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Motivating self-regulated learning in technology education

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Abstract This paper proposes a compensative model for self-regulated learning in technology education (SRLT) comprised of cognitive, metacognitive and motivational domains. Discussion of the cognitive domain centers on problem-solving and creativity, with a focus on the need to engage students in open-ended assignments in informal contexts and to teach them a repertoire of methods, strategies and heuristics for inventive design and problem-solving, rather than letting them search randomly for ideas or use the trial-and-error method. The notion of metacognition deals with peoples' ability to be aware of and control their own thinking, for example, how they selects their learning goals, use prior knowledge or intentionally choose problem-solving strategies. Self-regulatory behaviour is highly correlated with an individual's motivation to handle challenging assignments, and with his or her internal satisfaction from being engaged in a task that contributes more to creativity than to receiving external rewards. Another important factor is an individuals' self-efficacy belief in their ability to handle a highly demanding assignment determined by previous positive experience in similar tasks and the existence of a supportive social and emotional environment. The SRLT model highlights the interrelationships between the cognitive, metacognitive and motivational aspects of learning, problem-solving and invention. For example, teaching students problem-solving strategies could help them accomplish a task, improve their ability to monitor their own thinking and reflect on their learning, and enhance their self-efficacy beliefs about problem-solving and creativity. The teachers' role in promoting SRLT education and directions for further research are also discussed.

Keywords Cognition · Metacognition · Motivation · Self-regulated learning · Technology education

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Introduction

Scholars in technology education, as well as in other disciplines, are becoming increasingly aware of the need to design instruction using learning theories that can help in understanding how people learn and how intellectual skills are developed. For example, Johnson (1997) wrote about learning technology and developing intellectual skills; McCormick (1997, 2004) discussed issues related to learning and knowledge in technology education; Lewis (2009), Middleton (2005) and Barak (2007) addressed fostering creativity in technology education; De Miranda and Folkestad (2000) and Zuga (2004) pointed out the need to improve technology education research on cognition, and Petrina et al. (2008) wrote about researching cognition and technology. However, as Johnson (1997) noted, the development of higher-level cognitive skills is a complex task that has not been addressed sufficiently in education, and more work is required to form a theoretical framework for studying the enhancement of students' socio-cognitive abilities in technology classes.

This paper intends to open a discussion and foster additional research in this direction. I discuss how the theory of self-regulated learning (Zimmerman 2008) can help in exploring the objectives and methods of technology education in light of the broad theories of learning and instruction, on the one hand, and in providing a more in-depth understanding of the role of technology education in cultivating students' intellectual competencies, on the other. In the first part of the paper, I present a model of self-regulated learning in technology (SRLT) education, with a focus on three dimensions—cognition, metacognition and motivation. The second part of the paper shows how this model accounts for one of the main issues in technology education—problem-solving and creativity, and the aspect of using computers and communication technologies in technology education. Finally, the implications on teacher education and directions for further research are raised.

What is self-regulated learning?

Zimmerman and Schunk (1989) define self-regulated learning (SRL) in terms of self-generated thoughts, feelings and actions that are systematically oriented toward the attainment of students' own goals. This term refers to the ability to control and influence one's learning processes, for example, planning, goal setting, strategy implementation, summarizing, and monitoring one's progress. Zimmerman (2008) stresses that self-regulation is not a mental ability or academic performance skill, such as intelligence or reading proficiency. Rather, SRL refers to the self-directed process through which learners transform their mental abilities into academic skills. It is a multidimensional process involving personal (cognitive and emotional), behavioural and contextual components. A number of different self-regulation models have been proposed. For example, Zimmerman (2000) describes academic self-regulation as a cyclical process consisting of three phases: (1) forethought, including goal setting, strategic planning, self-efficacy beliefs and intrinsic motivation; (2) performance, volitional control, such as attention focusing, self-instruction and self-monitoring; and (3) self-reflection, such as self-evaluation, attributions and self-reactions. Boekaerts (1999) suggested a three-layer model of SRL, including: (1) regulation of the self-choice of goals and resources; (2) regulation of processing methods—use of metacognitive knowledge and skills to direct one's learning; and (3) regulation of processing modes—choice of cognitive strategies. Schraw et al. (2006) presented a self-regulation model in the context of science education and partitioning SRL into three components: (1) knowledge, such as how to solve domain-specific problems;

(2) metacognition, such as knowledge about oneself as a learner, goal setting, planning, implementing strategies, monitoring and evaluating one's learning; and (3) motivation, such as self-efficacy beliefs that influence one's engagement and persistence in performing a task. One can find literature on fostering SRL in mathematics education (Zimmerman et al. 1996; Panaoura and Philippou 2007), computer science education (Bergin et al. 2005), physical education (Cleary et al. 2006), science education (Schraw et al. 2006) and using computers for enhancing SRL in the class (Azevedo 2005). Nevertheless, this model was not yet been discussed in the context of technology education, which is the issue presented in the following section.

A model for self-regulated learning in technology education (SRLT)

In the above section, we have seen that the concept of SRL has no single or exact definition, but is often presented as a cyclic process influenced by a combination of cognitive and social factors. In this paper, I would like to suggest a general model of SRLT education characterized by three main dimensions: cognition, metacognition and motivation, as illustrated in Fig. 1. The aspects of instruction and learning relating to each of these dimensions in the SRLT model are discussed below.

The cognitive dimension

Cognition relates to the conscious mental processes by which knowledge is accumulated and constructed, such as being aware, knowing thinking, learning and judging. It is common to distinguish between lower-level cognitive processes, such as perceiving, recognizing, memorizing, understanding and conceiving, and higher-level mental functions, such as analyzing, conclusion drawing, reasoning, synthesizing, problem solving, assessing and creative thinking.

