INTERVENTION RESEARCH: A TOOL FOR BRIDGING THE THEORY-PRACTICE GAP IN MATHEMATICS EDUCATION?

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ABSTRACT Recent research on learning and instruction has substantially advanced our understanding of the processes of knowledge and skill acquisition. However, school practices have not been innovated and improved in ways that reflect this progress in the development of a theory of learning from instruction.
It is argued in this article that to be successful in making psychological theory and research applicable to education one should develop a strategy that combines the following basic characteristics:
- good communication with practitioners which means that the relevant outcomes are translated in such a way that they become palatable, accessible, and usable for the teachers;
- an orientation toward a fundamental change of teachers' belief systems about the goals of education and about good teaching and productive learning;
- a holistic (as opposed to a partial) approach to the teaching-learning environment, i.e. all relevant components of the learning environment should be addressed.

Taking this into account a successful approach for bridging the theory-practice gap is presented. This approach consists in carrying out design experiments involving the creation and evaluation in real classrooms of complex instructional interventions that embody our present understanding of effective learning processes and powerful learning environments. In order to make a reasonable chance to be successful, such attempts at fundamentally changing the classroom environment and culture should be undertaken in partnership between researchers and reflective practitioners. Such partnership is essential to promote mutual good communication, but also in view of modifying and reshaping teachers' beliefs about education, learning, and teaching. This intervention approach which is illustrated with a recent research example, has a twofold goal: it intends to advance theory building, while at the same time contributing to the optimization of classroom practices.

Introduction

Instructional science in general and instructional psychology in particular have undergone tremendous changes over the past decades, and at present important new developments are emerging. Those changes relate to the basic orientation of the field as well as to theoretical and methodological issues and problems (see e.g., Phillips, 1994; Salomon, 1996). The first *Handbook of educational psychology* reviews the state-of-the-art, albeit still strongly focusing on the American scene. In their "Afterword" to this impressive volume, the editors Berliner and Calfee (1996a) give a very positive evaluation of the field of educational psychology:

"Some observers have expressed concern about the decline in the research leadership of educational psychologists. We see a quite different picture reflected in the pages of this *Handbook*. First it is clear that our field has been and continues to be highly productive and remarkably influential ... We are "on the roll"; the preceding chapters exhibit an astounding freshness of ideas and enthusiasm for endeavours. Psychology as a discipline is in the midst of a paradigm shift, and educational psychology, as part of this discipline, is certainly in the forefront of these developments." (p.1020)

But have these developments also led to an instructional psychology that is relevant, useful, and productive in view of improving school practices? Different people have different opinions in this respect.

In the first chapter of his book *Schools for thought. A science of learning in the classroom*, Bruer (1993) writes:

"The science of mind can guide educational practice in much the same way that biology guides medical practice. There is more to medicine than biology, but basic medical science drives progress and helps doctors make decisions that promote their patients' physical well-being. Similarly, there is more to education than cognition, but cognitive science can drive progress and help teachers make decisions that promote their students' educational well-being." (p.2)

This optimistic perspective on the potential of linking theory and research to practice is toned down by many more sceptical positions that one can find in the literature. For instance, in the opening chapter of his book *The children's machine. Rethinking school in the age of the computer*, Seymour Papert (1993) argues that a group of time traveling teachers from an earlier century - in contrast to a group of surgeons visiting a modern hospital - would very well recognize what is going on in today's classrooms. And, in an article in the *International encyclopedia of developmental and instructional psychology*, Weinert and De Corte (1996) state:

