

# Constructive, Self-Regulated, Situated, and Collaborative Learning: An Approach for the Acquisition of Adaptive Competence

ERIK DE CORTE, CENTER FOR INSTRUCTIONAL PSYCHOLOGY AND TECHNOLOGY,  
UNIVERSITY OF LEUVEN, BELGIUM

## ABSTRACT

In today's learning society, education must focus on fostering adaptive competence (AC) defined as the ability to apply knowledge and skills flexibly in different contexts. In this article, four major types of learning are discussed—constructive, self-regulated, situated, and collaborative—in relation to what students must learn in order to acquire AC in a particular domain. Two questions are addressed: What are the characteristics of productive learning processes that are required in order to acquire AC?, and How can such learning be stimulated and sustained through instruction? An illustrative study is presented that focuses on the design of a learning environment for improving problem-solving competence in primary school students. Concluding comments address the challenges to the implementation of innovative learning environments.

## INTRODUCTION

In a report of the European Round-Table of Industrialists (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 competence* (AC), i.e., the ability to apply meaningfully learned knowledge and skills flexibly and creatively in a variety of contexts. This approach described in this article is in direct contrast to those used to develop *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.

The initial discussion will focus on and illustrate what students should learn in order to acquire AC in a particular domain. Then the key question will be addressed: What are the characteristics of productive and meaningful learning processes that are required for AC? The focus will be on four major characteristics: constructive, self-regulated, situated, and collaborative learning (CSSC). The approach integrates the acquisition and participation metaphors of learning, or the individual and social aspects of learning.

From a teaching perspective, the related question is: How can these CSSC learning processes be stimulated and sustained through instruction? An illustrative study will be presented that focuses on the design, implementation, and evaluation of a learning environment for improving the problem-solving competence of upper-primary school students. The article will conclude with final comments that address the crucial issue of effective and sustainable implementation of such innovative learning environments in daily classroom practice.

## WHAT SHOULD STUDENTS LEARN?

Many scholars in the field of education now agree that the ultimate goal of instruction and learning in the academic subjects consists of acquiring "adaptive expertise" (Hatano & Inagaki, 1986; Hatano & Oura, 2003; see also Bransford et al., 2006), or "adaptive competence," as opposed to "routine expertise." Although different levels of expertise can be distinguished (Hatano & Oura, 2003), the term "expertise" is associated with exceptional levels of performance. Because of this connotation, the term "competence" will be used, as one cannot expect that most students will achieve exceptional performances in the subject-matter domains of the school curriculum. Building adaptive competence in a domain requires the acquisition of several cognitive, affective, and motivational components:

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 (e.g., decomposing a problem into sub-goals, making a graphic representation of a problem) which do not guarantee but significantly increase the probability of finding the correct solution by inducing a systematic approach to the task;
3. meta-knowledge involving knowledge about one's cognitive functioning or "metacognitive knowledge" (e.g., knowing that cognitive potential can be developed through learning and effort) and knowledge about motivation and emotions that can be actively used to improve learning (e.g., becoming aware of one's fear of failure in mathematics);
4. self-regulatory skills for regulating one's cognitive processes/activities ("meta-cognitive skills" or "cognitive self-regulation," e.g., planning and monitoring problem-solving processes) and skills for regulating one's volitional processes/activities ("motivational self-regulation," e.g., maintaining attention and motivation to solve a given problem); and

5. positive affect, i.e., positive emotions and attitudes toward subject-matter domains and toward learning, as well as positive self-efficacy beliefs (De Corte, 2010).

Prioritizing adaptive competence does not mean that routine expertise becomes unimportant; it is obvious that mastering certain skills routinely (e.g., basic arithmetic, spelling, technical skills) is crucial to efficient functioning in all kinds of situations. If certain aspects of solving a complex problem can be performed more or less mechanically, such automaticity allows the learner to focus attention on the higher-order cognitive activities that are needed to reach the solution. However, adaptive competence is important because it goes beyond that—it “. . . involves the willingness and ability to change core competencies and continually expand the breadth and depth of one’s expertise” (Bransford et al., 2006, p. 223). It is therefore fundamental in acquiring the ability to transfer one’s knowledge and skills to new learning tasks and contexts (De Corte, 2007; Hatano & Oura, 2003) and to lifelong learning.

As will be documented below, the available literature shows in two different ways the importance of these components of AC. First, abundant evidence documents the lack of one or more of the components in novices or poor performers in a subject-matter domain (Garner, 1987; Schoenfeld, 1985). Second, a substantial amount of research demonstrates that acquiring mastery of those components through instruction improves students’ approaches to problems and results in better performance (Brown & Palincsar, 1989; De Corte, Verschaffel, & Masui, 2004). An extensive discussion of the five components from these two perspectives is beyond the scope of this article. Therefore, I will briefly and selectively document the importance of the following components: domain-specific knowledge, heuristic and cognitive self-regulation skills, and beliefs about subject-matter fields.