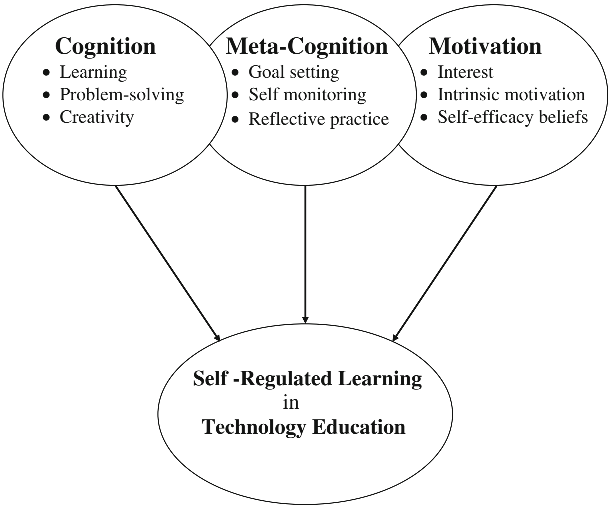

Fig. 1 Self-regulated learning in technology education (SRLT)

Western contemporary psychological and educational literature has been influenced by several main theories on cognitive development and learning.

According to the *behaviourist* view of learning (Watson 1913; Skinner 1973), learning is manifested by a change in behaviour, while internal thought processes are complicated and difficult to follow or study. Instruction should focus on clarifying objectives, drill and practice, and positive reinforcement.

Cognitivist theories of learning focus on an individual's mental processes in learning and knowledge building. Researchers such as Piaget (1952) and Bruner (1977) have explored changes in an individual's internal cognitive structure, the stages of mental development and growth, and how this development could be linked to teaching and learning in formal and informal contexts. This body of research has been translated into several instructional principles. For example, instruction should be well-organized in a way that reflects the logical relationships between key ideas and concepts; new knowledge is constructed based on existing knowledge and through learners' experience; differences between individuals affect learning; and reinforcement is achieved by providing the learner with significant feedback rather than simple rewards.

Socio-situational theories of cognition and learning shift the focus of research from what is happening in an individual's mind (cognitivism) to the cognitive process that results from the interaction of the individual with the social environment, the material world and artefacts *Social constructivism* stresses the collaborative nature of learning and suggests that meaningful learning occurs when individuals are engaged in social activities (Vygotsky 1978). Other related theories are the theory of *distributed cognition* (Salomon 1993; Hutchins 1995), *situated cognition* (Brown et al. 1989) and the *socio-cognitive* theory (Bandura 1997), which shows that knowledge exists within communities, and meaningful learning is the result of active social and cultural interaction. In the discussion of technology education, Petrina et al. (2008) used the term techno-cultural for theories such as *distributed cognition*, *activity theory* (Leontiev 1978), and the notion of *cognitive artefacts* (Norman 1990). Cognitive artefacts, for example, are defined as man-made things that apparently enhance our cognitive abilities. The constructionism learning theory (Harel and Papert 1991) suggests that learning can occur most effectively when people are actively engaged in making things that are meaningful to them and they can be shared with others.

The various perspectives of learning briefly reviewed above have influenced the increasing emphasis on introducing more learner-centered instructional strategies, such as authentic learning, problem-based learning and project-based learning into science and technology education (Thomas 2000; Blumenfeld et al. 1991; Barak and Shachar 2008).

The metacognitive dimension

Metacognition is broadly defined as any knowledge or cognitive process that refers to monitoring or controlling any aspect of cognition, for example, memory, attention, communication, learning, problem-solving and intelligence The notion of metacognition, which is sometimes presented as 'thinking about thinking,' 'knowing about thinking' or even 'thinking about knowing,' is commonly associated with the work of Flavell (1979), who distinguished between two concepts: *metacognitive knowledge* and *metacognitive regulation*. Metacognitive knowledge refers to "knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises" (Flavell 1999, p. 4). It consists of: (1) *knowledge of person variables*, namely, knowledge about how human beings learn and process information, as well as knowledge about one's own learning processes; (2) *knowledge of task variables*, such as the nature of the task or the type of demands required in handling it; and (3) *knowledge of strategy variables*, such as the optimal strategy to handle a problem. According to Pintrich (2002), metacognitive knowledge includes knowledge of general strategies that might be used for different tasks, knowledge of the conditions under which these strategies might be used, and knowledge of the extent to which the strategies are effective.

The second component of metacognition, metacognitive regulation, involves the use of knowable metacognitive strategies or sequential processes to control cognitive activities aimed at meeting a specific goal. Boekaerts (1999) contends that one of the key issues in SRL is an individual's ability to select, combine and coordinate different strategies in an effective way. It is essential that learners acquire strategies, such as identifying the major points in a task, asking questions, setting priorities, or dealing with a task from start to finish or vice versa.

The concept of *reflective practice* is quite close to metacognition, but the terms are not identical. As we have seen above, metacognition has to do with considering, selecting, controlling or regulating cognitive processes such as learning and problem-solving, before, during or immediately after executing a task. Reflective practice (Dewey 1933; Schön 1996) is a broader concept that relates to the continuous process of learning from experience, and involves the individual considering critical incidents in his/her life experiences, asking questions about what we know and how we came to know it, and 'learning to learn.' Schön suggested that reflective practice involves thoughtfully considering one's own experiences in applying knowledge to practice while being coached by professionals in the discipline. Johnson (1997) writes that even if instruction occurs in rich contexts and involves interacting with peers while working on various activities, quality learning will not take place unless there is reflective introspection. According to this author, while students may be able to solve a technological problem, they typically proceed in a linear fashion with no reflection. Therefore, teachers play a major role in fostering metacognition and reflection in the technology class, as discussed later in this paper.

Feedback is also an important aspect of instruction and learning (Thorndike 1913). However, the term is not precisely defined and is often understood in many ways, for example, assessment, interaction, discussion or reflection. Since the concept of feedback plays a major role in the study of behaviour of systems in areas such as electro-mechanical engineering, biology, neurophysiology and economy, it is useful to examine how scientists and engineers use this concept.

