domain-general self-regulating strategies like planning, monitoring and revisioning, self-regulation will many times also require the execution of domain-specific strategies (Alexander, 1995; Boekaerts, 1995; Boekaerts, Pintrich & Zeidner, 2000). It is becoming increasingly clear that successful self-regulation requires the orchestration of a number of different processes. In addition, each of the processes is comprised of many sub-processes thus making self-regulation an extremely complex phenomenon.

In recent years, a number of models have been published to describe self-regulatory processes. Zimmermann (Zimmermann, Bonner, & Kovach, 1996; Zimmermann, 1998a) suggested that self-regulation is achieved in cycles made up of (1) goal setting and strategic planning, (2) strategy implementation and monitoring, (3) strategic outcome monitoring, and (4) self-evaluation and monitoring. He later simplified the model by reducing the cycles to three phases: (1) forethought, (2) performance or volitional control, and (3) self-reflection (Zimmermann, 1998b, 2000).

Winne & Hadwin (1998) presented a model that conceives studying as metacognitively powered self-regulated learning which occurs in four recursively linked and weakly sequenced stages: (1) defining the task, (2) goal setting and planning, (3) enacting study tactics and strategies, and (4) metacognitively adapting studying for the future. At each stage, metacognitive monitoring takes place that may change perception of the task which in turn may lead to a change of strategy.

Returning to her distinction between pursuing learning goals (mastery mode) and self-defensive goals (coping mode), Boekaerts (1996) proposed a model for coping with stress that she later augmented to be a Model of Adaptable Learning (Boekaerts & Niemivirta, 2000). She assumes that (1) task in context, (2) domain-specific and metacognitive knowledge, and (3) self-related and motivational beliefs form the basis for (4) primary and (5) secondary appraisal processes that lead to (6) goal setting and (7) goal striving. Depending on the outcomes of preceding processes, goal striving behavior can be executed in the mastery or in the coping mode.

Carver & Scheier (1990, 1998, 2000) presented a model that depicts self-regulation as a process of feed-back control. They assume that the learner is constantly monitoring his behavior with respect to the goal state, trying to reduce differences between present state and goal state in test-operate-test-exit (TOTE) cycles (Miller, Galanter, & Pribram, 1960). In their hierarchical model, differences can be detected at two levels: one system monitors differences between intermediate outcomes and ultimate goals, while the second detects changes in the rate of progress. A high rate of change (with respect to a reference standard) is likely to induce positive effect in the learner while a low rate of change may cause a negative effect. If viewed as a feed-back system, negative as well as positive differences should be corrected, which is plausible in the first case but counterintuitive in the second because it implies that positive affect resulting from a high rate of change will lead to actions that reduce the rate of change. Carver & Scheier (2000) argue that in this case, the reference standard will be altered in order to make a (comparatively) high rate of change unlikely.

Although feedback is of great importance in self-regulated learning (Butler & Winne, 1995), closed-feedback loop models in self-regulated learning have met with some criticism (Zimmermann, 1995). As Bandura (1991) pointed out, positive feedback may foster the self-efficacy beliefs of the learner encouraging him to set new and more challenging goals for himself. Goal setting is therefore not directly influenced by positive (or negative) feedback, rather it is mediated by self-efficacy beliefs.

Self-regulation and computer-based learning

The use of the new Information and Communication Technology (ICT) is at present not as widespread in Europe as one might think – neither in primary and secondary education (Cox, 1993; Smeets *et al.*, 1999; Steffens, 1999) nor in distance education (Bartolomé & Underwood, 1998; Steffens, 1998, Steffens & Underwood, 1998, 1999). There is, however, little doubt that this will change. Multimedia computer programs have become very attractive and the Internet is becoming available to a steadily increasing number of people. At the same time, our societies have become rapidly changing societies making it necessary for their members to update their knowledge and skills at a much faster pace than in the centuries before. Life-long learning seems to become a task for almost everybody, and this will entail new forms of learning – learning that is largely done out of school, and learning that needs to be self-regulated. It is expected that ICT will facilitate this kind of learning and it seems therefore probable that computers – the medium through which we access multimedia programs and the Internet – will play an increasingly important role in self-regulated learning (Bandura, 1997).

There is empirical evidence that self-regulation does play a role in student-computer interaction. Moore (1993) showed that metacognitive processing of diagrams, maps, and graphs may be fostered in the context of a reciprocal teaching training program. Eteläpelto (1993) compared experts and novices with respect to computer program comprehension and found that experts exhibit a close interaction between metacognitive knowledge, task-specific awareness and cognitive monitoring which novices did not. Volet & Lund (1994) instructed their students to use metacognitive strategies in computer programming and found that this kind of instruction was a better predictor of success than traditional variables such as background knowledge, program major, gender, or age.

Young (1996) used computer-based instruction which gave students the opportunity to control the type and amount of information needed to master specific tasks. In this setting, high self-regulating students performed much better than low self-regulating students.