With respect to *domain-specific knowledge*, research has demonstrated that many students have only superficial, often deficient knowledge of basic concepts in several subject-matter domains, and moreover that they have serious misconceptions. For example, many students at the end of the primary school have the idea that multiplication results in a larger number, while the opposite is true for division. Many misconceptions have been observed in the domain of physics—for example, that heavier objects fall faster than light objects, and that continuing force is needed for continuing motion (De Corte, Greer, & Verschaffel, 1996).

In a classic expert-novice study by Chi, Feltovich, and Glaser (1981), Ph.D. students in physics (experts) and undergraduate students (novices) who had completed a mechanics course were asked to sort 24 physics problems into groups based on similarities of solution. The results showed that whereas the experts’ classification of the problems was based on underlying physical principles or laws needed to solve the problems (= a scientific problem representation), the novices used superficial features of the problems to classify them, such as the apparatus involved in the task, surface aspects of a diagram, or actual terms in the problem statement (= a naive problem representation). These distinct representations of the problems reflect differences in the content and the organization

of the *domain-specific knowledge* base between the experts and the novices. Together with similar studies in different domains, this study shows the important role of domain-specific knowledge in learning and problem solving, especially in view of the construction of an appropriate initial representation of a learning task or a problem (Chi, Glaser, & Farr, 1988; Ericsson, 2003; Schraw, 2006).

The lack of mastery and use of *heuristic methods and cognitive self-regulation skills* has also been clearly demonstrated, for instance, in mathematical problem solving, reading comprehension, and text writing. Heuristic methods are strategies for problem analysis that aim at transforming a problem situation into a routine task for which the problem solver has the knowledge and skills available to elaborate the solution of the task (De Corte, 2010). Additional examples include carefully analysing a problem, finding an easier related or analogous problem, visualizing a problem, working backward from the intended solution, and provisionally disregarding a requirement of the solution.

Cognitive self-regulation strategies constitute an executive control structure that organises, guides, and monitors learning and thinking processes. Examples include planning a solution process, monitoring an ongoing solution process, evaluating and debugging a solution, and reflecting on a finished solution process. Successful learners and problem solvers can *simultaneously* perform two functions, namely executing and elaborating the solution, and regulating the task-related activities, which involves orienting, planning, monitoring, evaluating, and reflecting.

Convincing evidence of the lack of heuristics and self-regulation skills in novices has been provided by Schoenfeld (1992). He videotaped high school and college students working in pairs on unfamiliar math problems during 20-minute sessions, and contrasted their solution processes with those of experts. The solution processes were parsed into episodes representing different activities: reading the problem, analysing, exploring, planning, implementing, and verifying. In about 60% of the novices’ solution attempts, heuristics (such as analysing the problem) and self-regulatory activities (such as monitoring the solution process), which are characteristic of an expert approach, were totally absent. The typical strategy used can be summarized as follows: reading the problem, deciding quickly about an approach, and then keeping at it without considering any alternative, even if no progress at all is made. In an earlier study, Schoenfeld (1985) found that teaching students heuristics and self-regulatory skills improved their problem-solving ability.

With respect to reading comprehension, Garner (1987) has documented that mastery and use of good regulatory skills, such as text re-inspection, distinguishes poor and skilled readers. Other researchers have found that teaching strategies for reading comprehension and writing has a positive effect, respectively, on students’ text comprehension (Brown, Pressley, Van Meter, & Schuder, 1996; De Corte, Verschaffel, & Van de Ven, 2001) and writing skills (Scardamalia, Bereiter, & Steinbach, 1984).

In sum, the available empirical evidence suggests that more successful learners master more effective and more sophisticated

heuristic and self-regulation skills than less successful learners, but also, that such skills can be learned as early as the primary-grade level if students are provided with appropriate instruction. Moreover, self-regulation skills foster the ability to transfer one's knowledge and skills to new problem situations and tasks. Brown and Campione (1994) observed improvement in students' reading comprehension results on materials outside the domain of biology that was studied in the classroom (see also De Corte, 2003).

The importance of *positive affect* for learning, especially of different categories of beliefs such as self-efficacy and epistemological beliefs, has been studied and stressed over the past decade (see Bendixen & Feucht, 2010). Epistemological beliefs, i.e., beliefs about knowledge and learning, have been found to affect the degree to which individuals actively engage in learning, persist in difficult tasks, comprehend written material, and approach and cope with learning tasks and problems in complex and ill-structured domains (Schommer, 1994b). However, the research of the past two decades reveals that in many subject-matter domains, students hold beliefs that are naive, incorrect, or both, and that these beliefs can have a negative or inhibitory effect on their learning activities and approaches. With respect to mathematics, many students believe that mathematics is a fixed body of received knowledge, not knowledge that is constructed by the learner. Related to this belief are the following features of the rather common view among students: mathematics is associated with certainty and being able to give quickly a correct answer, doing math corresponds to following rules described by the teacher, and an answer to a math question or problem becomes true when it is approved by the teacher (De Corte, Verschaffel, & Op 't Eynde, 2000). One pertinent illustration of these flaws in students' beliefs about mathematics as a domain derives from a study by Picker and Berry (2000) who asked 476 12- to 13-year-olds from five countries (Finland, Romania, Sweden, the United Kingdom, and the United States) to make a drawing of a mathematician and to comment on it in writing. Two distinct categories of drawings were obtained: some students depicted a mathematician who was clearly not a teacher, but others drew an image of a mathematician as a teacher. One major common theme among the drawings and comments of the subjects from the five countries is *mathematics as coercion*: the gist of the drawings of many students was indeed that of powerless little children confronted with a mathematician depicted as authoritarian and threatening. As it is plausible to assume that students' drawings reflect their beliefs about mathematics, it is obvious that they do not perceive this domain as attractive, interesting, and engaging.