The term feedback has to do with the theory of cybernetics (Wiener 1948). It represents a process in which a portion of the output of a system or a signal representing this output is fed back into the input of the system and influences its behaviour. *Negative feedback* in a system exists when the feedback stabilizes a specific variable or a set of variables. The flush cistern is one of the most frequent examples used in textbooks on feedback control (Barak and Williams 2007). In this system, the required water level (reference) in the cistern is determined mechanically, commonly at the factory or during installation. The ball-cock detects the actual water level and decreases the input flow as the level approaches the desired value. Another simple example of negative feedback is temperature control by a thermostat. In an oven, for example, the thermostat turns the heating ON when the temperature decreases below the desired level and OFF when the temperature increases beyond this point. *Positive feedback* in systems exists when the feedback acts to increase a change occurring in the output variable in the same direction, as in a nuclear chain-reaction.

This short review on how the concept of feedback is applied in various areas teaches us that in order to maintain feedback in a system, three conditions must be fulfilled: (1) the desired outcome of the system is well-defined; (2) a mechanism exists for measuring the actual outcome, comparing it to the desired value and activating a correction process aimed at reducing the deviation; and (3) the system's responses to the correction can be anticipated in advance.

Butler and Winne (1995) provided a comprehensive literature review related to feedback and SRL, and showed that studies of feedback in educational settings have traditionally focused on information provided to students by an external source, such as the teacher, peer, textbook or computer. In technology education, an important source of feedback for students is their success or failure in accomplishing a specific task, for example, the design, construction, evaluation and improvement of artefacts and control systems. However, while students learn naturally from their own experience in doing tasks, such as constructing technological systems or troubleshooting, teachers' feedback is important to develop higher-order cognitive skills and self-beliefs. To foster SRL in the technology class, it is important that teachers provide students with feedback related to all three domains previously discussed—cognitive, metacognitive and motivational behaviour—rather than focus solely on the acquisition of the knowledge domain. According to Halpern (2003), in order to improve students' metacognitive monitoring skills, teachers must make these skills explicit so that they can be examined and feedback can be given about how well they are functioning. In the context of problem-solving, students can be asked the following questions before they begin a task: What do you already know about this problem? What is the goal or reason for engaging in extended and careful thought about this problem? How difficult do you think it will be to solve the problem? How will you know when you have achieved the goal? As students work on a problem, they should be asked to assess their progress, and when the task is completed, to be asked how well the problem was solved and what they learned from solving it. Therefore, the teacher plays a major role in promoting SRLT education, as discussed later in this paper.

The motivational dimension

Hill (2007) specifically addresses the motivational aspects of teaching and learning technology in her chapter in the book entitled, "Analyzing best practice in technology education" (edited by De Vries et al. 2007). Hill reviews several current motivation theories, such as 'achievement goals,' 'interest and intrinsic motivation,' 'self efficacy,' and 'attribution theory and control beliefs.' The author mentions a range of key factors affecting students' motivation to learn, for example, contextualization learning in the students' world, bringing real-world subjects into the classroom, giving the students choice, autonomy and control over their learning, and providing feedback. Actually, this review also includes cognitive and metacognitive aspects mentioned in the previous paragraph. In the current analysis, the focus is on the term self-efficacy.

Zimmerman et al. (1992) stress that self-regulation depends strongly on self-efficacy beliefs because perceived self-efficacy influences the level of goal challenge people set for themselves, the amount of effort they mobilize, and their persistence in the face of difficulties.

Self-efficacy is defined as people's beliefs in their capability to produce designated levels of performance that exercise influence over events that affect their lives (Bandura 1997). It is a belief that one has the capabilities of executing the courses of actions required to manage prospective situations. It is important to understand the distinction between self-esteem and self-efficacy. Self-esteem relates to a person's sense of self-worth, whereas self-efficacy relates to a person's perception of his ability to reach a specific goal. Self-efficacy is a better predictor of task-specific goals and performance than more global evaluations, such as self-concept and self-esteem. Studies in which general or global self-concept was compared to specific achievements reported weak correlations (Pajares and Schunk 2001).

According to Bandura's (1997) social-cognitive theory, pupils with low self-efficacy avoid difficult tasks and have low aspirations and a weak commitment to goals. They interpret poor performance as low aptitude, and they lose faith in their capabilities. Bandura (1997) maintains that self-efficacy beliefs are constructed from four principal sources of information: (1) an active mastery of experience that serves as an indicator of capability; (2) vicarious experience that alters efficacy beliefs through the transmission of competencies and comparison with the attainment of others; (3) verbal persuasion and allied types of social influences that one possesses to master a given task; and (4) physiological and emotional states that affect people's judgment of their capabilities. Bandura (1997) indicates that the relevant information for judging personal capabilities, whether conveyed inactively, vicariously, persuasively or physiologically, is not inherently enlightening. It becomes instructive only through cognitive processes of efficacy formation and through reflective thought.

Regarding teaching and learning in school, it is important to acknowledge that an individual's self-efficacy beliefs are context bound. A student may have high self-efficacy with respect to knowledge and skills in a particular school subject, but low self-efficacy in another subject. This point is significant to technology educators because technology education has the potential to provide students with a learning environment that differs significantly from other school subjects such as mathematics or science. This includes, for example, engaging students in subjects that concern their daily life, design-based learning, hands-on based learning, and the use of advanced technologies for the design and construction of sophisticated technological system. Therefore, technology education provides tools for fostering students' self-efficacy beliefs that are less common in other areas learned at school. This point is especially important in efforts aimed at increasing the self-efficacy beliefs of low-achieving students in technology education (Barak 2004).

What makes technology education a good framework for fostering self regulated learning in school?

