JOHAN VAN DER SANDEN, JAN TERWEL AND STELLA
VOSNIADOU

7. NEW LEARNING IN SCIENCE AND TECHNOLOGY

A competency perspective

INTRODUCTION

The still rapidly growing importance of science and technology in the information society (see also Lintsen et al., 1998) has not only given rise to the establishment of communities of highly specialized scientists and engineers but has and is having profound effects on ordinary life as well. Everyone can be regarded a member of a diffuse and ever-increasing community of people for which a variety of scientific knowledge-based services and products is quite common, making a basic understanding of everyday science and technology necessary.

As an initially peripheral member of the communities of practice involved (Lave & Wenger, 1991), a collection of incidental and intentional learning processes is required to reach the status of a full member. More general as well as more specific competencies are needed to appreciate and comprehend the proliferation of scientific-technological offshoots. These competencies enable someone to participate in the everyday world of science and technology or, additionally, in more specialized communities engaged in the application, maintenance and/or creation of specific technological services and products. Science and technology literacy has become an important aspect of recent discussions about educational standards in the US, Canada, and European countries like the UK and the Netherlands.

In spite of its importance, the learning and instruction of science and technology are not simple. Many students do not manage to acquire basic science and technology-related competencies or have difficulties in applying knowledge and skills in out-of-school situations (Mayer & Wittrock, 1996). Others, though having science and technology-related abilities prefer not to take up educational programs in this field. In the Netherlands, for instance, almost half of the students in pre-university education are enrolled in science and technology examination programs, but a significant part of these students do not enter science and technology programs in higher education (Commissie Toekomst Natuur- en Technische Wetenschappen, 1997). Moreover, it is becoming increasingly difficult to find enough well qualified science and technology teachers, as a consequence of which even less students may be expected to choose science and technology programs.

The failure of teacher educators, curriculum developers and teachers to engage all students in the learning of mathematics, science and technology is due to a diversity

of factors. We want to draw attention to two close-to-school factors. First, there is a tendency in cognitive theories to attribute disappointing outcomes to individual learners. Second, the teaching of mathematics, science and technology can be characterized by a 'transmission model' and a 'content mastery' approach (Byrnes, 1996). Until recently, neither cognitive theory nor teaching practice has paid attention to the social context in which mathematics, science and technology is learned and used (Gauvain, 1998).

This chapter focuses on different approaches to learning and instruction in science and technology education. The content is organized around a number of specific issues, which are highly relevant for the field and which continue to provoke discussion among researchers as well as practitioners. These issues are considered from the perspective of the development of competencies in a community of learners, i.e., a participation perspective. The notion of 'becoming a member of a community of learners' plays an important role in this perspective. This also means special attention to non-participation and its negative consequences for the process and the outcomes of learning (Terwel, 1997). Initial differences between students in pre-knowledge - and as a consequence differences in the need for social and instructional support- are related to differences in participation and membership, which in turn are mediating factors in producing differential learning outcomes.

The first issue that is taken up in section 2 concerns the role of prior knowledge in the acquisition of science concepts as studied from a conceptual change perspective (e.g. Ali, 1990; Biemans, 1997; Vosniadou, 1991; Glynn, Yeany & Britton, 1991). This line of research has provided important information on the learning of science and has led to several proposals about instructional interventions.

Science learning is also studied by researchers interested in student goal orientations, learning conceptions and approaches to learning (e.g. Ng & Bereiter, 1992; Prosser, Walker & Millar, 1996) and epistemological beliefs (e.g. diSessa, 1985; Schommer, 1994; Wigfield, Eccles & Pintrich, 1996). The role these variables play in the process of conceptual change is elaborated in section 3.

In science and technology curricula it is common practice to confront students with a diversity of problems, exercises and practical tasks. It is assumed that students learn to apply earlier acquired knowledge and develop a number of cognitive and metacognitive skills. Transfer is often found to be problematic, however (Mayer & Wittrock, 1996). In section 4 we discuss a number of issues concerned with learning from problem solving or task execution.

In section 5 we pay some attention to the well-known finding that students of different ability levels often benefit differentially from available co-operative or other learning opportunities (especially multimedia). Differential effects in mathematics, science and technology is the last issue we will deal with in this chapter. The well-known 'Matthew effects' seem to especially occur in domains like mathematics, science and technology. As a consequence teachers may become increasingly frustrated and less prepared to deal with alternative science conceptions of students. In addition, they lack insight into why students

differentially benefit from teaching and learning in the classroom,. as a consequence of status problems in co-operative groups, for example. Cognitive psychologists, subject matter specialists and teachers often overlook contextual constraints by which students are excluded from the resources that are necessary for cognitive development and learning (Van Oers 1998; Gauvain, 1998).

We finalize our contribution to New Learning in section 6 by making some concluding remarks with regard to the learning and instruction of science and technology and offering some suggestions for further research and educational practice.