"After 100 years of systematic research in the fields of education and educational psychology, there is, in the early 1990s, still no agreement about whether, how, and under what conditions research can improve educational practice. Although research and educational practice have changed substantially since the beginning of the twentieth century, the question of how science can actually contribute to the solution of real educational problems continues to be controversial." (p.43)
Although Papert's claim seems to me exaggerated, it is certainly also true that on the whole the productivity and freshness of the field of educational psychology suggested by Berliner and Calfee (1996a), have not resulted in proportional innovation of school practices. Indeed, education has until now not been improved in ways that reflect the substantial advances made over the past decades in our knowledge and understanding of the processes of learning and teaching (see also Brown, 1994; National Research Council, 1999b). Moreover, the international literature shows convincingly that many students in today's schools do not, or at least not sufficiently master the knowledge and capabilities underlying skilled learning, thinking, and problem solving (see e.g., De Corte, 1995a). In this respect, Anderson (Glaser, Lieberman, & Anderson, 1997) was right in stating with regard to educational research as a whole:
"One continuing dilemma for educational research as we move toward and into the 21st century will be how the research and scholarship that we do are ever going to find their way into practice. We've had various models of the proper relationship between research and practice. None of the models work very well." (p. 25)
In this article it is first argued that the theory-practice gap in instructional psychology is maybe not too surprising. Then, it is briefly shown that there is an emerging practically relevant and research-based theory of learning from instruction. Against this background an approach is proposed that might lead to a "working and productive" marriage between research and practice. Finally, a recent example of research that is in line with this approach is described and discussed.

Explaining the theory-practice gap
In an article entitled "Promoting confusion in educational psychology: How is it done?", Fenstermacher and Richardson (1994) distinguish between a disciplinary and an educational orientation in educational psychology (see also Salomon, 1996). In the first case educational psychology is considered as an offshoot of psychology which mainly aims at contributing to the development of theory and methodology within the broader domain of the mother discipline. In the second case the focus is rather on acquiring a better understanding of education as a basis for the improvement of educational practices.
Traditionally the disciplinary orientation has dominated for a large part of this century. As a result the prevailing type of research were studies in what recently has been called "in vitro laboratory settings" (Cognition and Technology Group at Vanderbilt, 1996) characterized by a great concern for internal validity, and, thus, including a high degree of experimental precision. According to Salomon (1996) this approach to research has led to the study of psychological processes and variables in isolation, and of individual learners independent from their social and cultural environment. While this way of conducting research can easily overlook educationally important aspects, and, therefore, lacks classroom relevance, it has nevertheless led to what Ausubel (see Ausubel & Robinson, 1969) has called the "extrapolation viewpoint", claiming that many of the findings established "in vitro" can be extrapolated from the laboratory to the classroom.
This discipline orientation in instructional psychology has been strongly criticized already since the 1960s by Ausubel, but also by other leading scholars in the field (see e.g., Shulman, 1970; Wittrock & Farley, 1989). Moreover, the advent of cognitive psychology, which also became the dominating force in the study of performance, learning, and teaching especially from the 1970s on, induced to some degree a more educationally oriented trend in instructional psychology. Indeed, by focusing on the analysis of the information-processing activities involved in performance on more complex tasks, cognitive psychology engaged in the study of activities and problems that are more school-like than the simple and often artificial tasks investigated in traditional laboratory experiments. Nevertheless, the literature shows that the discipline orientation is still alive in instructional psychology, as is

illustrated by the 1994 special issue of the *Educational Psychologist* on "Epistemological perspectives on educational psychology" (Phillips, 1994; see esp. the article by Fenstermacher & Richardson, 1994).
But in addition and related to the discipline orientation of instructional psychology, a lack of good communication between researchers and practitioners is also responsible for the theory-practice gap. In this regard it is important to realize that in view of accomplishing good and effective communication that can have impact on educational practice, it is not sufficient to translate research outcomes in such a way that they become accessible to teachers. Indeed, studies have shown that practitioners' receptivity to innovative ideas is strongly determined by their prior beliefs and value orientations (Hollingsworth, 1989), but also that they often tend to adapt rather than to adopt novel concepts (Kennedy, 1997). In other words, providing accessible and digestible research-based information is mostly not sufficient to guarantee good communication that can affect teachers' classroom practice.