With respect to reading comprehension, Schommer (1994a) reported the following naive beliefs that play an important role in various aspects of reading: learning to read means memorizing words; reading to learn means reading to memorize facts; and reading to learn should be a quick process which reveals absolute, certain knowledge. With regard to history, Wineburg (1991) observed debilitating beliefs such as historical accounts are merely collections of "facts" and that learning history is passively accept-

ing and absorbing the factual information. Songer and Linn (1991) have shown that many students believe that knowledge in science is best characterized as bits of isolated and static knowledge.

## CHARACTERISTICS OF PRODUCTIVE LEARNING PROCESSES IN THE ACQUISITION OF AC

To pursue adaptive competence and overcome the shortcomings discussed above, and to take into account the importance of contextual and social factors that affect learning, contemporary school learning must embody more than it has in the past. The newer construct of learning can be defined as follows: learning is an active/constructive, cumulative, self-regulated, goal-directed, situated, collaborative, and individually different process of meaning construction and knowledge and skill building. These features of productive and meaningful learning are well documented by a substantial amount of research (De Corte, 2010; Kirby & Lawson, 2012; National Research Council, 2000, 2005). Since it is not possible to review all the research, the following discussion will focus on the four key characteristics noted earlier: constructive, self-regulated, situated and collaborative learning; building on students' prior knowledge; and taking into account individual differences. The three vignettes in Appendix A describe concrete examples.

### Learning Is Constructive

The constructivist view of learning has become more or less common ground among educational psychologists (see, e.g., Simons, van der Linden, & Duffy, 2000). Learners are viewed not as passively receiving information, but as actively constructing knowledge and skills through reorganisation of their previously acquired mental structures. There is strong evidence now that learning is in some sense always constructive, even in environments where direct instruction predominates. This is demonstrated by the research showing the occurrence of misconceptions (such as "multiplication makes bigger") referred to above, and defective procedural skills (as illustrated in Vignette 1 in Appendix A) among students in traditional mathematics classrooms. As Hatano (1996) suggests, "it is very unlikely that students have acquired them by being taught" (p. 201).

What is essential in the constructivist perspective is the mindful and effortful involvement of students in the processes of knowledge and skills acquisition in interaction with the environment. This is illustrated by the rather cumbersome but accurate calculation procedure invented by the Brazilian street vendor in Vignette 2 (see Appendix A). In previous work with a colleague (De Corte & Verschaffel, 1987), evidence supporting this constructive view of children's learning was found even in the simple domain of solving one-step addition and subtraction word problems. Indeed, first graders used a large variety of solution strategies, many of them not taught in school, but rather, constructed by the children themselves. The accumulating evidence in favor of the constructive nature of learning is in line with the earlier work of influential scholars like Piaget (1955) and Bruner (1961).

## Learning Is Self-regulated

Constructive learning is also self-regulated. As Zimmerman (1994) suggests, “individuals are metacognitively, motivationally, and behaviorally active participants in their own learning process” (p. 3). If students are to become lifelong learners responsible for their own progress, they must be able to manage and monitor their processes of knowledge building and skills acquisition. This characteristic of learning is illustrated in Vignette 2 (see Appendix A) by the calculation procedure of the Brazilian street vendor.

Although research on self-regulation in education began only about 25 years ago, a substantial amount of empirical and theoretical work has yielded important insights (for a detailed overview see Boekaerts, Pintrich, & Zeidner, 2000; Zimmerman & Schunk, 2011). First, major characteristics of self-regulated learners have been identified: these learners manage study time well, set higher immediate learning targets which they monitor more frequently and accurately, set a higher standard for satisfaction, and are more self-efficacious and persistent despite obstacles. Second, self-regulation correlates strongly with academic achievement across different subject areas (Zimmerman & Risemberg, 1997). Because research also shows that learners do not acquire sophisticated self-regulation spontaneously, self-regulation is not only a feature of productive learning, but as a component of AC, constitutes in itself a goal of a long-term learning process that should be encouraged from an early age (De Corte, Mason, Depaepe, & Verschaffel, 2011).

## Learning Is Situated or Contextual

It is also widely held in the educational research community that constructive and self-regulated learning should occur in context, i.e., in relation to the social, contextual, and cultural environment in which these processes are embedded and which influence their development (see Kirshner & Whitson, 1997; National Research Council, 2000). The situated view stresses that learning is enacted essentially in interaction with, and especially through, participation in social and cultural activities and contexts. This is also illustrated in Vignette 2 (see Appendix A) by the calculation procedure invented by the Brazilian street vendor in the real-world context of his business. In mathematics, the situational perspective has stimulated the movement toward more authentic and realistic mathematics education (De Corte et al., 1996).