PRIOR KNOWLEDGE AND CONCEPTUAL CHANGE

In educational psychology the role of prior knowledge in learning continues to intrigue researchers (e.g., Dochy, 1992). Prior knowledge variables have traditionally been studied from a quantitative and instructional viewpoint. A good example is the well-known Gagné-Briggs 'events of instruction' approach to teaching (Gagné & Briggs, 1979): in order for learning to occur there has to be relevant pre-knowledge, which has to be activated by the teacher. If there happens to be no relevant prior knowledge, it has to be 'installed' by the teacher first, before instruction proceeds. Another illustration is the so-called 'instructional support hypothesis' which was central in Tobias' ATI-research (e.g. Tobias, 1976). Tobias was interested in interactions between the *amount* of instructional support and the *quantity* of students' prior knowledge and achievement:

> "…the higher the level of prior achievement, the lower the instructional support required to accomplish instructional objectives. Conversely, as level of prior achievement decreases, the amount of instructional support required increases" (op. cit, p. 67).

Typically, these examples illustrate the objectivist view on learning and instruction. Learning is seen as taking in externally defined and stored knowledge; teaching as handing down new pieces of knowledge by the teacher to increase the amount of knowledge in the learner's heads. Byrnes (1996) has clarified the differences between objectivist and constructivist approaches to learning and. instruction by comparing a student's knowledge with a 'brick wall', which somehow has to be built up. Objectivist teachers typically try to build the wall inside the student's head by laying neatly organized bricks in the 'right spot'. Constructivist teachers, on the other hand, provide the bricks and help the students build their own wall (p. 13-14).

Constructivism and social constructivism have no doubt given a new impulse to the acknowledgment of the essential role of prior knowledge in learning (Driver, Asoko, Leach, Mortimer & Scott, 1994; Dudley Herron, 1996). This revitalized interest can be mainly attributed to the constructivist position that learning should be basically seen as the process of elaborating and restructuring prior knowledge (Boekaerts & Simons, 1993). Not only formal school-based knowledge is

considered, but also intuitive and more tacit types of knowledge, which may express themselves as ideas, beliefs, opinions, images or naive theories, are taken into account. In this respect it is interesting to note that 'everyday cognition' and 'practical intelligence' are becoming important concepts in cross-cultural psychology (e.g. Schliemann, Carraher & Ceci, 1997) as are 'informal learning' and 'tacit knowledge' in work and organizational psychology. Furthermore, not only quantitative, but also and especially qualitative aspects of prior knowledge form the object of study. Interactions between prior knowledge and different kinds of new information, the learner is confronted with are the particular focus of recent research and theorizing.

In this respect Vosniadou has made a distinction between initial or naive models, which represent students' prior knowledge before they are exposed to science instruction and synthetic models, which result from students' attempts to interpret scientific information within their existing frameworks (Vosniadou, 1994; Vosniadou & Brewer, 1992; 1994). This process may give rise to the development of synthetic models which are formed when the knowledge students acquire during periods of formal science instruction is at odds with currently accepted scientific ideas. Synthetic models are one type of what has been known in the science education literature as misconceptions. This type of misconception is formed when students attempt

> "… to interpret scientific information within an existing framework theory that contains information contradictory to the scientific view' (Vosniadou, 1994, p. 46).

In other words, misconceptions are thought to result from negative transfer occurring while students are involved in learning from instruction (Vosniadou, 1996).

In the meantime several researchers in different countries have documented student misconceptions with regard to science and technology-related phenomena (see, amongst others, Clement (1982) for an older study on physics student's misconceptions of the relationship between force and acceleration and Biemans (1997), Pfundt & Duit (1991, 1994) and Vosniadou (1994) for more recent overviews). In these studies researchers describe and categorize student misconceptions in a variety of domains and try to find out more about the roots, functions and characteristics of misconceptions. In the domain of science there is a great deal of similarity in the kinds of explanations children and adults generate for physical phenomena, both before they are exposed to scientific information as well as in the way they misinterpret scientific explanations, In this regard Vosniadou (Vosniadou, op. cit; Vosniadou & Ionannides, in press) has argued that the process of acquiring knowledge about the physical world is constrained by persistent 'entrenched presuppositions' that are organized in a framework theory of naive physics. These presuppositions not only hold amongst different people in the same

culture, but also across different cultures, such as the presupposition that force, heat or pressure are properties of objects.

Students' general framework theories of physics as well as their specific personal theories pertaining to certain classes of events are assumed to play an important role in the way meaning is imposed on physical phenomena in everyday situations. Colloquial, nonscientific speech (e.g. animistic ways of talking about inanimate objects) and a tendency to describe things at a concrete and superficial level can easily contribute to ways of dealing with natural phenomena that are at odds with the ways scientists usually deal with and talk about these phenomena. However, the way subject matter is presented to students in textbooks (for examples with regard to chemistry, see Abraham, Grzybowski, Renner & Marek, 1992; with regard to biology, see Storey, 1992), the way teachers explain and coach students, and the way subject matter is organized all can contribute to the formation or preservation of misconceptions as well. As to subject matter organization, for instance, linear bit-by-bit subject matter sequences may not be beneficial in helping students to build up adequate and integrated mental models of fields of study and may, thereby, contribute to a poor conceptual understanding of subject matter components (e.g. Reigeluth, 1987; Van der Sanden & Van Bussel, 1995; Teurlings, Van der Sanden, Simons & Lodewijks, submitted). Also the breadth of coverage of science topics may play a role. According to Vosniadou and Ioannides (in press):

> "..it may be more profitable to design curricula that focus on the deep exploration and understanding of a few, key concepts in one subject-matter area rather than curricula that cover a great deal of material in a superficial way".