A nascent practically relevant and research-based theory of learning from instruction is available

Taking together that there is an obvious research-practice gap, on the one hand, and that the discipline orientation in instructional psychology is still around, on the other, one can raise the question whether there is at this moment emerging a research-based theory of learning from instruction that offers a fertile soil for the innovation and improvement of school practices?
In answer to this question, it is argued here that the educational orientation that was induced in the 1970s has already resulted in an empirically underpinned knowledge base that can guide the analysis of the effectiveness and the quality of teaching practices and educational systems, but also research focusing on the design of new and more powerful teaching-learning environments for the acquisition of worthwhile educational objectives. The emergence of such a knowledge base has been facilitated by the growing subject-matter orientation in instructional psychology. This latter trend is clearly reflected in Part III of the 1996 *Handbook of educational psychology* (Berliner & Calfee, 1996b) entitled "School curriculum and psychology", that involves seven chapters covering major subject-matter domains, namely science, mathematics, literacy, history, second language, besides a chapter on the comparative psychology of school subjects, and one on the informal curriculum. More recently an excellent synthesis of a large body of research on human learning over the past decades - albeit also mainly focusing on the North American scene - has been published in a report of the National Research Council in the U.S.A. entitled *How people learn: Brain, mind, experience, and school* (National Research Council, 1999a).
For instance, with respect to mathematics the research results can already help us to give better answers than before to the following major questions, but also to formulate well founded hypotheses for further inquiry (for a more detailed discussion see De Corte, 1995b; De Corte, Greer, & Verschaffel, 1996):
1. What has to be learned (theory of expertise)?
2. What kind of learning processes are necessary to attain the intended goals (theory of acquisition)?
3. What are appropriate instructional methods and environments to elicit and maintain those acquisition processes in students (theory of intervention)?
4. What types of assessment instruments are required to evaluate the degree of attainment of the intended goals (theory of assessment)?

The general answer to the first question emerging from the analysis of expertise in mathematics is that students should acquire a mathematical disposition. Such a disposition involves the mastery of four categories of aptitudes, namely
- a well-organized and flexibly accessible domain-specific knowledge base;
- heuristic strategies for problem analysis and transformation
- metacognitive knowledge and self-regulating skills;
- positive beliefs, attitudes, and emotions related to mathematics.

In addition students should become inclined to use their knowledge and skills whenever appropriate, and also develop a sensitivity for situations and contexts in which it is appropriate to do so.

As far as the second question is concerned, research has led to the identification of a series of characteristics of effective learning processes. They can be summarized in the following definition: learning is a constructive, cumulative, self-regulated, goal-oriented, situated, collaborative, and individually different process of knowledge building and meaning construction.

With respect to the third question listed above, a series of guiding principles for the design of powerful learning environments, that are in line with the preceding features of effective acquisition processes, has emerged from the available literature. Some major, interrelated guidelines can be summarized as follows (see De Corte, 1995b for a more detailed discussion):

- Learning environments should induce and support constructive, cumulative, and goal-oriented acquisition processes in all learners - also in the more passive ones - through a good balance between discovery learning and personal exploration, one the one hand, and systematic instruction and guidance, on the other.
- Learning environments should foster students' self-regulation of their learning processes: as students competency in a domain increases, external regulation of knowledge and skill acquisition should be gradually removed so that they become more and more agents of their own learning.
- Learning environments should embed acquisition processsses as much as possible in authentic contexts that have personal meaning for students, are rich in resources and learning materials, and offer ample opportunities for collaboration.
- Learning environments should flexibly adapt the instructional support, especially the balance between external regulation and self-regulation, taking into account individual differences among learners in cognitive aptitudes as well as in affective and motivational characteristics.
- Because domain-specific and domain-general knowledge play a complementary role in competent learning and thinking, learning environments should integrate the acquisition of general (meta-)cognitive skills within the subject-matter domains.

Finally, a theory of assessment offers methods for the construction and application of proper assessment instruments that are compatible with the new view about the objectives and the nature of mathematics learning and teaching. In this respect strong criticisms of traditional techniques and practices of educational testing, predominantly based on the multiple-choice item format, have led to the development of alternative forms of assessments that reflect more complex, real-life or so-called “authentic” performances (see e.g., Lesh & Lamon, 1992; Lester, Lambdin, & Preston, 1997; Romberg, 1995). At the same time the need to integrate assessment with learning and teaching, and the importance of assessment instruments yielding information to guide further learning and instruction have been emphasized (see e.g., Glaser & Silver, 1994).