So far we have seen the model of SRLT education as being comprised of three aspects: cognition, metacognition and motivation. At this point, it would be useful to make some comments regarding the unique attributes of technology education that make this field a good platform for fostering students' self-regulatory capabilities, and to explain how the theory of SRL relates to other learning theories often associated with technology education.

Aims and scope of technology education

In the past, technology education has often been associated with subjects such as crafts, industrial production, or vocational education. Technology education was sometimes considered a sub-field of science education ('the application of science') or applying technology for teaching and learning ('educational technology'). Currently, we can mention several main conceptual frameworks or approaches that underlie technology education in countries such as the United States, England and other European countries, Australia and New Zealand. Among these approaches are design, engineering, technological literacy, sustainable education, and the integration of teaching mathematics, science and technology. Among the subjects frequently addressed in technological classes are problem-solving, invention of new artefacts, systems and control, robotics, communication technologies and computing. Barlex (2007), in his introduction to the book "Design and technology for the next generation," summarizes the document published by the Qualification and Curriculum Authority in England about technology education, as follows (p. 12):

> In design and technology pupils combine practical and technological skills with creative thinking to design and make products and systems that meet human needs. They learn to use current technologies and consider the impact of future technologies development. They learn to think creatively and intervene to improve quality of life, solving problems as individuals and as members of a team. Working in stimulating contexts that provide a range of opportunities and draw on the local ethos, community and the wider world, pupils identify needs and opportunities. They respond with ideas, products, and systems, challenging expectations where appropriate. They combine practical and intellectual skills with an understanding of aesthetic, technical, cultural, health, social, emotional economic, industrial and environmental issues. As they do so, they evaluate present and past design and technology and its effects. Through design and technology pupils develop confidence in using practical skills and become discriminating users of products. They apply their creative thinking and learn to innovate.

The above concise review of the objectives of education highlights that technology education, more than other school subjects, relates to peoples' daily lives, needs and desires, and combines the acquisition of both theoretical knowledge and practical skills. This makes technology education an especially appropriate framework for fostering students' aptitudes related to the cognitive, metacognitive and motivational dimensions in line with learning and cognition theories, as discussed throughout the paper.

Technology education and learning theories

As mentioned earlier, during the 1970s and 1980s, the psychological and educational literature paid considerable attention to the cognitivist theories of learning and their implications on education. Later, the focus of the discussion shifted more to socio-situational views of learning and cognition. This has influenced the introduction of more situated or learner-centered instructional strategies, such as authentic learning, problem-based learning and project-based learning into school. Although technology education is a natural arena for creating an authentic learner-centered environment in school, the analysis of technology education in light of socio-cognitive learning theories was similar to what has been written in regard to teaching other school subjects, with only little emphasis placed on the unique aspects of technology education. Stevenson (2004) specifically argues that "technology education is under-theorised." This author used the cultural-historical activity theory (Leontiev 1978) as a basis for conceptualization of teaching and learning technology. This theory examines learning as an activity system consisting of: Subject (learner), Object(ives) (e.g., knowledge; skills; values), Mediating artefacts (e.g., tools; materials; theoretical knowledge), Rules (e.g., syllabus; norms), Community (e.g., teachers; parents; industry), and Division of labour (e.g., listening; doing; communicating). As Stevenson contends, this model uses more than one cognitive theory to arrive at the conceptualization of technological knowledge and its acquisition. The weak point here is that the activity theory does not address some questions explicitly, such as how to raise students' motivation to learn or what is the role of metacognition in learning.

The theory of SRL discussed in this paper relies on the cognitive and motivational theories mentioned above, but provides a broader view of learning and intellectual development in that it ties together the cognitive, metacognitive and motivational theories of learning, with special attention being paid to the metacognitive dimension. In practical terms, fostering SRL in the technological class means not only designing instruction aimed at imparting a repertoire of strategies to the students that they can use appropriately in learning and problem-solving (cognitive aspect), but also making learners more cognizant to their learning. According to this view, it is important to discuss explicitly with students the objectives of learning and the nature of the task or problem-solving strategies they are using, as detailed later in the paper. In addition, fostering SRL also requires giving students feedback about their learning motivation and self-efficacy of a task, rather than focusing feedback solely on performance or accomplishing a task, as frequently occurs in conventional schooling. Therefore, the SRLT theory adds a significant layer to the discussion on the objectives, methods and unique attributes of technology education.

In the following section, I will discuss more specifically how the theory of SRL relates to some major issues in technology education—problem-solving and creativity.

Problem-solving, creativity and self-regulated learning

Although the terms problem-solving and creativity are discussed frequently in psychological and educational literature in general, and in literature on technology education in particular (McCormick 2004; Lewis et al. 1998), this term has remained rather vague. Questions such as whether there is an all-purpose problem-solving model or to what extent and how teachers can enhance students' problem-solving and creativity in school still trouble educationalists.

Problem-solving

The term 'problem' expresses a state of difficulty, situation, condition or issue that must be resolved, or a question to be solved. Problem-solving can involve, for instance, seeking solutions to human needs and desires, inventing new artefacts, improving technological systems, or troubleshooting. In technology education, a general model for problem-solving and design is commonly taught consisting of the following stages (in various variations): identifying a human need or problem to be resolved; carrying out an investigation; setting demands or specifications for the desired solution; suggesting a number of solutions and selecting the optimal one; implementing; evaluation; improving. In real life, however, engineers and experts in different disciplines do not always follow this sequence in design and problem-solving. Thinking, learning and problem-solving are iterative processes that often require the learner or designer to check and revisit earlier assumptions about the nature of the problem and the required solution (McCormick 2004; Williams 2000; Barak 2007).