Taking a developmental perspective researchers want to describe

> '… changes in students' representations of the physical world as their qualitative understanding of the domain changes' (Vosniadou, op. cit, p. 45),

which usually is a slow process. Vosniadou (1994) supposes that it is not the misconceptions as such that are resistant to change, but that the 'entrenched presuppositions' behind misconceptions are difficult to change. The so-called confirmation bias (e.g. Byrnes, 1996) presumably contributes to this tendency to resist the exchange of personal misconceptions for formal scientific explanations: people tend to cling to preferred personal explanations or ways of handling things in spite of disconfirming evidence. Conceptual change is usually defined as the process of more or less gradual restructuring of preconceptions or naive theories, which occurs when these theories or their components no longer seem to function as useful frameworks for describing, explaining and predicting events or phenomena the learner is confronted with (e.g. Posner, Strike, Hewson & Gertzog, 1982; Biemans, 1997).

Vosniadou and Ioannides (op. cit.) emphasize the slow revision of initial conceptual systems, as opposed to Posner et al.'s tendency to focus

"… on the incompatibility between two distinct and equally well organized explanatory systems, one of which will need to be abandoned in favor of the other".

Vosniadou (1994) assumes that conceptual change proceeds

'… through the gradual modification of one's mental models of the physical world, achieved either through *enrichment* or through *revision"* (p. 46).

Enrichment refers to the process of assimilation or adding new information into and to existing frameworks; revision to the process of accommodation or altering existing frameworks in such ways that discrepant information can be incorporated. This is a broad view on conceptual change, because assimilation as well as accommodation are considered to contribute to the gradual process of deepening understanding (i.e. bringing preconceptions closer to scientific understanding). In a more restricted view only accommodation is held responsible for conceptual change: students need to perceive incongruency between preconceptions and new information, and as a consequence have to adjust their current frameworks to accommodate the new information (in a Piagetian sense).

An instructional strategy for overcoming misconceptions and promoting conceptual change, which has provoked much discussion among researchers, is the so-called cognitive conflict approach (see Nussbaum & Novick, 1982; Strike & Posner, 1985; 1992). The CONTACT strategy, a process-oriented, heuristic activation model which was central to a number of studies performed by Ali (1990) and Biemans (1997) is an example of an instructional strategy based on this cognitive conflict model of conceptual change. Sixth and seventh graders were trained with a computer-assisted version of this instructional method. It was applied to basic physical geography and involved the following five steps: 1) searching for preconceptions; 2) comparing and contrasting preconceptions with new information; 3) constructing new conceptions, based upon the previous step; 4) applying new conceptions; and 5) evaluating new conceptions. In order to trace the effects of the various steps and to increase the effectiveness of the procedure as a whole Biemans (op. cit.) studied several variants of this instructional strategy. Acknowledging the high degree of external control of the strategy, he also designed training procedures by which external regulation was gradually diminished to foster self-regulation skills aimed at prior knowledge activation and conceptual change. Moreover, he was interested in differences between the way successful and less successful students performed the various steps of the strategy. The quality of step 2, and more particularly, the quality of student-generated elaborations when performing this step, was found to be the critical factor in the heuristic. Indeed, requiring a student to compare his own ideas to the ideas put forward in an instructional text, even if additional strategic help is available by means of 'how' and 'why' screens, as was the case in Biemans' study, may not be enough to foster the process of conceptual change. It may be a step which is too big and/or too

difficult for students who have inadequate strategic knowledge and skills with regard to the integration and differentiation processes that are required for comparing and contrasting prior knowledge and new information.

Apparently, for many students refinements or alternatives to the 'classical' Piagetian cognitive conflict approach are needed to provide them with experiences that are meaningful and motivating enough to help them understand the insufficiency of their knowledge base. Moreover, for conceptual change to occur, it is not enough for students to see the discrepancies between two sets of ideas. Students need to become aware of the underlying beliefs and presuppositions (as components of their framework theories) as well (Vosniadou & Ioannides, op. cit.). Co-operative learning environments and information technology can be of help here, because they offer ample opportunities for students to express their ideas and compare them to other students' ideas. The same goes for the use of so-called bridging analogies (e.g. Clement, 1993): these are well-chosen intermediate examples or cases that bridge the gap between the student's preconceptions and the ideas they are required to understand (see also D.E. Brown, 1992).

Many instructional interventions aimed at overcoming misconceptions and promoting conceptual change require a high degree of teacher control and ample knowledge about the particular preconceptions that are typical of a certain group of students with regard to a certain domain. By means of gradual withdrawal of external control Biemans (op. cit.) managed to increase the quality of student' self-regulated learning for conceptual change. Eventually, students themselves should be inclined to and capable of comparing new information with existing knowledge structures. This requires what Vosniadou & Ioannides (op. cit.) have called

"metaconceptual awareness of ...the explanatory frameworks they have constructed..."

and the acknowledgement

"...that their explanations of physical phenomena are hypotheses that can be subjected to experimentation and falsification".

They advocate instructional interventions that make students aware of

"…their implicit representations, as well as of the beliefs and presuppositions that constrain them…" (op. cit.)

and provide students with meaningful experiences to promote insightful learning. However, not only do prior knowledge variables need to be taken into account, other student variables do as well. In the next section we will pay some attention to a set of student characteristics we consider relevant for the process of conceptual change.