The challenging task becomes then to elaborate an appropriate strategy for the rapprochement between theory and research, on the one hand, and educational practice, on the other.

Toward a strategy for marrying theory building and the improvement of school practices

As remarked by Anderson in the quotation in the Introduction section, various models of the proper relationship between research and practice have been proposed; however, apparently these models are not very productive (Glaser, Lieberman, & Anderson, 1997). In an article in the *International encyclopedia of developmental and instructional psychology*, Weinert and De Corte (1996) describe six different approaches to the problem of translating research results into practice:

1. applying theoretical knowledge to improve the technologies for learning and teaching;
2. using the outcomes of research on teaching to train teachers and to improve their expertise;
3. using the studies on classroom learning to make teaching more adaptive to the individual differences between learners;
4. applying research on cognitive development and learning to promote through instruction students' learning competencies and self-instructional skills;
5. research-based design, implementation, and evaluation of new models of education and schooling;
6. using research results as a source of background knowledge for practitioners.

The effectiveness of those different approaches to the problem of bridging the theory-practice gap (see Weinert & De Corte, 1996 for a more detailed description) has not been systematically studied. However, it is plausible that each of them will have some merits as well as weaknesses. Moreover, much will depend on how each approach is used in translating research findings into practice. Taking into account the explanations for the lack of connection between research and practice presented above, it is likely that to be successful in making psychological theory applicable to education, one should develop a strategy that combines and integrates the following basic characteristics (see also National Research Council, 1999b):

- a holistic (as opposed to a partial and reductionist) approach to the teaching-learning environment, i.e. all relevant learner and teacher variables, but also the important aspects of the environment should be addressed;
- good reciprocal communication with practitioners based on a translation of the goals, approaches, and outcomes of research in such a format that they become accessible, palatable, and usable for the teachers;
- induction of a fundamental change of teachers' beliefs systems and value orientations with respect to the goals of education and to good teaching and productive learning (in line with the conception described in the previous section).

It is easy to identify examples of attempts to apply new ideas and tools to educational practice that were unsuccessful because one or more of those features were lacking. A major case that relates to Weinert and De Corte's first approach, is the relative failure of educational computing. The high expectations that rose in the early 1980s with respect to the potential of the computer as a lever for the innovation and improvement of schooling, have not at all been redeemed. A major reason for this failure of computers in education is that the machine has been mainly introduced as add-on to an existing, and largely unchanged traditional classroom setting (De Corte, 1996). In addition, due to lack of good communication, teachers usually had only low expectations about computer support for their teaching (see e.g., Kaput, 1992). And, there was mostly no question at all of an orientation toward modifying teacher's conceptions about educational goals and their beliefs about learning.
For similar reasons another initially promising idea for improving teaching practices - in line with Weinert and De Corte's second approach - also largely failed, namely the attempts to promote teacher effectiveness by training them in using a series of so-called teaching skills that emerged as successful from the well-known process-product studies in research on teaching. Here too the approach was partial and rather technical.
The preceding discussion suggests at the same time a potentially more promising strategy for a "working" theory-practice marriage, which is in accordance with both Weinert & De Corte's fifth and sixth approaches, namely using research for the design, implementation, and evaluation of new models of education and schooling, on the one hand, and research as a source of background knowledge for teachers, on the other. This strategy for which there is now a substantial research base (National Research Council, 1999a), consists in the creation and evaluation in real classrooms of complex instructional interventions that reflect and embody our present understanding of effective learning processes and powerful learning environments . In order to make a reasonable chance of being successful, such attempts at fundamentally changing the classroom environment and culture should be undertaken in partnership between researchers and knowledgeable practitioners (see also National Research Council, 1999b). This partnership is an essential condition to promote mutual good understanding, but also in view of modifying and reshaping teachers' beliefs about education, learning, and teaching. This standpoint derives from the conception that in the near future instructional psychology should focus on the educational orientation, but following thereby an approach to research that allows to make progress in theory building, while at the same time contributing to the optimization of school practices.
A similar view concerning the interplay between theories of learning and educational practice, but focusing on the use of instructional technology, has recently been presented by the Cognition and Technology Group at Vanderbilt (1996; see also Cognition and Technology Group at Vanderbilt, 1997). More specifically, the Group has elaborated an interesting framework for looking at the research on educational technology in the context of learning theory and educational practice (see Figure 1). Their LTC (Looking at Technology in Context) framework consists of two dimensions:

- research contexts ranging from laboratory settings over individual classrooms to connected sets of classrooms and schools;

In Vitro In Vivo Connected

	Laboratory	Individual classes & schools	Classes, schools, Communities	
Transmission Models	1	2	3	
Constructivist Models: Part of School Day	4	5	6	Theoretical Context
Constructivist Models: All of Schooling	7	8	9	

Research Context
Figure 1. LTC (Looking at Technology in Context) framework (CTGV, 1996)

- theoretical contexts ranging from the transmission model of learning over constructivist models applied during a part of the school day to constructivist approaches used during all of schooling.

According to the CTGV technology applications that fit into row 1 of the LTC framework have dominated so far; they are of the add-on type mentioned above, and can easily be assimilated into traditional classrooms. The challenge for technology research, but as well for an educationally oriented instructional psychology is to move toward the second and third rows of the LTC framework; (technology-supported) interventions in the second and certainly in the third rows that are based on constructivist models of learning require the kind of fundamental changes in traditional schooling suggested in the strategy described above.
A specific approach which is in line with the intended holistic strategy, is represented by scholars who advocate the use of so-called design experiments, and aim at the development of a design science of education (Brown, 1992; Collins, 1992). According to Collins (1992) " a design science of education must determine how different designs of learning environments contribute to learning, cooperation, motivation, etc." (p.15). As a result a design theory should emerge that can guide the implementation of educational innovations by identifying the variables influencing their success or failure. In line with the conception underlying our strategy for bridging the research-practice gap, this intervention approach has a twofold goal: it intends to advance theory building about learning from instruction, while at the same contributing to the fundamental innovation of classroom education (Brown, 1994; see also Greeno, Collins, & Resnick, 1996). As argued by Brown (1994), theory building is crucial for conceptual understanding as well as for practical dissemination.
This approach seems to become more and more a mainstream in research on learning and instruction, as is illustrated by a volume edited by Schauble and Glaser (1996):
"*Innovations in learning: New environments for education* documents the growth of a new kind of interdisciplinary teamwork that is evolving among practitioners, researchers, teacher educators, and community partners. The premise of this work is that the design of learning environments and the development of theory must proceed in a mutually supportive fashion" (p.XI)
The chapters in that book report several projects that illustrate this mainstream. A representative examples is Brown and Campione's project "Fostering communities of learners" (Brown, 1994; Brown & Campione, 1996). Starting from a series of principles of learning (such as active and strategic learning, importance of metacognition and self-regulation, shared discourse and collaborative learning) the learning environment is fundamentally redesigned using innovative components such as reciprocal teaching, the "jigsaw method" of collaborative learning, and the creation of a new classroom climate and culture.
In the perspective of the further dissemination of this kind of innovative learning environments, it is important to keep in mind that they should be feasible in existing classrooms. Therefore, the idea of partnership between researchers and practitioners is also crucial in view of the necessary research-practice reciprocity. Whereas practitioners can help in translating theory into practice, and, thus, in making classroom teaching more research-based, their partner role can also contribute to make research more practice-driven. Moreover, as argued by Greeno, Collins, and Resnick (1996):
"by embedding research in the activities of practical reform, the theoretical principles that are developed will have greater scientific validity than those that have been developed primarily in

laboratory work and in disinterested observations of practice, because they will have to address deeper questions of how practices function and develop." (p.41)

The next section of this article reviews briefly a recent study that illustrates the application of the described strategy for bridging the theory-practice gap with the dual goal of advancing theory building about learning mathematical problem solving, on the one hand, and contributing to the innovation of educational practices in mathematical classrooms, on the other (for a more detailed report about this study see Verschaffel, De Corte, Lasure, Van Vaerenbergh, Bogaerts, & Ratinckx, 1999; Verschaffel, De Corte, Van Vaerenbergh, Lasure, Bogaerts, & Ratinckx, 1998).