It is, however, questionable whether increased learner control will automatically and by itself lead to better and more self-regulated learning (Becker, 1994; Large, 1996). Brown (1997), based upon an extensive review of the literature, therefore suggests that multimedia programs should provide some system of guidance to help learners use programs efficiently. Although his review only covers publications until 1991, his suggestions are still valid. Mortimer, Farrell, & Kahn (1997) who took into consideration more recent literature on the topic of learner control, come to the conclusion that empirical findings related to the issue of learner control are still inconclusive. More research in this field is therefore needed. At the same time, instructional designers will have to develop tools that will help students navigate efficiently through the program and allow them to gain maximum benefit from working with it. One road that has been taken is to design learning environments that are to be used for self-instruction as electronic performance support systems (EPSS, Gery, 1991; McGraw, 1994; Sleight, 1997). It is, however, highly desirable to include components that help the users to self-regulate their learning (Brown, Hedberg & Harper, 1994). At the same time, a number of programs have been developed that explicitly aim at developing and fostering metacognitive skills.

Puntambekar (1995) developed a computer-based tutorial system that helps students learn how to learn from texts, i.e. it helps students develop metacognitive skills in reading and understanding written texts. By asking the students questions about the structure of the text and the nature of the learning task, it prompts them to think about the way they learn. The tutorial system is divided into three stages: (1) planning, (2) text processing, and (3) memory enhancement. It provides the students with options that facilitate specific metacognitive activities during each of the learning stages. The tutorial system has an option for reviewing progress which encourages reflecting on the progress the student has made and another option for collaborative learning. The first results that the author obtained with high school students look promising.

Hasebrook (1999) presents a Web-based training module that is being developed by the German Bank Academy with the idea of using the computer as a tool for «learning through reflection» (Collins & Brown, 1988). In the course of the program, the user is introduced to learning strategies for computer-based training which are geared at facilitating self-regulated learning. In studying students who worked with the system, Hasebrook & Nathusius (1997) found that the more information students have, the less willing they are to accept advice from the system - possibly an indication of increased self-efficacy beliefs that are based on the experience of increasing competence.

Stoney & Oliver (1999) offered their students a multimedia computer program on the principles of financial investment. To assess higher order thinking, the following categories were established: (1) planning/strategy, (2) uncertainty, (3) predicting, (4) multiple perspectives, and (5) coaching. They came to the conclusion that working with the program led their students to a greater degree of cognitive engagement (Corno & Mandinach, 1983) which resulted in more frequent use of higher order thinking. Unfortunately, they did not use a control group, nor did they administer pre-tests; this makes interpretation of the results difficult.

Karacapilidis, Khaled, Pettenati, and Vanoirbeek (2000) developed a multimedia environment for distributed interactive learning (MEDIT). This Web-based learning environment explicitly aims to foster the acquisition and cultivation of higher-order skills, thereby augmenting the effectiveness of learning. It is a tool which teachers and students may use in co-operation to work on a variety of course-related activities. Providing for three virtual workspaces (Course, Cooperative, Exercises), it offers services for (1) authoring, (2) information access and retrieval, (3) communication and collaboration, and (4) management. The authors assume that the tools they implemented will facilitate higher-order skills; these are (1) multiple view representation of a course, (2) the creation and maintenance of student customized courses, (3) exercise methods, (4) argumentative discourse between teachers and students, and (5) group decision making. It seems very likely that these tools will help students acquire and improve their self-regulatory skills; empirical data to corroborate this expectation are, however, still lacking.

The pivotal role of self-regulation in using multimedia computer programs and the Internet is recognized by Lehman (2000). In his opinion, some of the important issues related to the use of hypermedia in education include (1) user orientation, (2) cognitive overload, (3) user commitment, and (4) the learner's ability to self-regulate his learning. Some of the features that have shown to be effective in multimedia computer programs include (1) cognitive breathers, (2) user prompt to follow hypermedia links, (3) advance organizers, (4) self-elaboration, (5) scaffolding, (6) concept map organizers, and (7) prompts to promote metacognitive processing. It is, however, necessary to continue this line of research in Web-based instruction.

Computers have been looked upon as cognitive tools, i. e. as tools that may help students accomplish cognitive tasks (Jonassen, 1992; Pea, 1985; Perkins, 1985; Salomon, Perkins, & Globerson, 1991; Solomon, 1993; Steffens, 1997). According to Lajoie (1993), four types of cognitive tools may be identified:

1. Tools that support cognitive and metacognitive processes.

2. Tools that share the student's cognitive load by providing support for lower level cognitive activities so that the student may concentrate more on higher level cognitive activities.

3. Tools that allow the student to engage in cognitive activities which otherwise would be out of his reach (to provide a zone of proximal development, in Vygotskyan terminology).

4. Tools that make it possible for the student to generate and test hypotheses in problem solving activities.

Salomon's (1993) distinction between performance-oriented tools and pedagogical tools largely coincides with Lajoie's distinction between type 2 versus type 1 cognitive tools. While the former help the learner in a given situation to improve his actual performance, the latter aim at helping the students acquire and cultivate generalizable skills, particularly higher-order thinking skills which later on may be employed in the absence of the tool. Examples of the former kind would be a word processor or one of the electronic performance support systems (EPSS) mentioned earlier, while an example of the latter kind would be Salomon's Writing Partner, a computer program that helps students write a creative story.