## Learning Is Collaborative

The collaborative nature of learning is closely related to the situated perspective that stresses its social character. Effective learning is a distributed activity, not a purely solitary one. The learning effort is distributed over the individual student; the partners in the learning environment; and the available resources, technology, and tools (Salomon, 1993). For example, social interaction is considered essential for mathematics learning as individual knowledge construction occurs through interaction, negotiation, and cooperation (Wood, Cobb, & Yackel, 1991). Vignette 3 in Appendix A provides an illustration in the format of the “jigsaw method.”

The literature provides substantial evidence supporting the positive effects of collaborative learning on academic achievement (Lehtinen, 2003; Salomon, 1993; Slavin, 2010). It suggests that a shift toward more social interaction in classrooms would represent a worthwhile move away from the traditional emphasis on individual learning; learning can be made more productive by ample application of collaboration between students in such activities as exchanging ideas, comparing solution strategies, and discussing arguments. Of special importance is that such interactions induce and mobilize reflection, and, thus, foster the cognitive self-regulation of learning. However, going too far to the opposite direction should be avoided because the learning of collaboration and interaction does not exclude the individual development of new knowledge.

## Responses to Critiques of Constructivist Approaches

The understanding of learning as described above is a broad representation of the socio-constructivist view, combining and integrating acquisition and participation (Sfard, 1998) or the individual and social aspects of learning (Salomon & Perkins, 1998). Although the available literature provides support for CSSC learning (see Bransford et al., 2006; National Research Council, 2000, 2005), the constructivist perspective has also been criticized. Kirschner, Sweller, and Clark (2006) argue that approaches based on constructivism rely excessively on discovery learning and provide minimal guidance to students, ignoring thereby the structure of human cognitive architecture and resulting in cognitive overload of working memory. These authors argue for a return to direct instruction.

While the critics are correct that pure discovery does not yield the best learning gains, as evidenced by Mayer (2004) in an overview of the literature of the past fifty years, constructive learning cannot be equated with discovery learning. The concept of learning as an active, constructive, self-regulated process does not imply that students’ construction of their knowledge and skills cannot and should not be guided and mediated through appropriate modelling, coaching, feedback, examples, and scaffolding by teachers, peers, and educational media. Mayer concludes that guided discovery learning in the reported studies led to better learning outcomes than direct instruction. A powerful innovative learning environment is characterized by an effective balance between discovery and personal exploration, and systematic instruction and guidance, while being sensitive to learners’ individual differences in abilities, needs, and motivation. A recent meta-analysis of the relevant research confirms Mayer’s conclusion: direct teaching is better than unassisted discovery, but guided, enhanced, or assisted discovery learning is superior to direct or explicit teaching (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011). However, it is important to note that the balance between external regulation by the teacher and self-regulation by the learner will vary during students’ learning history; as competence increases self-regulation can grow and explicit instructional support can diminish. Informed by these conclusions, the design



of learning environments will prevent cognitive overload and simultaneously induce “germane cognitive load” that facilitates effective learning (Schmidt, Loyens, van Gog, & Paas, 2007).

## DESIGN OF LEARNING ENVIRONMENTS TO STIMULATE CSSC LEARNING PROCESSES

Starting from the CSSC view of learning, a major challenge from the perspective of teaching is: How can such learning processes be stimulated and sustained through instructional intervention? The study that is the subject of this article focused on the design, implementation, and evaluation of a learning environment intended to foster CSSC learning processes for adaptive competence in mathematical problem solving among upper primary school students (for a more detailed report see Verschaffel et al., 1999). The aim of the study was to investigate whether immersing students in this learning environment resulted in an improvement of their problem-solving competence as well as in more realistic and more positive mathematics-related beliefs.

### The Experimental Learning Environment

The learning environment in the experimental classes was fundamentally changed with respect to the following components: the content of teaching and learning, the nature of the problems, the instructional techniques, and the classroom culture. First, students were taught a five-stage general *self-regulation strategy* for solving mathematical application problems, and a set of eight heuristic strategies which are especially useful during the first two stages of the process (see Appendix B). Acquiring this problem-solving strategy involved: (1) becoming aware of the different phases of a competent problem-solving process (awareness training), (2) becoming able to monitor and evaluate one’s actions during the different phases of the solution process (self-regulation training), and (3) gaining mastery of the eight heuristic strategies (heuristic strategy training).

Second, a varied set of *realistic, complex, and open problems* was used. The problems differed substantially from traditional textbook tasks and were presented in different formats: a text, a newspaper article, a brochure, a comic strip, a table, or a combination of several of these formats. The example in Appendix C illustrates the kind of tasks used in the learning environment.