Zimmerman and Campillo (2003) show that self-regulatory behaviour is fostered only when problem-solving takes place in informal contexts rather than in formal learning. These authors contend that much of the research on problem-solving focuses on formal contexts where problems are well-defined and have a specific correct answer. In school, problems of this type are frequently found in teaching subjects such as mathematics or science. According to Zimmerman and Campillo, because anticipated problems are structured to be interesting and soluble, they are less dependent on sources of motivation than informal problems, including perceptions of efficacy, outcome expectations and goal orientations. Therefore, problem-solving in formal contexts contributes only little to fostering an individual's self-regulatory skills. In informal contexts, problem solvers:

1. Are often engaged in open-ended assignments.
2. Must be able to address a number of solutions or problem-solving methods and select the optimal one depending on the specific context.
3. Are required to anticipate likely outcomes of various courses of action and subsequently restructure their approach to the problem itself to adjust for potentially negative outcomes.
4. Need to constantly not only think of the problem, but also be aware of their thought process regarding solving the problem.

Although the four points mentioned above have been suggested by Zimmerman and Campillo (2003) in a general book on problem-solving, they are very applicable to technology education. Engaging students in open-ended tasks, teaching them to address a number of solutions for a problem before choosing the best one, or educating them to consider the advantages as well as disadvantages of a solution lie at the heart of teaching and learning technology. In addition, problem-solving in technology differs from learning other school subjects in that technological problems are often derived from several contexts, and can involve cultural, social, economical, mathematical, scientific or technical aspects. Engineers and technologists must often consider issues such as moral dilemmas, ethical questions, responsibility, integrity, reliability, risks, safety and environmental issues (De Vries 2005; Harris et al. 2000). Let us now examine an example demonstrating how a technological solution to a problem is often more than a technical matter. An engineering company has been requested to provide a system for automatically opening the entrance door to an apartment building for the local residents. A possible solution is by using a digital camera with an image-processing system identifying peoples' faces. Learning how this system works requires the integration of knowledge from areas such as physics, mathematics, electronics and computing. In addition, one must also consider cultural, legal and ethical questions involved in using a face-detection system. For example, this type of system requires that each individual look directly into the camera. The system is also capable of collecting information about residents entering and exiting the building. Engaging students in solving rich, authentic and open-ended technological problems of this type could serve as an excellent platform for fostering SRL among learners, as recommended by Zimmerman and Campillo (2003).

While it is clear how dealing with technological problems could foster students' cognitive aptitudes and motivation to learn, we must pay greater attention to the question of how to foster the metacognitive side of problem-solving, namely, raising problem-solvers' awareness and control over their thoughts or the problem-solving strategies they are using. This point deals with teaching individuals problem-solving methods and strategies, as discussed later in this paper.

Creativity

Creativity is often defined as the ability to produce ideas, processes or products that are novel (original, unexpected, imaginative) and useful (appropriate or adaptive regarding task constraints) (Guilford 1967; Sternberg and Lubart 1996). In technology, the notion of creativity has to do with finding new and efficient solutions to problems or the invention of new products and services. Several authors (Lewis 2009; Sternberg and Lubart 1996) argue that the enhancement of creativity has been rather neglected in traditional schooling. One reason for this is that many people regard creativity as 'spiritual process' that cannot be thought or improved. Therefore, the important question for educators is to what extent and how can school foster this ability among students. A second explanation for the relatively low interest in fostering creativity in schools is that creativity is frequently concerned with areas such as literature, music, painting, sculpture or other plastic arts. This makes people regard this human ability as less serious or important in comparison to thinking patterns characterizing the exact sciences like mathematics and science. The question is, therefore, how to make the fostering of creativity a regular component of schooling.

Nickerson, in his chapter on Enhancing Creativity in the *Handbook of Creativity* edited by Sternberg (1999), points out that a clear, unequivocal and incontestable answer to the question of how creativity can be enhanced is not found in the psychological literature. However, this author suggests a range of recommendations for enhancing creativity that are consistent with what is known about creativity and what have been learned from the efforts of teaching creativity in the classroom. Among the measures Nickerson states are:

- Establishing purpose and intention
- Building basic skills
- Encouraging the acquisition of domain-specific knowledge
- Stimulating and rewarding curiosity and exploration
- Building motivation—especially internal motivation
- Encouraging confidence and willingness to take risks
- Focusing on mastery and self-competition
- Promoting supportable belief about creativity
- Providing opportunities for choice and discovery
- Developing self-management (metacognitive) skills
- Teaching techniques and strategies for facilitating creative performance

The ideas about enhancing creativity in school mentioned above, which represent fairly well the literature in this subject, mainly account for the creation of a good atmosphere and for supporting conditions for fostering creativity in school. Yet, this is not enough, and the last item in the above list—namely, teaching people inventive thinking methods for problem-solving and design—is very important. This is the focus of the following sections.

The advantage of teaching strategies and heuristics for inventive problem-solving

So far we have seen that problem-solving and creativity play an important role in technology education and in fostering SRL. The aim of this section is to emphasize the point that merely engaging students in challenging assignments or creating a learning environment that supports creativity does not ensure success in fostering these competences in the classroom. Rather, there is great benefit in teaching students a repertoire of strategies and heuristics that are likely to help them in the process of problem-solving and invention. The discussion addresses the cognitive, metacognitive and motivational aspects of problem-solving and creativity in accordance with the SRLT model presented earlier in this analysis.

The *cognitive aspect* of creativity has to do with the question of how people arrive at new and original ideas. Following Guilford's (1967) distinction between divergent and convergent thinking, it is common to regard creativity as a two-stage process: first comes divergent thinking, aimed at collecting as many ideas as possible; then comes convergent thinking, aimed at investigating these ideas, evaluating them and choosing the best or optimal one. The notion of creativity as collecting ideas has been the basis of developing creativity methods such as brainstorming, associated thinking and so forth. However, this view of creativity as 'thinking out of the box' became an obstacle for efforts at teaching people how to think creatively, because it seems that there is a logical contradiction in trying to teach people how to arrive at ideas that are unexpected and surprising. Authors like Boden (2004), Goldenberg and Mazurski (2002), and Barak (2009) have pointed out that the notions of creativity as 'disordered thinking' is not the only way for invention and inventive problem-solving. Instead, considering constraints and using strategies such as applying systematic manipulations with the components and functions in a system can help in inventive problem-solving, as discussed below.

