Learning Design: Creating Powerful Learning Environments for Self-Regulation Skills

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Received in July 2019

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Abstract. The interdisciplinary research in the learning sciences has and still does substantially contribute to meeting the current need for new environments for learning by developing and elaborating new perspectives on the ultimate goal of school education, and on the nature of learning to achieve this goal. The presentation start with a brief review of such a perspective. Against this background the article will focus on self-regulation as a major component of the goals of education. Findings about the positive relationship between self-regulation and student learning have lead researchers to design learning environments for improving students' self-regulation skills. Several metacognitive methods have been designed especially for the math learning; as an example the IMPROVE model developed by Mevarech and Kramarski (2014) well briefly be presented. Research evidence will then be discussed showing that such learning environments are effective for developing and improving self-regulated learning in Kindergarten children and primary and secondary school students. Of course, realizing this potential requires in the classroom teachers pay explicit attention to the teaching of self-regulated activities. Therefore, a major challenge for teacher training and professional development consists in improving teachers' awareness and knowledge of self-regulation and equipping them with effective strategies for developing self-regulation skills in students.

Keywords: school, environments for learning, student's self-regulation, self-regulated learning, metacognitive methods for learning.

DOI: 10.17323/1814-9545-2019-4-30-46

Introduction

The interest in learning and how to influence it have been around throughout history. But the scientific study of learning only started at the beginning of the 20th century in the US with Thorndike as one of the pioneers. During that century several perspectives on learning succeeded each other, such as behaviorism, Gestalt psychology, cognitive psychology, constructivism. But overall, notwithstanding high expectations throughout the 20th century about the potential of the scientific study of learning for the improvement of educational practices, the relationship between research and practice remained a rather awkward and not very productive one.

The situation started to change in the last decades of the 20th century, due to the emergence of the learning sciences (LS): a new interdisciplinary field based on research emanating from cognitive science, computer science, educational psychology, philosophy, sociology, anthropology and applied linguistics [Evans, Packer, Sawyer 2016]. The LS aim at better understanding of learning in different real-world situations, namely in classrooms, in workplaces, in the family, and in informal environments. Researchers in the LS apply a variety of methodologies, such as experimental and quasi-experimental designs as well as qualitative approaches. Important from an educational perspective is that they engage in design-based research focusing on the development and evaluation of innovative learning environments (LEs), and by so doing contributing to the improvement of instructional practices.

This pursuit of innovative educational practices was supported by rapid changes in society during the late part of the 20th century, especially the development toward a learning society. Indeed, it has repeatedly been observed that education has not been able to keep up with these changes. This has raised the challenge and the growing need to reform education in view of preparing the future generation for the learning society and for today's technologically complex and economically competitive world through the acquisition of high literacy skills, such as critical thinking, solving complex problems, creativity, regulating one's own learning, and communication skills. Interestingly, the interdisciplinary research in the LS has and still does substantially contribute to meet this need for new environments for learning by developing and elaborating new perspectives on the ultimate goal of school education, and on the nature of learning to achieve this goal.

This article will first present briefly such a perspective. Against this background it will focus on self-regulation as a major component of the goals of education. The positive relationships found between self-regulation and student learning have lead researchers to design learning environments for improving students' self-regulation skills. As an example the IMPROVE model developed by Mevarech and Kramarski [2014] well briefly be presented. Research evidence will then be discussed showing that such learning environments are effective for improving self-regulated learning in Kindergarten children and primary and secondary school students. Taking this into account it will be argued that a major challenge for teacher training and professional development consists in improving teachers' knowledge of self-regulation and equipping them with effective strategies for developing self-regulation skills in students.

1. The goal of education and the nature of productive learning

Traditionally educational psychologists were focused on how to pursue and achieve the objectives of education, but not on determining those goals. However, learning scientists discovered that the challenge of educational reform required reconsidering also the objectives, namely the need for a shift from the traditional focus of learning and teaching on the transition of (surface) knowledge, and toward the acquisition of deep conceptual knowledge and learning and thinking skills.

1.1. Adaptive competence (AC) as the ultimate goal of education

In a report of the European Round-Table of Industrialist [1995] today's learning society is defined in terms of the following characteristics:

- "learning is accepted as a continuous activity throughout life;
- learners assume responsibility for their own progress;
- assessment is designed to confirm progress rather than to sanction failure;
- personal competence and shared values and team spirit are recognized equally with the pursuit of knowledge;
- and learning is a partnership among students, teachers, parents, employers and the community working together" (p. 15).