Third, a learning community was created through the application of *interactive instructional techniques*, in particular, small-group work and whole-class discussion. The basic instructional model for each lesson consisted of the following sequence of classroom activities: (1) a short whole-class introduction; (2) two group assignments solved in fixed heterogeneous groups of three to four pupils, each of which was followed by a whole-class discussion; and (3) an individual task with a subsequent whole-class discussion. Throughout the lessons the teacher’s role was to encourage and scaffold students to engage in, and to reflect upon, the cognitive and self-regulation activities involved in the five-stage strategy of skilled problem solving. Instructional supports were gradually

faded out as pupils became more competent and self-regulated in their problem-solving activities.

Fourth, an *innovative classroom culture* was created through establishing new norms about learning and teaching problem solving (Yackel & Cobb, 1996), and aiming at fostering positive mathematics-related beliefs. Typical aspects of this classroom culture were: (1) stimulating pupils to articulate and reflect upon their solution strategies and beliefs about problem solving; (2) discussing what counts as a good problem, a good response, and a good solution procedure (e.g., there are often different ways to solve a problem; for some problems, a rough estimate is a better answer than an exact number); and (3) reconsidering the role of the teacher and the pupils in the mathematics classroom (e.g., the class as a whole will decide which of the generated solutions is the optimal one after evaluating the pros and cons of different alternatives).

The learning environment was refined in partnership with the teachers of the experimental classes and their principals. The model of teacher development emphasized the creation of a social context wherein teachers and researchers learn from each other through continuous discussion and reflection on the basic principles of the learning environment, the learning materials developed, and the teachers’ practices during the lessons. The result was a set of ten general guidelines for the teachers comprising specific actions they should take and ways they should be involved with students before, during, and after the individual and group assignments in order to strengthen the power of the learning environment (see Appendix D). In the teacher’s guide that was used in the project, each of these ten guidelines was accompanied by an explanation of its purpose and examples of implementation.

The intervention consisted of 20 lessons that were taught in the experimental classes by the regular teachers over a period of four months during school hours regularly allocated to mathematics. During the same period the pupils from the control classes continued to follow the regular mathematics curriculum, which also involved a considerable number of lessons in word problem solving, however with little or no attention to the intentional and systematic teaching of heuristics and self-regulation skills.

### Design of the Study

*Participants.* Four experimental fifth-grade classes ( $n = 27, 19, 21, 19$ ) and seven comparable control classes ( $n = 29, 22, 19, 21, 20, 17, 18$ ) participated in the study. All these classes were in elementary schools in an urban region of Belgium and included both genders and students of mixed SES backgrounds; the majority of the population was autochthon Belgian. Every faculty member was a qualified teacher certificated by a teacher training college for primary education, and had at least five years of experience.

*Data collection procedures.* The effects of the learning environment were evaluated using a pretest–posttest retention design with an experimental and a comparable control group, applying a wide variety of data-gathering and analysis techniques (see Appendix E). The parallel word-problem tests used as the pretest, posttest,

and the retention test measures consisted of 10 non-routine tasks that lent themselves to the application of the heuristic and self-regulation skills taught during the intervention. The following is an example from the pretest:

Lies has two doll's houses. The square floor of the small doll's house has a side of 40 cm and consists of 16 tiles. The square floor of the large doll's house has a side which is exactly twice the side of the small doll's house. How many tiles are needed for the floor of the large doll's house if the same tiles are used?

Each answer on an item was scored either as correct, wrong, technical computation error, or no answer.

The self-made questionnaire consisting of 21 Likert-like items aimed at assessing students' beliefs and attitudes about teaching and learning mathematical problem solving. Based on a factor analysis two subscales were distinguished: a first subscale containing seven items dealing with pupils' "pleasure and persistence in solving word problems" (e.g., I like to solve word problems; difficult problems are my favourites, . . .), and a second subscale with 14 items expressing "a problem- and process-oriented view on word problem solving" (e.g., there is always only one solution to a word problem; listening to explanations of alternative solution paths by other pupils is a waste of time . . .). On each item the students responded by indicating whether they strongly agreed, agreed, were uncertain, disagreed, or strongly disagreed with the statement.

To assess pupils' general mathematical knowledge and skills, an existing standardized achievement test was administered. The test consists of 58 multiple-choice items belonging to eight subscales: logical operations, sets, relations, numbers, arithmetic operations, word problems, measuring, and geometry (Stinissen, Mermans, Tistaert, & Vander Steene, 1985).

To gain more insight into the qualitative changes in pupils' problem-solving processes as a consequence of the intervention, three pairs of children were selected from each experimental class (one pair of high-ability, one pair of medium-ability, and one pair of low-ability pupils), and asked before and after the intervention to solve five new non-routine application problems in dyads of equal ability. The problem-solving interviews of these dyads were video-registered and afterward analysed by means of a self-made scoring scheme consisting of three aspects: (1) the final result of the problem-solving process (correct, wrong, technical error or no answer), (2) the use of the eight heuristics taught in the program, and (3) the frequency of occurrence of four valuable self-regulation activities (i.e., orientation, planning, monitoring, and evaluation).