The program is based on the psychological analysis of composition writing by Bereiter and Scardamalia (1987), on their theory of procedural facilitation (Scardamalia *et al.*, 1989), on Vygotsky's (1978) sociohistorical theory of development, and on the author's theory of technology and mind (Salomon, 1990). Basically, it is a program that is designed to help students shift from writing compositions in a free-association, less-than-thoughtful mode of «knowledge telling» to writing better planned, self-guided, self-diagnosed and revised compositions of the «knowledge transformation» mode (Salomon, 1993, p.185).

The program offers four types of assistance (procedural facilitations) to the student:

1. The student is guided through a forced process of planning his story, brainstorming and outlining.

2. While writing, the student can ask for assistance which will be given in the form of expert-like questions that depend on the key-words typed earlier in the composition.

3. Once the student does not know how to continue his story («I am stuck»), the program will help him diagnose where and with what he is stuck (Opening, Lost the main idea, Plots don't meet, Need a word, etc.).

4. Finally, the student's ideas that he downloaded from his mind into the program (idea list and outlines) may be retrieved at any time during the writing process.

A more complex program that may be categorized as a pedagogical tool, although it would also qualify for the other three types of cognitive tools suggested by Lajoie (1993), is SMART (Scientific and Mathematical Arenas for Refining Thinking, Vye *et al.*, 1998), a learning environment developed by the Cognition and Technology Group at Vanderbilt. The SMART environment is an example of what the authors call anchored instruction (Bransford *et al.*, 1990; Cognition and Technology Group at Vanderbilt, 1990, 1993, 1997), a term that refers to the ideas that learning is situated (Brown *et al.*, 1989) and that instruction should be anchored in concrete and authentic problems. The environment is conceived as a framework that will help fifth graders to learn about ecosystems with a focus on the pollution of Stone River. Additional features are Web-based components that aim at encouraging students to monitor and reflect on their learning, and to revise decisions in preference of alternate learning paths.

At the subject matter level, the goal of the program is to enable students to control the degree of pollution of a river in their neighborhood. In the first two phases of the project, the students observe experts on a video examining the quality of the water of Stone River. In phase 3, they have to generate suggestions on how to clean up the pollution, and in phase 4 they actually go to a river and do the testing themselves.

A number of tools implemented in the SMART environment aim to scaffold students' thinking. Students have access to a Web site that allows them to enter their choices with respect to possible paths of actions and to give reasons for their choices. The Web site provides the students with feedback on their input. SMART lab, another Web-based component of the SMART environment, produces graphs which summarize the choices the students made, thus supporting reflection. Kids Online is a Web page where the students as a class can give feedback to other students working on the project. Finally, the students may use the Web to run a simulation of specific water testing procedures.

Observing children while working in the SMART environment as well as interviewing and testing them after they had worked with the program revealed that they not only liked to work in the SMART environment, but also that their knowledge and understanding of the subject matter increased and their argumentation and learning strategies improved (Vye *et al.*, 1998).

Concluding remarks

Although self-regulation refers to metacognitive as well as to metamotivational processes, computer- and Web-based learning environments that claim to foster self-regulatory skills seem to address cognitive and metacognitive skills only. This does not mean that working with this kind of environment does not produce non-cognitive effects. Cox (1997), for example, did a study on the effects of ICT on students' motivation in the U.K. With a sample of more than 400 students from three schools and one university in the London area, she found that ICT use did in fact increase students' enjoyment and interest in learning, facilitated self-directed learning, enhanced their self-esteem, and enhanced potential for achieving longer term goals. But it might be argued that if computer-based learning environments provided for the scaffolding of non-cognitive self-regulation explicitly, these effects might even be more pronounced.

In order to be able to design good scaffolding components for non-cognitive self-regulation, we need to have a very precise understanding of how metamotivational processes function at a very fine-grained level. The same has to be said, of course, with respect to components that are to facilitate metacognitive self-regulation. The models of self-regulation that were presented earlier are still relatively coarse-grained. Human self-regulation is infinitely more complex, and although we may eventually gain an understanding at a very fine-grained level of how human beings actually do their self-regulation, it may be technically too difficult and too cumbersome to implement this knowledge in computer-based learning environments.

This is a lesson that we might learn from the development in the field of Intelligent Tutorial Systems – which, by the way, Salomon (1993) does not consider to be pedagogical tools. ITS were based on the idea that they should construct a model of the learner they are tutoring. Tutorial systems are still being developed, but many researchers have rejected the student modeling paradigm because of the enormous problems they encountered when trying to implement intelligent student behavior in all its complexity and irregularity (Derry & Lajoie, 1993). However, even if a tutoring system is not intelligent, it may still do a good job as a tutor (Katz & Lesgold, 1993). In the same vein it may be argued that computer-based learning environments may facilitate self-regulation even if it impossible to implement really fine-grained scaffolding.

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