THE ROLE OF GOAL ORIENTATIONS, LEARNING CONCEPTIONS, EPISTEMOLOGICAL BELIEFS AND APPROACHES TO LEARNING IN THE PROCESS OF CONCEPTUAL CHANGE

Recently, Gordijn (1998) has examined the effects on learning results of complex forms of feedback, which were added to computer-offered modules on engineering and technology in junior secondary technical education. Feedback was based on Merrill's Component Display Theory (Merrill, 1983) and thought to promote insightful learning for all students. However, compared to students who learned under simple feedback conditions only students with reproductive learning styles (as measured by an adapted version of Vermunt's Inventory of Learning Styles; Vermunt, 1992) were found to improve their learning scores on reproduction type questions. It seems that they managed to use the extra help and explanations offered by the complex feedback information not primarily for insightful learning (as intended by the researcher and the teachers involved), but for (their preferred ways of) reproduction-oriented learning.

This study, set up from an instructional design perspective (Reigeluth, 1987; Dijkstra, 1997), unintentionally but nicely illustrates the role that student learning conceptions and motivational orientations play with regard to learning activities deployed and learning results obtained in teacher-designed learning environments. According to Vermunt's learning style theory, learning styles are general, relatively consistent and characteristic combinations of learning conceptions, motivational orientations, preferred regulation activities and preferred subject matter processing activities (Vermunt, 1998). Higher education students with constructive learning conceptions appear to prefer self regulation and deploy 'deep' (Van Rossum & Schenk, 1984) meaning-oriented learning activities, whereas students with reproductive learning conceptions mainly rely on external regulation and prefer shallow reproduction-oriented learning activities (see also Slaats, Lodewijks & Van der Sanden (1999) for similar results in the field of senior secondary vocational education).

Taking a more domain-specific perspective Prosser, Walker and Millar (1996) studied student conceptions with regard to learning physics as did Schoenfeld (1985), as well as Stodolsky, Salk and Glaessner (1991) with regard to learning mathematics. Pupils' attitudes towards technology were investigated in a series of studies conducted at Eindhoven University of Technology (De Vries, 1988; De Klerk Wolters, 1989). In these studies age- and sex-related differences concerning the interpretation and appreciation of technology were central. Ng and Bereiter (1992) performed an in-depth study on the influence of goal orientations on learning activities and learning results. Adult subjects in this study voluntarily took a BASIC programming course. On the basis of thinking-aloud-protocols the researchers were able to determine three different goal-orientations: completing the tasks set by the teacher (task-completion goals), trying to reach the instructional goals set by the teacher (instructional goals) and striving for personal knowledge construction (personal knowledge-building goals).

Subjects with personal knowledge building-goals obtained the best learning results. They were found to set goals for themselves and to actively use their prior

knowledge in solving the diversity of problems they were involved in. When judged appropriate they reconsidered and accommodated their preconceptions; moreover they themselves generated additional questions and posed themselves new problems, which they subsequently tried to solve. Ng and Bereiter characterized the learning situation these subjects created as a

> '…constructive interaction between prior knowledge and new information' and as '… a dialectical process in which prior knowledge not only influenced new learning, but new learning was used to reconstruct prior knowledge' (p. 258).

Subjects with instructional goals restricted themselves to learning activities and issues, which were explicitly programmed. They, too, used their prior knowledge in solving the assigned problems, but they never appeared to reorganize or accommodate their personal frameworks, which guided their problem-solving actions. Students who set themselves task-completion goals were found to work diligently and purposefully and laid an emphasis on exercising. Out of the three goal-orientation groups they spent the most learning time on the BASIC course. They regularly asked themselves whether they were performing up to the standards set by the teacher. It appeared that they used their prior knowledge only in relation to solving small problems they were confronted with and not for gaining deeper insight into the BASIC programming language.

The above-mentioned and other related studies provide interesting insights into the role student learning styles, learning conceptions and motivational orientations play in the different ways students interpret and approach learning situations. It is remarkable that conceptual change studies have not paid much attention to these variables up to now. It is obvious, however, that these variables are potentially relevant for researchers as well as teachers involved in the process of conceptual change, as are other student characteristics like, for instance, personality characteristics like uncertainty orientation (Sorrentino, Short & Raynor, 1984) and Big Five factor 5: 'intellect/openness to experience' (De Raad, 1996).

Pintrich, Marx and Boyle (1993) and other researchers have criticized the dominant 'cognition-only' approach in the conceptual change literature. They have articulated that '.... the classroom community does not generally operate in the same fashion as the scientific community' (p. 170) and that '....the assumption that students approach their classroom learning with a rational goal of making sense of the information and coordinating it with their prior conceptions may not be accurate (p. 173).

Indeed, the classical cognitive conflict approach, as described in the previous section, is based on the assumption that humans react rationally to a situation of disequilibrium that comes about when new information conflicts with existing beliefs or ways of thinking. They will experience dissatisfaction with their habitual ways of seeing things and therefore will be amenable to alternative explanations (i.e. will be willing to accommodate their preconceptions).