Designing a powerful teaching-learning environment for mathematical problem solving: A design experiment with fifth graders

In 1997 new standards for primary education in the Flemish part of Belgium were approved by the Flemish parliament (Ministerie van de Vlaamse Gemeenschap, 1997). With respect to mathematics - and in line with other recent reform documents such as the *Curriculum and evaluation standards for school mathematics* (National Council of Teachers of Mathematics, 1989) in the U.S.A. - these new standards stress more than was hitherto the case the importance of mathematical reasoning and problem-solving skills and their applicability to real-life situations, as well as the development of more positive attitudes and beliefs toward mathematics. As a contribution to the implementation of those new standards the Leuven Center for Instructional Psychology and Technology has carried out a research project aiming at the design and evaluation of a powerful learning environment, that can elicit in upper primary school children the appropriate learning processes for acquiring the intended competence in mathematical problem solving and positive mathematics-related beliefs.

In line with the strategy described in the previous section the learning environment in the classroom was fundamentally changed, and the preparation, the implementation, and the evaluation of this environment were done in narrow cooperation with the teachers of the four participating experimental classrooms and their principals. Considered in terms of the LTC framework of the Cognition and Technology Group at Vanderbilt described above, this design experiment fits in cell 5 which refers to innovative, constructivist-oriented learning environments relating to only a part of the school day, and where the teaching is done by the regular classroom teacher.

The major changes in the classroom learning environment related to the following components: the content of learning and teaching, the nature of the problems, the instructional techniques, and the classroom culture.

First, in terms of content the learning environment focused on the acquisition by the pupils of an overall metacognitive strategy for solving mathematical application problems consisting of five stages, and embedding a set of eight heuristics which are especially valuable in the first two stages of that strategy (see Table 1). Acquiring this problem-solving strategy involves: (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 which can be successfully used especially in the first two phases of the solution process (heuristic strategy training). This component of the learning environment converges with the design principle described earlier, that the acquisition of cognitive and metacognitive skills should be facilitated within the subject-matter domains.

Table 1. 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

Second, a varied set of carefully designed realistic (or authentic), complex, and open problems were used that differ substantially from the traditional textbook tasks. Moreover, these problems 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. This is in line with the design principle relating to embedding learning in authentic and meaningful contexts.

Third, a varied set of activating instructional techniques were applied. The basic instructional model for each lesson period 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; (3) an individual task also with a subsequent final whole-class discussion. Throughout the whole lesson the teacher's role was to encourage and scaffold pupils to engage in, and to reflect upon, the kinds of cognitive and metacognitive activities involved in the model of skilled problem solving. These instructional supports were gradually faded out as pupils became more competent in and aware of their problem-solving activity, and, thus, took more responsibility for their own learning and problem-solving processes. Several of the previously described design principles are at stake here: stimulating active and constructive learning, creating opportunities for collaboration, fostering students' self-regulation of their learning taking into account individual differences.

Fourth, an innovative classroom culture was created through the establishment of new socio-mathematical norms about learning and teaching mathematical problem solving, and aiming at fostering positive mathematics-related attitudes and beliefs in children, but in teachers as well. Typical aspects of this classroom culture are: (1) stimulating pupils to articulate and reflect upon their solution strategies, (mis-)conceptions, beliefs, and feelings relating to mathematical problem solving; (2) discussing about 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"): (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 an evaluation of the pros and cons of the different alternatives"). This component of the learning environment also connects with several design principles, namely eliciting active and collaborative learning, enhancing self-regulation, and facilitating the embedded acquisition of (meta) cognitive strategies; in addition, the new classroom climate solicited the participation of all pupils, and, in so doing, individual differences were as much as possible taken into account.