Many authors (Nickerson 1999; De Bono 1992; Barak 2007) noted that creativity-relevant skills include knowledge of strategies and heuristics for generating ideas. Therefore, there is room for teaching individuals methods for innovative problem-solving and new product development, rather than hoping that they spontaneously acquire these competencies. A variety of strategies, techniques, heuristics and semi-structured inventive problem-solving methods have been proposed, many of them have been identified by observing how inventors and proficient problem-solvers work. Heuristics are rules-of-thumb for reasoning, a simplification, or an educated guess that reduces or limits the search for solutions in domains that are difficult and poorly understood (Soegaard 1985). For example, Eberle (1977) suggested the SCAMPER method; Berne and Raviv (2004) presented the eight dimensional methodology; Altshuler (1988) developed the TRIZ method for inventive problem-solving in engineering; Horowitz and Maimon (1997) suggested the systematic inventive thinking (SIT) method; and Goldenberg and Mazurski (2002) established a set of creativity templates aimed at innovation in new product development. Barak and Goffer (2002) showed that applying the SIT method among engineers and designers in an Israeli medium-size manufacturing plant of measuring instrumentation for the building industry resulted in the development of a series of innovative products that were highly successful on the market. Barak and Mesika (2007) investigated the impacts of teaching a 30-h inventive problem-solving course based on the SIT method to 72 junior high school students. The findings showed that the students significantly improved their ability to suggest original and useful solutions to problems presented to them, and demonstrated greater interest, self-confidence and motivation in dealing with invention and problem-solving compared to other students in the same school.

Let us examine a specific example. During the course, the students learned five principles that could help in inventive problem-solving and the invention of original artefacts: (1) assigning a new function to an existing component in the system; (2) adding a component to the system that is a slightly modified copy of an existing component; (3) eliminating a component from the system, along with its function; (4) dividing or disassembling a system into it parts; and (5) adding, removing or changing relations between variables in a system. In one of the classes, the students prepared final projects on how to increase road safety. A group of students that addressed the problem of train accidents came up with the idea of safely stopping a train entering a station by placing magnets of increasing size along two sides of the railway, as illustrated in Fig. 2. The students explained that the solution is based on one of the principles they had learned in the

Fig. 2 Pupils proposed safely stopping a train entering a station by placing magnets of increasing size along the railway. The idea is based on the principle of solving a problem by making connection between two variables in the system that the students learned in the course

course—solving a problem by establishing connection between two variables in the system—the train's location and the force acting on it.

It is worth mentioning that the students did not possess enough knowledge in physics or engineering to estimate if the magnets could actually stop a train. The important point is, however, that they used a strategy they had learned in the course regarding the solving-problem process, rather than searching randomly in different directions. More information on the course method and its impacts on students and teachers can be found in Barak (2007, 2009) and Barak and Mesika (2007).

Metacognition is an important aspect of problem-solving and creativity. As already mentioned, the term metacognition refers to our ability to actively control our thinking during learning and problem-solving (Flavell 1979). When individuals learn to use strategies, principles or schemas that could help in the process of problem-solving and invention, they are more likely to be aware of their own thinking during the process of problem-solving and inventive design, and reflect on their experience after accomplishing a task. Authors such as Feldhusen (1995) and Sternberg (1988) stress that using strategies in the process of problem-solving and creativity, and the ability to recognize or evaluate a creative idea or product, are best seen as metacognitive functions. However, we must recognize that fostering metacognition in the technology class has received relatively little attention in the literature on technology education. Teachers sometimes encourage students to reflect on their learning in technology, but this is often considered as marginal or the side-effect of accomplishing a design task. To put it differently, students are frequently rewarded for producing a working model, artefact or system and for documenting the design process, while the question of what they have learned from this experience in terms of their learning and thinking capabilities is considered less. Explicitly teaching a range of marked problem-solving strategies, as mentioned above, is also important for metacognition. Individuals are able to acknowledge their own thinking or consciously select a problem-solving method only if they can distinguish between different strategies or heuristics useful for problem-solving and invention.

It well known that *motivation* and creativity are positively correlated. Deci (1975) and Amabile (1996) distinguished between the roles of extrinsic versus intrinsic motivation in the creative process. Intrinsic motivation exists when fulfillment is reached by merely engaging in a task and attaining a solution to a problem. It has been found that intrinsic motivation promotes commitment to work and encourages exploration, flexibility, spontaneity and risk-taking in invention and problem-solving (Collins and Amabile 1999). Extrinsic motivation means that individuals engage in an activity in order to meet given requirements or to expect some reward, beyond the self-satisfaction from accomplishing a challenging task. In the school context, external motivation frequently has to do with evaluation and grades. Since it is commonly accepted that intrinsic motivation spurs creativity more than external motivation, the challenge for educators is how to design instruction that engages students in interesting assignments that sparks their imagination and intrinsic motivation.

What can technology education learn from the literature on the role of computer technologies in fostering self-regulated learning?

Recently, a great deal of literature has dealt with the role of computers and information technologies in fostering instruction and learning in formal and informal education. Many authors point out that learning about complex and challenging topics and domains in computer-based learning environments typically involves the use of numerous self-regulatory processes, such as planning, knowledge activation, metacognitive monitoring and regulation, strategy deployment, and reflection (Azevedo 2005; Jonassen and Reeves 1996; Lajoie and Derry 1993). More specifically, technological environments that support learning are often presented as ‘cognitive tools’, metacognitive tools’ and ‘motivational tool’ because these technologies can assist learners in (a) accessing information, (b) developing ideas, (c) communicating with others, (d) making decisions regarding their learning goals or how much support is needed from contextual resources, (e) intentionally choosing problem-solving strategies, and (f) effectively receiving and using feedback from their tutors, peers or technological means.