To assess the fidelity of implementation of the learning environment by the teachers of the experimental classes, a sample of four representative lessons was videotaped in each class and analysed afterward in terms of an implementation profile. This profile consisted of 10 categories of teacher activities which we considered as essential for the successful implementation of the learning environment, and which corresponded more or less to

the ten general guidelines mentioned in Appendix D (e.g., provide a good orientation to the task, observe the group work and provide appropriate hints when needed, demonstrate the existence of different appropriate solutions and solution methods for the same problem during the whole-class discussion, etc.).

## Results

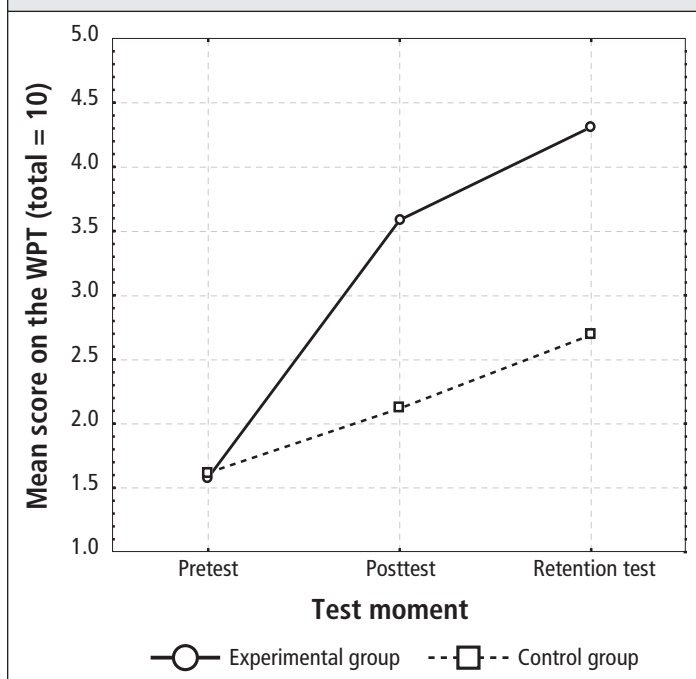
According to the scores on a word-problem pretest and a parallel posttest and retention test, in comparison with the control group, the intervention had a significant and stable positive effect (effect size .31) on the experimental students' problem-solving performance (see Figure 1).

The results of the questionnaire indicated that the learning environment had a significant, albeit small positive impact on children's pleasure and persistence in solving mathematics problems, and on their problem- and process-oriented view of word problem solving (effect size .04).

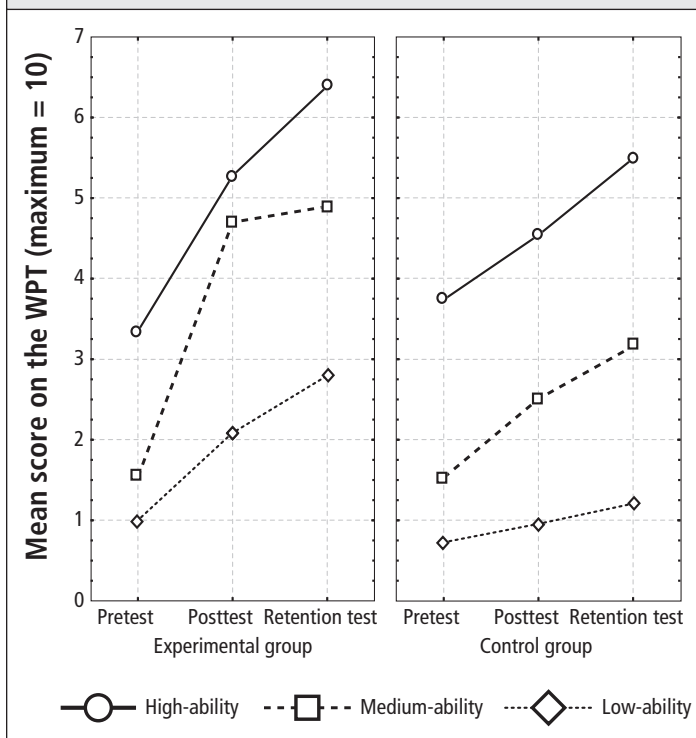
The scores on the standardized achievement test covering the entire math curriculum showed that during the mathematics lessons, the extra attention to cognitive and self-regulation strategies in the experimental classes had no negative influence on the learning outcomes for other parts of the curriculum (measurement, geometry). To the contrary, there was a significant positive transfer effect; the experimental classes performed significantly better than the control classes on this test (effect size 0.38).

Analysis of pupils' written notes on their response sheets of the word problem test showed that the better results of the experimental children were paralleled by a substantial increase in the spontaneous use of the heuristic and self-regulation skills (orienting, planning, monitoring, evaluating) (effect size .76). This finding

**Figure 1. Mean Scores of the Experimental and the Control Group on the Three Versions of the WPT (Pretest, Posttest, and Retention Test)**



**Figure 2.** Mean Scores of the High-, Medium-, and Low-Ability Students of the Experimental and the Control Group on the Three Versions of the WPT (Pretest, Posttest, and Retention Test)



was confirmed by a qualitative analysis of videotapes of the problem-solving interviews of three groups of two children from each experimental class before and after the intervention.