Taking this into account, education at all levels must focus more than has been the case on developing and fostering in students' adaptive expertise/competence [Hatano, Inagaki 1986] (see also [Bransford et al. 2006]), i.e. the ability to apply meaningfully learned knowledge and skills flexibly and creatively in a variety of contexts, opposed to routine expertise, i.e. the ability to complete typical school tasks quickly and accurately but without understanding the process that was required to accomplish the task. Considering also research on expertise in a variety of disciplines, there is today a fairly broad consensus that achieving AC in a domain requires the integrated acquisition of several categories of cognitive, motivational and affective components [De Corte 2012; Ligorio, De Corte, Dochy 2015]:

1. A well-organised and flexibly accessible domain-specific knowledge base involving the facts, symbols, concepts, and rules that constitute the content of a subject-matter field.
2. Heuristics methods, i.e. search strategies for problem analysis and transformation which do not guarantee but significantly increase the probability of finding the correct solution through a systematic approach to the task (e.g., decomposing a problem into sub-goals).
3. Metaknowledge: knowledge about one's cognitive functioning (metacognitive knowledge; e.g., knowing that one's cognitive potential can be developed through learning and effort), and knowledge about one's motivation and emotions that can influence learning (e.g., becoming aware of one's of fear of mathematics)

4. Self-regulation skills: skills for regulating one's cognitive processes (cognitive self-regulation; e.g., reflecting on a solution process), and skills for regulating one's motivation and emotional processes (motivational self-regulation; e.g., maintaining attention and motivation to solve a given problem)
5. Positive affect: positive emotions and attitudes toward subject-matter domains and toward learning, and positive self-efficacy beliefs

1.2. Constructive learning as the road to AC

To pursue AC taking thereby into account the importance of contextual and social factors that affect learning, contemporary school learning should embody more than it has in the past the current prevailing perspective on learning as an active/constructive, cumulative, self-regulated, goal-directed, situated and collaborative, individually different process of knowledge and skill building. These features of productive and meaningful learning are well documented by a substantial amount of LS research [De Corte 2010; National Research Council 2000, 2005; Woolfolk 2016]. Therefore they can and should guide educational practices.

This constructive perspective on learning has been criticized by authors who argue in favor of direct instruction (e.g., [Kirschner, Sweller, Clark 2006]). However, based on an analysis of the literature of the past fifty years, Mayer [2004] has concluded that guided discovery/constructive learning leads to better learning results than direct instruction. But the learning environment should be characterized by an effective balance between discovery and personal exploration, on the one hand, and systematic instruction and guidance on the other hand, while being sensitive to learners' individual differences in abilities, needs, and motivation.

2. Defining self-regulation

There is today a broad consensus that self-regulation has significant impact on students learning activities and their school achievement (see e.g., [Schunk, Greene 2018]). But as shown by Dinsmore, Alexander, Loughlin [2008] after about 25 years of research on self-regulation there is still no clear and unequivocal definition of this construct. Our perspective on self-regulation as a component of adaptive competence described above, is in line with Pintrich's [2000] general working definition: "… it is an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment". (p. 453)

In accordance with our socio-constructivist conception of mathematics learning, we thus share the view that SRL is — as stated by Winne [1995] — an inherently constructive and self-directed process. It is a form of action control characterized by the integrated regulation of cognition, motivation, and affect. Likewise we share the broad perspective on SR as involving besides cognitive and metacognitive aspects, also motivational and affective components [De Corte, Verschaffel, Op't Eynde 2000]. This implies at the same time that we consider metacognitive skills as a subordinate component of self-regulation.

Research on SR of learning and thinking has been mainly undertaken from two theoretical perspectives that provide a further specification of this component of adaptive expertise: Zimmerman's model of SR based on social-cognitive theory (see e.g., [Schunk 1998]), and theories of problem solving, especially the work of Schoenfeld [1985]. Zimmerman's [2000] cyclical process model of SR consists of three phases:

- forethought which relates to processes (e.g., goal setting) and beliefs (e.g., self-efficacy beliefs) that precede action and efforts to learn or to solve a problem;
- performance or volitional control which refers to processes that occur during learning or problem solving (e.g., monitoring, attention focusing);
- self-reflection which includes processes that take place after performance (e.g., self-evaluation, attribution) and influence forethought for the next regulatory cycle.

Schoenfeld's [1985] theory of problem solving is less elaborated than Zimmerman's model as far as the SR component is concerned. It focuses on metacognitive or cognitive self-regulatory skills that accompany an expert problem-solving process or learning task, namely:

- orientation toward the task (e.g., building a representation of a problem),
- planning a solution process or an approach to the task,
- monitoring during task execution,
- evaluating the outcome,
- reflecting on a solution or a learning process.

There is obviously a strong parallelism between both perspectives with respect to the metacognitive processes: building a representation of the task and planning an approach fit well in Zimmerman's forethought; monitoring converges with a major process of the performance phase, and evaluation and reflection correspond to Zimmerman's self-reflection phase.