Although the above brief review of the role of computer technologies in fostering SRL is derived from the literature on using technology in education (Educational Technology), it also concerns teaching and learning concepts of technology, such as design and problem-solving (Technology Education). An increasing amount of technology education takes place in advanced technological environments. In robotics, for example, computers are simultaneously at the heart of the technological systems the students create and means for design, testing, idea expressing and collaboration between team members. For these students, as well as for many professional designers, engineers or architects, it is difficult to distinguish between applying technology for invention and problem-solving and using technological means for learning and developing ideas.

In summary, the use of computers and information technologies could contribute greatly to fostering SRL in the technology class, namely, cognition, metacognition and motivation in learning technology.

The need to enhance teachers’ pedagogical content knowledge (PCK) in order to promote self-regulated learning

The educational literature widely acknowledges that teachers’ views of teaching and learning, as well as their beliefs about knowledge and intelligence, have a direct impact on the way they teach (Borko and Putnam 1996; Pajares 1992). The task of planning, executing and improving instruction aimed at fostering higher cognitive processes in class is not easy for teachers since this type of teaching is often regarded as exceptional in traditional schooling. Zohar (1999) found that teachers' intuitive knowledge of metacognition of thinking skills is unsatisfactory for teaching higher-order thinking in science classrooms and suggested that courses that prepare teachers for the instruction of higher-order thinking should address extensively the issue of metacognition of thinking skills. In technology education in particular, many teachers have an engineering background, a field that is characterized by a heavy emphasis on delivering subject matter in subjects such as mechanics, electronics or computing. Following Shulman's (1986) work, it is common to distinguish between three types of teachers' knowledge: subject matter knowledge, general pedagogical knowledge, and pedagogical-content knowledge (PCK), which relates to the pedagogy of teaching a specific domain. In the discussion on fostering SRL in the technology class, it is not enough to enhance teachers' knowledge and views about intelligence and learning or impart to them the pedagogical content knowledge about how to foster self-regulatory behaviour in the technology class. Zohar (2006) uses the term Meta-Strategic Knowledge (MSK) to describe the explicit knowledge of cognitive procedures that are being manipulated in learning, such as making generalizations and drawing rules regarding a thinking strategy, naming the thinking strategy, explaining when, why, and how such a thinking strategy should be used, when it should not be used, what are the disadvantages of not using appropriate strategies, and what task characteristics call for the use of the strategy. This type of knowledge seems to have a regulative significance for our thinking because it may give us regulative advice about how to apply correct cognitive processes to specific, contextually rich situations that are often 'messy' in terms of their underlying logical structures. This researcher conducted a study that addressed the following questions in the context of science teaching: (1) what types of knowledge do teachers need for applying MSK in the course of instruction; (2) is it feasible to help teachers develop the knowledge that is required for applying MSK in the classroom during a professional development course; (3) how do teachers develop working MSK in a professional development environment designed for promoting such learning; and (4) what could the answers to the first three questions teach us about designing professional development courses that could promote the use of MSK in the classroom. Zohar concludes that teachers need to learn not only MSK pertinent to their field of expertise but also how to transform initially implicit meta-level knowledge into explicit meta-level knowledge, as well as how to introduce changes into the class culture to assess new forms of discourse regarding thinking and problem-solving. Much work is required to explore the use these ideas in programs aimed at pre-service and in-service training of technology teachers.

Preliminary research findings

The aim of this section is to present preliminary findings from the attempt at improving the teaching and learning of technology in Israeli schools based on the SRLT model. Technology education in Israeli secondary schools is fairly developed, and about 40% of high school students study subjects such as electronics, electricity, mechanics and computer sciences under the umbrella of technology education. The focus of the curriculum is on teaching engineering concepts. In the field of electricity and electronics, the students have the option of preparing a graduation project in their final year at high school (12th grade) as a substitute for a conventional final high school matriculation exam ("Bagrut'). About 1,800 students (50% of the learners) prepare final projects each year in subjects such as robotics, communication systems and control systems. A previous study showed that projects in technology provide a good opportunity to engage students in challenging tasks that enhance their learning skills. To maximize this potential, however, the teachers with a strong engineering orientation also must acquire pedagogical knowledge on issues such as fostering independent learning, creativity, peer learning and reflective practice in the technological classroom. In light of these findings, we recently initiated a program aimed at raising the level of students' projects. The program, entitled "fostering thinking in technological projects," is derived from the SRLT model discussed in this paper. The main components of the program are: providing an in-service teachers' training course (seven-four-hour sessions); preparing new students' and teachers' guides on the project work process; and providing in-school guidance to a sample of schools countrywide. In parallel, the Ministry of Education's Chief Inspector for teaching electricity and electronics has declared a gradual reform in formal requirements for the projects in the spirit of fostering SRL in the schools. The main points of this reform are:

- The projects will address open-ended tasks, with priority given to authentic subjects that personally interest each student.
- Each project will include aspects of self-learning, problem-solving and creativity, beyond the construction of specific electronic circuits or programming.
- The students will document electronically (e-portfolio) the entire project work process. For instance, each student will construct a personal website and include in it all the information on the project development, the working process, design sketches, calculations, data collected during the experimentation and testing, problems the student encountered and how he/she handled them.
- The students will be encouraged to consider the thinking or problem-solving strategies they are using—namely metacognition, and reflect on the process they went through during the project work.

In the 2009 academic year, three groups of 45 teachers (a total of 135) participated in an in-service course that took place in the country's south, center and north. The teachers learned subjects such as: higher-order thinking skills in the context of learning technology, Bloom's taxonomy, an engineering-oriented Problem-solving Taxonomy (PST), types of knowledge in technology (propositional, procedural, conceptual and qualitative), metacognition, motivation, and self-efficacy beliefs. New criteria for evaluating students' work in the spirit of fostering SRL were also discussed.