Finally, in the experimental classes not only the high and the medium ability pupils, but also those of low ability benefited significantly, albeit to a smaller degree, from the intervention in all aspects (see Figure 2).

## CONCLUSIONS

The results of this study support the view that a CSSC learning environment, combining a set of carefully designed word problems with highly interactive teaching methods and the introduction of a new classroom culture, can significantly increase students' competency in solving mathematical word problem and foster their mathematics-related beliefs. A study by Mason and Scrivani (2004) yielded the same major finding as this investigation. Interestingly, the basic principles underlying the intervention applied in these two studies 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 practising strategies and provide feedback about strategy use; and (4) create an innovative classroom culture that stimulates self-regulated learning, especially reflection (Dignath & Büttner, 2008; Dignath, Büttner, & Langfeldt, 2008; see also De Corte, Depaepe, & Verschaffel, 2010; Veenman, Van Hout-Wolters, & Afflerbach, 2006).

## IMPLICATIONS FOR PRACTICE AND POLICY

The findings of this intervention study suggest that the CSSC conception of learning can guide the design of novel, but also practically applicable positive learning environments—that is, settings that facilitate students' acquisition of AC, in particular, heuristics and self-regulation skills. It is also important to note that the intervention yielded a sustained effect; the teachers who participated continued to apply the innovative approach to math teaching after the investigation was ended. However, the positive effects of the intervention were the result of intense collaboration with, and guidance of, the teachers and their principals. This is not surprising. Indeed, the effective and sustained implementation of innovative learning environments places high demands on the teachers and requires substantial changes in their role and practices. Instead of being the main source of information, the teacher becomes a "privileged" member of a knowledge-building community who creates an intellectually stimulating classroom climate; models learning, thinking, and problem-solving activities; asks thought-provoking questions; provides support to learners through coaching and guidance; and fosters students' self-regulation of their own learning. In other words, the teacher provides for guided-discovery learning.

In view of the implementation of the CSSC conception of learning, it is interesting to ask whether teachers' and students' ideas and beliefs about learning converge with this view. Taking as a starting point De Corte's (1995) conception of effective learning as a constructive, cumulative, self-regulated, goal-oriented, situated, and collaborative process of knowledge and meaning building, Berry and Sahlberg (1996) developed an instrument to measure and analyse ideas about learning of 15-year-old students in five schools in England and Finland. A major conclusion of the study was that most students adhere to the knowledge transmission model of learning that is difficult to accommodate the CSSC conception. Berry and Sahlberg conclude: ". . . our pupils' ideas of learning and schooling reflect the static and closed practices of the school" (p. 33). They add that this conclusion is mirrored by similar findings from other studies of teachers and adult students.

These findings suggest that students' and teachers' beliefs about learning can be a serious obstacle for the implementation of the CSSC learning approach because the history of education shows the deeply entrenched stability of teaching practices (Berliner, 2008). Therefore, changing these beliefs and practices in view of the large-scale and sustained implementation of innovative learning environments based on the CSSC conception of learning is a challenge to educational professionals, especially educational leaders and policy makers. First, curricula and textbooks need to be designed or revised to reflect this conception. However, integrating new ideas in textbooks does not guarantee that they will appropriately be used in practice (Depaepe, De Corte, & Verschaffel, 2007). Research shows that teachers interpret new ideas through past experiences (see, e.g., Remillard, 2005), and as demonstrated by Berry and Sahlberg (1996), they often rely on traditional beliefs about learning and teaching. Moreover, as

argued by the Cognition and Technology Group at Vanderbilt (1997), the requested changes are “much too complex to be communicated succinctly in a workshop and then enacted in isolation once the teachers returned to their schools” (p. 116). Therefore, there is a strong need for intensive professional learning for school leaders and teachers that addresses the “high fidelity” application of innovative learning environments and materials, while focusing on changing predominant perceptions and beliefs about learning. Such changes can be facilitated by an iterative process in which current views are challenged by learning about successful alternative practices (National Research Council, 2000; Timperley, 2008). At the pre-service level, student teachers should be immersed in the kind of learning environments that they are advised to create and refine in the classrooms in the future.

Finally, the sustainable implementation of the CSSC learning conception requires that it is appropriately communicated to, and supported by the broader community (Stokes, Sato, McLaughlin, & Talbert, 1997) in order to avoid what Dewey (1916) called the isolation of the school. The support of the larger community is important in order to foster synergies between formal learning in the classroom and informal learning in activities outside the school (Bransford et al., 2006; National Research Council, 2000) and for the model described here to reach its fullest potential.

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**Erik De Corte** is Emeritus Professor in the Center for Instructional Psychology and Technology (CIP&T) at the University of Leuven, Belgium. Professor De Corte can be reached at erik.decorte@ppw.kuleuven.be.

## APPENDIX A. FOUR VIGNETTES ILLUSTRATING CHARACTERISTICS OF EFFECTIVE LEARNING

### Vignette 1

Solution of a simple subtraction by a primary school pupil:

$$\begin{array}{r} 543 \\ -175 \\ \hline 432 \end{array}$$

How did this pupil proceed in making this subtraction?