However, according to Pintrich et al. (op. cit.) student motivational factors, specifically goals, values, self-efficacy and control beliefs, should be treated as potential mediators of the process of conceptual change. Moreover, a number of

classroom contextual factors may play an important role in this process, i.e. task structures, authority structures, evaluation structures, classroom management, teacher modeling, and teacher scaffolding.

When a broader perspective of conceptual change is taken, it is also interesting to take students' epistemological beliefs into account (Van der Sanden, 1997; Vosniadou & Ioannides, in press). Schommer (1994) and Hofer and Pintrich (1997) recently reviewed the relatively scarce body of research on the relations between epistemological beliefs, learning activities and learning results. Epistemological beliefs have to do with the potentiality, nature, reliability, scope and origins of knowledge. According to Hofer and Pintrich (op. cit.) it is worth studying personal epistemological development to find out.

> '....how individuals come to know, the theories and beliefs they hold about knowing, and the manner in which such epistemological premises are a part of and an influence on the cognitive processes of thinking and reasoning' (p. 88).

Confining ourselves to research on the subject of science and technology, a study on the role of epistemological beliefs with regard to physics learning performed by Schommer (1990) serves as an illustration. Schommer postulates five more or less independent epistemological dimensions: certainty of knowledge, structure of knowledge, source of knowledge, control of knowledge, acquisition, and speed of knowledge acquisition. The latter dimension contrasts knowledge acquisition as a gradual and time-consuming process with knowledge acquisition as something that occurs quickly or not at all. In Schommer's study students completed a questionnaire on epistemological beliefs, measuring the five dimensions mentioned above. Students were required to study a physics text at the end of which a conclusion was deliberately left out and were asked to formulate a conclusion for themselves. The more students gave evidence of the opinion that learning and understanding is an all-or-nothing process ('quick learning') the less elaborate their conclusions were, the more certain they were about their learning results and the worse they performed on a test regarding the physics text.

In the previous section we dwelled upon the human tendency to develop individual theories to create a frame of reference for describing and categorizing things, people and phenomena, for explaining and anticipating differences between events and for undertaking purposeful action in a variety of situations when required (see also Driver & Easley, 1978). In the realm of human behavior Kelly's cognitive theory of personality stands out as an early example of a scientific theory in which individual naive personality theories, consisting of systems of more or less related personal constructs, take up a central position (Kelly, 1955). A similar tendency to develop naive theories has been described with regard to everyday natural phenomena that are also studied from a scientific point of view (e.g. Carey, 1985, 1986; Vosniadou, 1994). We want to draw attention here to the operational or procedural side of these individual theories. Individual theories serve a conceptual-

declarative function, but usually also involve procedural blueprints or action scripts. In this respect the concept of action theory (Argyris & Schön, 1978; Van der Krogt, 1995), is gaining importance in the field of work-related organizational learning theory. Action theories refer to the more or less integrated and explicit set of personal goals, norms, convictions and rules that govern and authorize people □s actions in work situations.

From the research on learning conceptions, goal orientations and epistemological beliefs, it becomes apparent that individual theories operate with regard to learning and school-related issues as well. So, when one wants to understand and influence processes of learning and conceptual change it is fruitful to take students' individual learning theories into account (cf. Van der Sanden, 1997). These individual learning theories serve as personal frameworks for learning and instruction with regard to a particular domain, are composed of conceptual as well as procedural elements, and may consist of a more or less integrated and more or less internally consistent set of:

- Ideas, beliefs and convictions about the entities and issues that are dealt with in a certain domain and, consequently, where learning in the domain is about (compare Vosniadou and Ioannides' notion of 'ontological presuppositions' (Vosniadou & Ioannides, in press)).
- General and domain-related epistemological beliefs (cf. Vosniadou & Ioannides, in press).
- General and domain-related learning conceptions.
- Presumptions about the distinctive features of competent behavior regarding the subject matter area, about the typical difficulties involved in thinking and problem solving and about one's subjective competence concerning the field.
- Individual goals and goal orientations (see also Boekaerts, 1998).
- Preferences for particular learning situations and learning activities.
- Preferences for particular instructional events and measures, and ideas about the role of experts, teachers and fellow students in acquiring competence.

LEARNING FROM PROBLEM-SOLVING AND TASK-EXECUTION

Solving problems, doing exercises and executing tasks are quite common activities in school-based science and technology courses. Students as well as teachers may even have a tendency to narrow down science and technology-related activities to exercising (Taconis, 1995; Taconis & Ferguson-Hessler, 1994). An illustration of this tendency is found in a study of diSessa (1985; quoted in Greeno, Collins & Resnick, 1996, p. 19-20). DiSessa compared the learning activities of two students enrolled in a college physics course. They differed with regard to their personal epistemological theories on the nature of the knowledge to be acquired in connection with the domain of physics. One student characterized himself as a 'results man'; during the course he concentrated his activities on acquiring the ability to solve physics problems efficiently and correctly. The other student was focused on conceptual understanding and emphasized learning activities that led to an understanding of concepts and principles.

Interesting too, in this respect, is Schoenfeld's study on student conceptions about learning mathematics (Schoenfeld, 1985). Schoenfeld noticed that many students thought that it is necessary to solve math problems in less than ten minutes and that it is useless to spend more time finding a solution. Schoenfeld attributes the development of this type of personal math theory to the common school practice of confronting students with large amounts of short problems (taking 2 minutes solution time, on the average). As a consequence of this praxis students come to erroneously believe that expert mathematicians are able to solve problems in a few minutes. In his study students as a rule were of the opinion that math competence essentially consists of knowing a sufficient number of standardized procedures and knowing which procedure to use for what type of problem.