As mentioned before, beliefs are an important component of our model of adaptive competence. Research shows indeed that epistemic and motivational beliefs that students hold play an important role in SRL [De Corte et al. 2000; Muis 2007]. Epistemic beliefs involve beliefs about math as a discipline, about the learning math, and about the social context of math activities in the classroom. For example: if students believe that math knowledge consists of a set of separate facts and rules, they are more likely to activate memory strategies focused on remember formulas and procedures. Motivational beliefs about the self in relation to math learning concern several constructs examined in motivation research, such as achievement goal orientation, perceived responsibility for failure and success, and self-efficacy. For example: self-efficacy beliefs seem to play a crucial role in the processes by which students actively manage their learning activities.

3. Learning design for improving self-regulation skills

Findings about the positive relationship between SR and student learning have lead researchers to design learning environments for improving students' self-regulation skills [Mevarech, Verschaffel, De Corte 2018]. Several metacognitive methods have been designed for the math learning, mostly based on the work of Polya [1945] and Schoenfeld [1985]. They use self-addressed metacognitive questions and share common stages as suggested by the model IMPROVE (see e.g., [Mevarech, Kramarski 2014]):

- Introducing the new materials, concepts, problems or procedures using metacognitive scaffolding.
- Metacognitive self-directed questioning in small groups or individually.
- Practicing by employing the metacognitive (MC) questioning.
- Reviewing the new materials by teacher and students, using the MC questioning.
- Obtaining mastery on higher and lower cognitive processes.
- Verifying the acquisition of cognitive and metacognitive skills based on feedback-corrective processes.
- Enrichment and remedial activities.

The core component of the IMPROVE consists in training the students to use four kinds of metacognitive self-directed questions:

- Comprehension: What is the problem all about?
- Connection: How is the problem at hand similar to or different from problems you have solved in the past? Please explain your reasoning.
- Strategies: What strategies are appropriate for solving the problem and why?
- Review: Does the solution make sense? Can you solve the problem differently, how? Are you stuck? Why?

3.1. Research evidence at the Kindergarten level

Studies conducted in the 1980s-1990s claimed that children younger than 10 years old have limited metacognitive skills: they are in the concrete developmental stage and therefore cannot use higher-order skills, such as those involved in metacognition. However, in the years 2000s, research started to report other evidence. Veenman, Van Hout-Wolters, & Afflerbach [2006] indicated that children at the age of 4-5 years can estimate the difficulty of a task and have some knowledge which strategies to use. Whitebread and Coltman [2010] showed that without adult intervention, kindergarten children at the age 3-5 spontaneously plan, monitor, control, and reflect on their mathematics activities. Based on this research, several intervention studies applied metacognitive pedagogies for enhancing kindergarten's children metacognition and mathematical reasoning (e.g., [Ginsburg, Lee, Boyd 2008]).

In these studies, the teacher scaffolds children's thinking by providing metacognitive hints based on IMPROVE and asks to explain their reasoning. For example, Mevarech and Eidini (in preparation) conducted a study in which the teacher read aloud from an e-book embedded with metacognitive scaffolding. The metacognitive questions were modified to fit the child's age: What does this page tell us? What do you have to do in order to find the answer? Please explain your thinking. Why do you think you have to add/subtract? The intervention highly enhanced children's metacognition and mathematical reasoning: the experimental group could better explain their reasoning, used richer mathematical language, and improved their problem solving skills more than the control groups.

3.2. Developing SR skills for word problem solving in the primary and secondary school

De Corte and Verschaffel [2006] designed an innovative learning environment ("Skillfully Solving Context Problems (SSCP)") for acquisition of cognitive self-regulation skills for mathematical problem solving by fifth graders. It consist of a series of 20 lessons involving of five stages:

- I build a representation of the problem.
- I decide how to approach and solve the problem.
- I do the necessary calculations.
- I interpret the outcome and formulate an answer.
- I control and evaluate the solution.

A set of eight heuristic strategies was embedded and taught in the first and second stages; for example: draw a picture of the problem situation, distinguish relevant from irrelevant data. Acquiring this problem-solving strategy involved: awareness training (becoming aware of the phases of a competent problem-solving process); self-regulation training (becoming able to monitor and evaluate one's actions during the solution process); and heuristic strategy training (gaining mastery of the heuristic strategies). The environment was designed in narrow cooperation with the teachers of the participating classes who were intensively prepared for implementing of the learning environment.

The effects of the intervention were evaluated using a pre-test-posttest-retention test design with an experimental group consisting of four fifth-grade classes (n = 86) and a control group of seven comparable classes (n = 146). A wide variety of instruments was applied: word problem solving tests, and a standardized math achievement test, an attitude questionnaire, interviews teachers and students, and video-registration of some lessons.