The program's evaluation consisted of the following measures: distributing feedback questionnaires to the participants during five out of the seven sessions held in the three classes; videotaping almost fully the lectures and discussions held in each group; documenting examples the teachers presented in the course from the current project work in their school and their thoughts on how to put the proposed reform into practice.

Although a systematic analysis of the findings from the course has not yet been completed, and the actual change in school level is still ahead of us, we can outline some important findings already at this stage:

- The vast majority of the participants, including senior teachers and leading figures in technology education, expressed full support for the program.
- Some teachers explicitly said that this was the first time they had participated in an in-service course that was only about pedagogical issues, instead of routinely learning new subjects in electronics or computers.
- Of the 135 participants, only a few said that they had been previously exposed to terms such as higher-order thinking, metacognition or reflection.

- Many teachers said that the course made them understand that they are focusing merely on teaching the subject matter, or that they are teaching propositional or procedural knowledge (terms they learned in the course) most of the time.
- In each one of the classes, several teachers reported that they immediately changed some aspects of project work the students were doing in the current academic year. For example, in one school the students were asked, for the first time, to include in the portfolio they were preparing reflection on their work on the project. In a second school, the teacher encouraged four relatively poor achievers to prepare an e-portfolio on their project in the form of a personal website and they included in it many aspects of how they developed their project. The teacher presented this example in last session of the in-service course, and said that this change considerably raised students' motivation to accomplish their project. In a third case, a team of teachers reported that they had decided to introduce projects into their school for the first time. Moreover, they will start the process by having the 11th grade students prepare mini-projects in preparation for working on the graduating project in 12th grade.
- The Chief Inspector for teaching electricity and electronics and his team (six supervisors) felt completely committed to the proposed reform. They attended all the class sessions, and two supervisors lectured to the participants in the courses about how the reform would be implemented in practice.
- At the end of course, some of the teachers as well as the supervisors recommended immediately implementing the change in schools, rather than gradually incorporating the change over 2–3 years, as was initially designed.
- In one of the groups, 13 teachers (out of 45) volunteered to be among the first schools to fully implement the new program.

In conclusion, the preliminary findings about presenting a program aimed at fostering SRL in technological classes to teachers, as described above, are very encouraging. It was found that educators were interested in shifting the focus of schooling from teaching the subject matter to enhancing students' learning skills. In our estimation, the fact that the program concentrates on enhancing students' work on their graduating projects rather than on improving conventional instruction was a key factor in the program's initial success. We expect that project-based learning in technology would serve as the main framework for fostering students' cognitive and metacognitive skills, as well as increasing their motivation to learn and strengthen their self-efficacy beliefs about learning. This will be the focus of our research in the near few years.

Summary

The SRL theory suggests a comprehensive framework for understanding factors that affect an individual's transition from a dependent to an autonomous learner. We have seen a model of SRLT comprised of cognitive, metacognitive and motivational domains, and analyzed how technology education relates to fostering people's competencies in each of these domains. Regarding the cognitive domain, the discussion focused on problem-solving and creativity. To foster students' self-regulatory behaviour, it is necessary to engage them in open-ended assignments in informal contexts. It is also important to encourage students to think iteratively and be ready to reconsider or revise earlier assumptions about the nature of the problem they are addressing or the required solution. In addition, there is great benefit in teaching students a repertoire of methods, strategies and heuristics for inventive design and problem-solving rather than letting them search randomly for ideas or use the trial-and-error method. Metacognition deals with an individual's ability and aptitude to be aware of and control his own thinking, such as considering how learning goals are selected, the use of prior knowledge and experience, or intentionally choosing problem-solving strategies. Self-regulatory behaviour in learning and problem-solving depends largely on an individual's motivation to deal with an assignment, and the internal satisfaction of being engaged in a task contributes more to creativity than external rewards. Self-regulated learning is also highly correlated with people's self-efficacy beliefs about their ability to accomplish a task successfully, which is determined by previous positive experience in dealing with similar tasks, as well as by a supportive social and emotional environment. The SRLT model emphasizes the interrelationships of the cognitive, metacognitive and motivational aspects of learning, problem-solving and creativity. For example, teaching the students strategies and heuristics for creativity in problem-solving could help them handle challenging tasks, improve their ability to monitor their own thinking and reflect on their learning, and increase their self-efficacy beliefs about problem-solving and invention.

Technology education has the potential of being one of the best platforms for fostering students' self-regulatory behaviour in school for several reasons. Firstly, technology studies deal with issues that could interest students personally, enhance their imagination, relate to daily life or concern the needs of individuals and society, for example, individuals with special needs. Secondly, technology studies put into practice the notion of 'learning by doing,' which educationalists have recognized long ago as being an essential ingredient in developing an individual's cognitive and social aptitudes. Thirdly, technology studies take place in a rich learning environment, which includes, for example, materials, tools, instrumentation and computers. Moreover, while in many disciplines computers and communication technologies serve as aides for instruction and learning, in technology education the students often use computers and other interactive technologies as an integral part of the systems they design and construct. And fourthly, in learning technology students get feedback not only from their teachers and peers, but also from their success or failure in their efforts to design, construct, troubleshoot and improve original and useful artefacts and systems. Perhaps the technology class is a natural arena for putting into practice the notion of artefacts as cognitive tools, which assist learners not only in developing, examining and expressing ideas but also in cultivating their own learning and cognition.

I would like conclude by proposing two directions for further research in promoting SRLT education. The first is an investigation of the nature of metacognition in the context of technological problem-solving, design and invention, and how to enhance students' metacognitive performance in the technology class. The second could relate to teachers' pedagogical content knowledge about fostering cognition, metacognition and motivation in technology education, and how this knowledge affects students' performance, achievements and perceptions about learning technology. Such studies would contribute to our theoretical knowledge and schooling practice related to making technology education an important aim in cultivating students' intellectual skills in school.

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