These examples point to two important issues: 1) different students can learn different things from solving the same problems and 2) the very praxis of having students do a lot of exercises can lead to an undesirable separation between conceptual and procedural knowledge. Students' individual learning theories play a role here and may lead students to the shallow application of procedures instead of conceptual understanding.

A well-organized knowledge base with strong internal connections between different types of knowledge is supposed to be an important prerequisite for effective problem solving and task execution (Boekaerts & Simons, 1993; Prawat, 1989; Taconis, 1995). Students, however, often are unwilling or incapable of building bridges between more conceptual and more procedural knowledge. Also they often do not manage to achieve a balance between contextualized and decontextualized knowledge. When practical assignments at school are more or less divorced from or not sufficiently tied to 'theoretical' lessons, students may experience too little support to lay relations between different types of knowledge or knowledge tied to different situations. Such school practice can contribute to the development of student learning theories in which learning and doing or experiencing (Slaats, Van der Sanden & Lodewijks, submitted) are disconnected or too loosely coupled.

Probably objectivistic transfer conceptions are embedded in such individual learning theories: specific practice situations are viewed as occasions for applying previously learned knowledge, which is considered as general and 'ready-made'. More constructivistic transfer conceptions, on the other hand, would lead to an interpretation of practice situations as settings in which new knowledge and skills can be constructed or prior knowledge be reconstructed, instead of settings that merely serve to apply previously acquired, not yet deeply rooted and personalized knowledge (Van der Sanden & Teurlings, 1998; compare also Ng and Bereiter's students with personal knowledge building goals; Ng & Bereiter, 1992).

It is remarkable that there also seems to be a gap between researchers studying science and technology with a conceptual change approach (e.g. Glynn, Yeany & Britton, 1991) and researchers with a more procedural problem-solving perspective. The latter as a rule adopt a strategy-oriented systematic problem-solving approach

(e.g. Mettis & Pilot, 1980; Kramers-Pals, 1994). They compare good and bad beginners' approaches and solutions to expert performance and devise heuristic-based training programs to improve problem-solving skills. The same tendency is apparent in the work of researchers involved in studies on the learning and instruction of practical-technical skills and design skills (e.g. Van der Sanden, 1994; Doornekamp, 1997; Montague, 1988; Van Merriënboer, 1997).

While cognitive and metacognitive strategies undoubtedly are important constituents of problem-solving competence, the quality of domain relevant knowledge plays a major role as well. Taconis (1995), for instance, has drawn attention to the negative role misconceptions can play in problem solving. He claims that

> '…studies on problem solving usually do not take the results of studies on misconceptions into account. Neither do studies on misconceptions explicitly take findings concerning problem solving into account' (Taconis, 1995, p. 45-46).

Naturally, doing exercises or projects like solving problems (e.g. design problems), executing tasks (e.g. laboratory tasks) or, more generally, applying procedures to new situations may lead to rich and diverse learning experiences. Students may develop general and domain-specific strategic knowledge, and/or domain-specific declarative, procedural and situational knowledge (Ferguson-Hessler & De Jong, 1993). They may grasp the opportunity to reconstruct their knowledge base, test and adjust their individual learning theories, gain confidence etc. Such learning effects, however, too often do not come of their own accord and therefore explicit instructional measures to increase the odds that students learn optimally from practical assignments seem necessary. Preferably, such measures should be part of specific programs for learning to learn with regard to science and technology. In this respect we want to draw attention to two related points, which in our view are especially relevant for such programs, viz. (a) learning to integrate situational, episodic, conceptual and procedural information and (b) the development of individual learning theories in which problem solving and practical assignments figure as means to enhance both procedural knowledge and conceptual understanding.

Process-oriented science and technology instruction and interactive learning groups composed of students with different learning styles (Boekaerts, 1996) are promising in this respect. Recently, process-oriented instructional approaches were applied to learning word-processing skills by Teurlings, Van der Sanden, Simons and Lodewijks (submitted; see also Teurlings & Van den Berg, 1995) and physics instruction (Brand-Gruwel, Van der Sanden, Teurlings & Vermetten, in press). In the former study the so-called Leittext-method (Selka & Conrad, 1987) was completed by a number of additional process-oriented instructional measures. In the latter study a special emphasis was placed on learning from previously solved science problems. Interesting too is Taconis' program for understanding-based problem-solving (Taconis, 1995). In this program conceptual change and problem solving were integrated with regard to physics learning, emphasizing co-operative learning from solved physics problems and the development of cognitive and

metacognitive skills. Besides these embedded instructional approaches, specific science and technology-oriented thinking and learning skills programs, like CASE (Cognitive Acceleration through Science Education; Shayer & Adey, 1997) or ARL (Ateliers de Raisonnement Logique, Logical Reasoning Workshops; Attigui, Nasson & Boughers, 1995) may play a supporting role, provided that achievements of these stand-alone training programs are systematically tied too other science and technology courses.