The learning environment consisted of a series of 20 lessons that were taught by the classroom teacher. With two lesson periods each week the intervention was spread over ten weeks. The series of lessons had three parts:

- Introduction of the content and the organization of the learning environment (lesson 1);
- Systematic acquisition of the five-step problem-solving model and the embedded heuristics (lessons 2 to 16);
- Learning to use the competent problem-solving model in a spontaneous and flexible way in four project lessons (lessons 17 to 20) in which the pupils solved and discussed only one more complex application problem.

As mentioned before, the learning environment was elaborated in partnership with the practitioners. The model of teacher development adopted emphasized the creation of a social context wherein teachers and researchers learn from each other, rather than a model in which the researchers transmit knowledge to the teachers; in this respect the model resembles the approach taken by the Cognition and Technology Group at Vanderbilt (1997). Regular meetings were attended by all members of the research team and by the teachers of the four experimental classes and their principals. After initial contacts two formal meetings took place before the actual start of the implementation of the learning environment. The teachers were invited to comment on first drafts of the teacher guides and the lesson materials which they received some time before the meetings. The materials were revised taking into account their remarks and suggestions, and this resulted in a general teacher guide about the environment, specific teacher guides for each lesson, and lesson materials for the pupils; all these documents were made available as support for implementing the intervention program. Three meetings were organized during the intervention, and focused on exchanging positive experiences as well as difficulties with the implementation of certain aspects or parts of the learning environment. Appropriate solutions for the difficulties were proposed and discussed; for instance, quite a bit of discussion took place about the advantages and disadvantages of heterogeneous small groups, as well as concerning the appropriateness and meaningfulness for the pupils of certain problems. In this respect, it is also worth mentioning that all lessons in each of the experimental classes were attended by a member of the research team, who did not intervene but had before and after the lesson respectively a preparatory and an evaluative conversation with the teacher. During a final meeting some time after the intervention ended, the major outcomes of the project were presented to and discussed with the teachers and the principals, and they were invited to give their overall impressions about their participation as well as possible suggestions for modifications and improvements of the learning environment. All these components of teacher support aimed at inducing and maintaining continuous reflection on the basic principles of the learning environment, the learning materials developed, and the teachers' practices during the lessons. As was also observed by others (e.g., Carpenter & Fennema, 1992; Cognition and Technology Group at Vanderbilt, 1997; Yackel & Cobb, 1996), the appropriation of the intended approach to learning and teaching, and the effective implementation of the learning environment was extremely demanding for the teachers. It is an interesting issue for further inquiry to do a comparative analysis of the approaches to researcher/teacher collaboration used in the different research programs in which learning environments were designed and implemented in collaboration between researchers and practitioners. Such an analysis could lead to identifying and unravelling the distinctive features of those approaches.

In view of contributing to theory building, the effects of the learning environment on pupils were evaluated in an experiment with a pretest-posttest-retention test design with an experimental group and a comparable control group, using thereby a wide variety of data-gathering and analysis techniques. The results can be summarized as follows (for an extensive presentation, see Verschaffel et al., 1998; 1999). According to the scores on the self-made written word problem pretest and a parallel posttest and retention test, the intervention had - in comparison with the control group - a significant and stable positive effect (effect size .31) on the experimental pupils' skill in solving mathematical application problems. The learning environment had also a significant, albeit small positive impact on children's pleasure and persistence in solving mathematics problems, and on their mathematics-related beliefs and attitudes, as measured by a self-made Likert-type questionnaire (effect size .04). The results on a standard achievement test showed that the extra attention during the mathematics lessons for problem-solving strategies, beliefs, and attitudes in the experimental classes did not have a negative influence on the learning outcomes for other, more traditional parts of the mathematics curriculum; to the contrary, there was even a significant positive transfer effect: indeed, the experimental classes performed significantly better than the control classes on this standard achievement test (effect size .38). The analysis of pupils' written notes on their response sheets of the word problem tests showed that the better results of the experimental children were paralleled by a very substantial increase in the spontaneous use of the heuristics taught in the learning environment (effect size .76); this finding was confirmed by a qualitative analysis of videotapes of the problem-solving processes of three groups of two children from each experimental class before and after the intervention. Finally, we found that 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 just mentioned. In theoretical perspective these results show that a substantially modified learning environment, combining a set of carefully designed complex and realistic word problems with highly interactive teaching methods and the introduction of new socio-mathematical classroom norms, can significantly improve pupils mindful approach toward mathematical problem solving. Of course, further inquiry is needed to possibly identify the critical aspects of the learning environment which contribute especially to its success. A comparative study suggested above of the distinct research programs in which new learning environments have been designed and implemented, would also be relevant in view of discovering such critical "difference-making" components