### Vignette 2

(From Nunes, Schliemann, & Carraher, 1993)

Someone buys from a 12-year-old street vendor in Recife, Brazil, 10 coconuts at 35 cruzeiros per piece. The boy figures out quickly and accurately the price in the following way: “3 nuts is 105; 3 more makes 210; . . . I have to add 4. That makes . . . 315 . . . It is 350 cruzeiros.”

When the boy had to solve traditional textbook problems in school, he did much poorer than while doing his business on the street. In the class he did not use the procedures that he used so fast and readily on the street, but he tried to apply the formal algorithms learned in the school, which he apparently did not master very well.

### Vignette 3

In connection with the events in Kosovo, a project focusing on studying the situation in the Balkans was set up in a class of 25 students of the third year of secondary school. One pupil in the class had an ethnic Albanian background. His parents emigrated a few years before from Kosovo to Belgium. In the first phase of the project the class was divided into five ‘research groups’ of five pupils. Each group studied the Balkans from a different perspective:

- Research group 1: politically
- Research group 2: socially
- Research group 3: economically
- Research group 4: culturally
- Research group 5: religiously

When the research groups were ready with their study work after several lesson times, the class was reorganised into ‘learning groups.’ In each learning group there was a representative of the different research groups. By combining and discussing in each learning group their knowledge about the five perspectives, all pupils were now learning about the global situation and problems of the Balkans.

## **APPENDIX B. THE COMPETENT PROBLEM-SOLVING MODEL UNDERLYING THE LEARNING ENVIRONMENT**

### **STEP 1: BUILD A MENTAL REPRESENTATION OF THE PROBLEM**

Heuristics:     Draw a picture  
                  Make a list, a scheme or a table  
                  Distinguish relevant from irrelevant data  
                  Use your real-world knowledge

### **STEP 2: DECIDE HOW TO SOLVE THE PROBLEM**

Heuristics:     Make a flowchart  
                  Guess and check  
                  Look for a pattern  
                  Simplify the numbers

### **STEP 3: EXECUTE THE NECESSARY CALCULATIONS**

### **STEP 4: INTERPRET THE OUTCOME AND FORMULATE AN ANSWER**

### **STEP 5: EVALUATE THE SOLUTION**



## APPENDIX C. SCHOOL TRIP PROBLEM

The teacher told the children about a plan for a school trip to visit the Efteling, a well-known amusement parc in The Netherlands. But if that would turn out to be too expensive, one of the other amusement parcs might be an alternative. Each group of four pupils received copies of folders with entrance prices for the different parcs. The lists mentioned distinct prices depending on the period of the year, the age of the visitors, and the kind of party (individuals, families, groups). In addition, each group received a copy of a fax from a local bus company addressed to the principal of the school. The fax gave information about the prices for buses of different sizes (with a driver) for a one-day trip to the Efteling.

The first task of the groups was to check whether it was possible to make the school trip to the Efteling given that the maximum price per child was limited to 12.50 euro. After finding out that this was not possible, the groups received a second task: they had to find out which of the other parcs could be visited for the maximum amount of 12.50 euro per child.

*Note: The problem is not presented in its original format due to space constraints. Moreover, translating from Flemish to English is somewhat cumbersome.*

## **APPENDIX D. GENERAL GUIDELINES FOR THE TEACHERS BEFORE, DURING, AND AFTER THE GROUP AND INDIVIDUAL ASSIGNMENTS**

### **BEFORE**

1. Relate the new aspect (heuristic, problem-solving step . . .) to what has already been learned.
2. Provide a good orientation to the new task.

### **DURING**

3. Observe the group work, and provide appropriate hints when needed.
4. Stimulate articulation and reflection.
5. Stimulate the active thinking and cooperation of all group members (especially the weaker ones).

### **AFTER**

6. Demonstrate the existence of different appropriate solutions and solution methods for the same problem.
7. Avoid imposing solutions and solution methods on pupils.
8. Pay attention to the intended heuristics and self-regulation skills of the competent problem-solving model, and use this model as a basis for the discussion.
9. Stimulate as many pupils as possible to engage in and contribute to the whole-class discussion.
10. Address (positive as well as negative) aspects of the group dynamics.

## APPENDIX E. DESIGN OF THE STUDY

	<b>Experimental group (4 classes)</b>	<b>Control group (7 classes)</b>
Test moment 1	Word problem pretest Beliefs and attitudes questionnaire Standardized achievement test Problem solving interviews with dyads	Word problem pretest Beliefs and attitudes questionnaire Standardized achievement test
Intervention	Teaching-learning environment (20 lessons) Video-registration of 4 lessons	Regular mathematics program
Test moment 2	Word problem posttest Beliefs and attitudes questionnaire Standardized achievement test Problem solving interviews with dyads	Word problem posttest Beliefs and attitudes questionnaire Standardized achievement test
Test moment 3	Word problem retention test	Word problem retention test