To elicit and support in students constructive, self-regulated, situated and collaborative learning the environment was based on the three pillars that embody those characteristics of productive learning:

- A varied set of complex, realistic, and open problems that lend themselves well for the application of the SR skills and the heuristics.
- Creating a learning community through the application of a varied set of activating and interactive instructional techniques: group work, whole class discussion, and individual assignments.
- Establishing an innovative classroom culture through the introduction of new social norms with respect to learning and teaching problem solving; e.g., stimulating students to articulate and reflect upon their cognitive and SR regulation activities; discussion about what counts as a good problem, a good response, and a good solution procedure; and reconsidering the role of the teacher and the students in the learning community.

Main results can be summarized as follows. The intervention had a significant and stable positive effect on the experimental pupils' skills in solving math problems (in comparison with a control group). The positive effect was stronger for the high ability students, but also the low ability ones benefited significantly from the intervention. The results on a math achievement test revealed a significant transfer effect to other parts of the math curriculum (measurement, geometry). There was a substantial significant increase in the experimental students' spontaneous use of heuristic and self-regulation skills (orienting, planning, monitoring, evaluating).

Studies by Mason & Scrivani [2004] and by Panaoura, Demetriou, & Gagatsis [2010] in which an SSCP-based learning environment for problem solving was used also with fifth graders, yielded similar major findings. These studies show that innovative learning environments in which SR skills for solving math problems are learned by using interactive instructional methods in a new classroom culture can significantly increase students' competence. The basic principles of the interventions converge with the characteristics of the effective learning environments that derive from recent meta-analyses of teaching experiments:

(1) train in an integrated way cognitive, metacognitive, and motivational strategies, using thereby a variety of teaching methods;
(2) pay explicit attention to the usefulness and benefits of strategies;

(3) create opportunities for practicing strategies and provide feedback about strategy use;
(4) create an innovative classroom culture that stimulates SR learning, especially reflection [Dignath, Büttner 2008; Dignath, Büttner, Langfeldt 2008; Veenman, Van Hout-Wolters, Afflerbach 2006].

Studies on the effects of SRL on secondary school mathematics achievement reveal similar findings to those conducted at the lower levels of education. Metacognitive pedagogy via IMPROVE is particularly beneficial for promoting students' mathematical literacy, because it trains students to activate higher-order cognitive skills which are crucial for solving math literacy tasks [Mevarech, Lianghuo 2016].

To conclude, meta-analyses [Dignath, Büttner, 2008] based on 49 studies at the primary school and 35 at the secondary school level, that analyzed the effects of SRL on reading and math achievement reported an average effect size of 0.69. For both school levels, higher effect sizes were observed when the training was conducted by researchers instead of regular teachers. Moreover, higher effects were attained in the domain of math than in reading/writing or other subjects. The main conclusion of these meta-analyses is that SRL can be fostered effectively at both primary and secondary school level.

4. Teachers and self-regulation teaching

As a major aspect of adaptive competence self-regulation skills constitute a critical component of students' ability for successful academic learning and performance. Indeed, research shows convincingly for that the positive relationship between SRL and student achievement. Moreover, research also confirms that learning environments can be designed and implemented that support and foster students' SR learning.

Of course realizing this potential requires in the classroom teachers pay explicit attention to the teaching of self-regulation activities. In the respect research indicates that teachers have difficulties in teaching self-regulation skills in their classroom, thus in practicing self-regulated teaching [Kramarski 2018]. For instance, we videotaped and analyzed in 10 sixth-grade classroom the teaching activities during two math problem-solving lesson. In these classes a reform-oriented mathematics textbook was used which is inspired by the SSCP learning environment. The textbook proposed to that teachers pay the explicit attention to a list of heuristic and metacognitive skills, such a metacognitive strategy for solving math problem. The results showed that although some heuristics were regularly used during the lessons, many skills – especially the metacognitive strategy - very almost never addressed. In other words, when the teaching of math problem solving is done based on a textbook that explicitly presents and advocates the use and application of a SR skills, this does not easily nor automatically result in a high-fidelity and sustained implementation of the innovative approach [Depaepe, De Corte, Verschaffel 2007].

More recent studies confirm and further document what was observed in previous research, namely that teachers experience problems in applying SR learning and teaching [Kramarski 2018]. More specifically, their knowledge about SR and SRL is restricted; accordingly they are not good at implementing SRL, and they do not create learning environments that elicit and stimulate SR activities in their classroom. There is thus urgent need to focus on SR and SRL in initial teaching training as well as in the professional development. In that perspective research should engage in designing the development of appropriate tools and methods to enhance teachers' knowledge of SR, and to equip them strategies for fostering SR skills in students.

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