DIFFERENTIAL EFFECTS IN MATHEMATICS, SCIENCE AND TECHNOLOGY

While new learning theories, strategies and tools like constructivism, co-operative learning or educational technology often lead to positive effects on students' learning, research also shows that there are outcomes that are not intended and even contradictory to the expectations. The same instructional strategy, content, curriculum, textbook or educational technology produces different results for different categories of students e.g. boys and girls, students from high and low income families, high and low-ability students or students with different learning styles and orientations. These effects are often referred to as 'Matthew effects'.

Nowadays in the Netherlands two major innovations in secondary education are in the process of being implemented in respectively junior and senior high school education. Constructivist ideas are at the very heart of these innovations (Roelofs & Terwel, 1999). In the discussions involved there is serious concern that these constructivist ideas, if not rightly understood, may increase differences between the various student categories. Are educators and policy makers taking the wrong road in their eager embrace of constructivist ideas (Terwel, 1999)? The more the constructivist.doctrine is interpreted in a naive or radical way, the more educational outcomes may be detrimental to certain students. We will give a few examples.

First, the case of certainty orientation. In constructivist and co-operative learning environments students always have to cope with uncertainty. These experiences may be stimulating for uncertainty-oriented students. With regard to science, mathematics and technology it can be expected that these students are interested in exploring multiple perspectives. On the other hand, certainty-oriented students, like diSessa's 'results man', mentioned in section 3, may be more motivated by situations that do not entail ambiguity. Instead of favoring a 'participation model' low-achieving students may prefer and flourish under the conditions of a 'transmission model' in learning science, mathematics and technology (Huber & Sorrentino, 1996).

Second, the case of ability in technology. The outcomes of a study of Van der Sanden (1986) show clearly differential effects for high and low-ability students. High-ability students are hindered by detailed prescriptions for performing a technical construction task, while the performance of low-ability students is enhanced by these guidelines.

Third, the case of achievement in mathematics. From several studies it is known that high and low-achieving students differentially benefit from open, co-operative

learning environments in which mathematics is embedded in 'rich' contexts or daily life situations (Leechor, 1988; Hoek, Terwel & Van den Eeden, 1997; Hoek, van den Eeden & Terwel, 1999) Generally, high-ability students are more active in co-operative groups and provide more explanations than their low-ability peers. Van den Eeden and Terwel (1994) report similar results regarding the learning outcomes of high and low-achieving students in mathematics. The recent study of Terwel, Gillies, Van den Eeden and Hoek (1999) provides more insight into the crucial factors involved. In this multi-level analysis it is shown that the less effective (i.e., unsolicited) explanations were given more often by low-ability students. In the context of co-operative learning environments high-ability students tend to give more effective (i.e., solicited) explanations. As a consequence of these differences in participation between high and low-achieving students differences in learning outcomes occur. Furthermore, over and above the effects of student ability, the higher the class' ability level, the more explanations were given by the students. The results of this study are useful in explaining why high-ability students benefit more from open, constructivist learning than low-ability students.

Matthew effects also appear in applications of educational technology, like for instance in Integrated Learning Systems. ILS is an example of integrated, individualized software that is located on a central server which is linked via an electronic network to forty computers in a computer lab. ILS software contains instructions and problems for practice, covering the curriculum for one or more years. Lessons and previous accomplishments are automatically loaded into the computer when a student logs in. ILS provides a continuous assessment of students' progress and learning needs (Havita & Lesgold, 1996). Educators expected low-achieving students to like ILS because unlike whole-class teaching they are not visible as losers. ILS proponents promised success for all because the computerized work was adapted to the needs and pace of each student while failures were not visible to others. However, the outcomes were different as compared to the intentions and expectations. The better students were highly motivated by ILS because of the competition induced by ILS. The same competition caused demotivation in the low-achieving students and the results of all students were far below the level of expectation (Havita & Lesgold, 1996).

Although differential effects are rather persistent in new constructivism-based learning environments, research has shown that these Matthew effects can be overcome or mitigated by adequate training in social and cognitive strategies (Webb & Farivar, 1994; Hoek, Terwel & Van den Eeden 1997; Hoek, van den Eeden & Terwel, 1999). The lesson from these examples is that learning does not occur in a vacuum, but in a social context in which several variables are at work. Matthew effects seem to occur everywhere. As in society as a whole, most of the time the rich are getting richer from whatever innovation. These effects seem to be especially vital in subjects as mathematics, physics and technology. Matthew effects not only occur between achievement levels but also between male and female students (Webb, 1984; Canada & Pringle, 1995). Even in innovational situations that are designed to serve the needs of low-achieving students like co-operative learning or applications of educational technology, the outcomes are sometimes

contrary to the expectations. Skills training sometimes helps but low-achieving students often profit less from strategy training of most kinds (Hattie, Biggs & Purdie, 1996). Fortunately there are exceptions in which low achieving students were able to benefit and where Matthew effects could be mitigated (Chinnappan & Lawson, 1996; Webb & Farivar, 1994; Hoek, Terwel & Van den Eeden, 1997; Hoek, van den Eeden & Terwel, 1999). Also Taconis' program for understanding-based problem-solving (Taconis, 1995; see also section 4) turned out to be especially helpful for students with relatively low grades for physics as well as for girls.