In the perspective of bridging the theory-practice gap, it is first of all important to report that all four experimental teachers implemented the learning environment in a satisfactory way, although clear differences among them were observed on the distinct components of an implementation profile. In addition the following conclusions derived from an extensive interview with the four experimental teachers after the intervention but before they knew the children's results, are promising. First, they considered the five-step competent problem-solving model as appropriate and attainable for fifth graders. Second, they evaluated the content and the organization of the learning environment very positively, and were greatly satisfied with the support and help during the implementation of the intervention. Finally, they were very enthusiastic about their active involvement and participation in the project; that this meant more than just a momentary feeling is shown by the fact that three of them were immediately willing to participate in a subsequent similar, and again very demanding design experiment with respect to reading comprehension, and that they and - in the schools were there is one or more parallel fifth grade - even their colleagues continue to apply the basic principles of the learning environment in their mathematics teaching. In between the project and its results have already become rather well-known among knowledgeable practitioners in Flemish primary education, and there is a growing interest in the conception of mathematics learning and teaching that underlies the learning environment, as well as in the concrete materials that were designed in the project. As a result the lesson materials have been revised and transformed in a format that makes them appropriate for use in classroom practice and in teacher training (Verschaffel, De Corte, Lasure, & Van Vaerenbergh, 1999), conditional, however, on being accompanied by substantial teacher support. Indeed, as observed by the Cognition and Technology Group at Vanderbilt (1997), the changes that we are asking the teachers to make 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). This implies at the same time that there is a need for continued inquiry, aiming at the further elaboration of the strategy for bridging the theory-practice gap outlined in this article in view of facilitating and supporting the transition from small-scale researcher/practitioner collaborative design experiments to more large-scale implementations of the innovating, powerful learning environments. Such an endeavour transcends the field of instructional psychology, and constitutes a challenge for collaboration among educational researchers with a variety of expertise; for instance, it is indispensable to take into account the contextual, social, and organizational dimensions of classrooms and schools wherein reforms are induced (Stokes, Sato, McLaughlin, & Talbert, 1997).

Final comment

Starting from an explanation of the enduring theory-practice gap, and arguing that we have now available a research-based but at the same time practically relevant theory of learning from instruction, a strategy has been proposed that might lead to a more flourishing and productive marriage between research in instructional psychology and educational practice in classrooms. Furthermore, this strategy was illustrated by outlining a successful recent design experiment. The positive results of this experience should, of course, not be overrated. Indeed, while we consider these outcomes as promising, they are only a first, initial step. As already mentioned above, considered in terms of the LTC framework of the Cognition and Technology Group at Vanderbilt (1996), this design experiment fits in cell 5 which refers to innovative, constructivist-oriented learning environments relating to only a part of schooling teaching; this is still far remote from covering the whole curriculum in line with the approach underlying the basic principles of our learning environment. Moreover, we should realize that powerful learning environments as the one designed in our project, require drastic changes in the role of the teacher. Instead of being the main, if not the only source of information - as is often still the case in average educational practice - the teacher becomes a "privileged" member of the knowledge building community, who creates an intellectually stimulating climate, models learning and problem-solving activities, asks provoking questions, provides support to learners through coaching and guidance, and fosters students' agency over and responsibility for their own learning. Putting this new perspective on learning and teaching into practice will take a long time and much effort in partnership between researchers and practitioners. Indeed, it is not just a matter of acquiring a set of new instructional techniques, but - as already referred to earlier - it calls for a fundamental and profound change in teachers' beliefs, attitudes, and mentality. Achieving this will require substantial investments in the (re-)training of teachers, and in sustained staff development, taking into account the contextual, social, and organizational dimensions of classrooms and schools.

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