Instead of creating different streams and ability groups for low and high-achieving students in which different curricula and teaching methods are offered, we propose another road to new learning in which all students can develop science and technology related competencies without being separated from their more or less able peers. In this view combinations of whole class instruction, discussion methods, guided reinvention methods, supervised participation in meaningful tasks, and working in co-operative groups are recommended. There are moments when it may be necessary to provide more guidance to students who do not have sufficient prior knowledge or the required skills and meta-cognitive strategies. If some students lack the prerequisite knowledge, the teacher can conduct the role of expert and model, and provide scaffolding for those students who cannot cope with a given task independently. In this way teachers play a central and guiding role in the learning processes of students: teachers are cognitive guides and living models, and students are sense-makers who have to learn to learn strategically in different instructional contexts. In this option the instructional process may start from the 'bottom' of the real-life world and proceed by designing intermediate models toward more formal structures and concepts of science and technology.

CONCLUDING REMARKS

Because of the still rapidly growing importance of science and technology in the information society competencies for dealing with science and technology are becoming increasingly important. People should be able and willing to categorize, interpret, and predict science and technology related phenomena and events (science literacy), to act purposefully when required under diverse circumstances, and to learn (and keep on learning) actively and independently in a variety of situations (in and out of school, at work, or at home). Competence is often defined as 'having sufficient skill' or 'being sufficiently qualified' (Eraut, 1994). We prefer to take a broader perspective and point to the organized whole of knowledge, skills, attitudes and learning abilities that is typical of competence. Learning ability is deliberately included as an important aspect of competence. It is regarded as a mixture of metacognitive knowledge and learning skills, a disposition to apply and improve one's learning skills in varied potential learning situations, an adequate individual learning theory and the willingness to test, elaborate, and refine this theory.

Taking this perspective, competence development with regard to science and technology means that students continuously make efforts to achieve personal growth in five related areas:

X   Building up a sound knowledge base, which requires conceptual change.

X   Acquiring understanding-based problem-solving skills, as well as research and technical design skills.

X   Coming to appreciate the value of science and technology.

X   Developing the ability to learn in the field of science and technology, including developing one's individual learning theory (Van der Sanden, 1997).

X   Participating in 'communities of learners', which entails sharing 'resources', understanding each other, taking different perspectives, and giving explanations and adequate feedback in the process of co-construction in science and technology education (Terwel, 1997).

Designers of learning environments and teachers in the fields of science and technology should focus on competence development and foster the acquisition of a cohesive and coherent blend of knowledge, skills, attitudes and learning abilities (including adequate individual learning theories). Learning to learn is seen as an integral and important part of science and technology instruction. Influencing students' individual learning theories should be an important issue, because these theories are the main determinants of learning activities students deploy (Vermunt, 1998).

We reviewed a number of instructional approaches that are promising for competency-based science and technology instruction. Process-oriented instruction, interactive and co-operative learning, conceptual change-oriented instructional approaches and understanding-based problem-solving programs served as examples.

In the previous sections we already alluded to several questions, that demand new research. Design experiments (A.L. Brown, 1992; Van den Akker, 1996) seem especially suited to us to develop action-relevant theories of learning and instructing science and technology. Longitudinal research designs, new forms of competency-based measurement (e.g. portfolio measures) and other non-traditional outcome measures (see also, Salomon, 1998, p. 10) are needed to study science and technology-related competencies over longer periods of time. In these longitudinal studies the role of teachers and new educational technologies in fostering learning ability of students with different ability levels deserves special attention. Paying attention to the social context in which science and technology is learned and used is of utmost importance for competency-based instruction.

REFERENCES

Abraham, M.R., Grzybowski, E.B., Renner, J.W., & Marek, E.A. (1992). Understandings and misunderstandings of eighth graders of five chemistry concepts found in textbooks. *Journal of Research in Science Teaching, 29,*105-120.

Ali, K. (1990). *Instructiestrategieën voor het activeren van preconcepties.* Tilburg: Katholieke Universiteit Brabant.

Argyris, C., & Schön, D.A. (1978). *Organizational learning: A theory of action perspective.* Reading, MA: Addison-Wesley.

Attigui, A, Nasson, E., & Boughers, O. (1995). Logical Reasoning Workshops. In: J.M.M. van der Sanden, & F. J. J. van Bussel (Eds.), *Atrium in Europe. The development of learning abilities in youth training* (pp. 74-79). Bielefeld: W. Bertelsmann Verlag.

Biemans, H.J.A. (1997). *Fostering activation of prior knowledge and conceptual change.* Arnhem. H.J.A. Biemans.

Boekaerts, M. (1996). *Self-regulated learning goes to vocational school: Intervention programs in Dutch schools.* Paper presented at the symposium "New perspectives on learning and instruction go to schools", XXVI International Congress of Psychology, Montreal, Canada.

Boekaerts, M. (1998). Boosting students' capacity to promote their own learning: a goal theory perspective. In: M. Vauras (Ed.), *Research Dialogue in Learning and Instruction* (pp. 13-22), Vol. 1. No. 1.

Boekaerts, M. & Simons, P.R.J. (1993). *Leren en instructie: Psychologie van de leerling en het leerproces.* Assen: Dekker & Van de Vegt.

Brand-Gruwel, S., Van der Sanden, J., Teurlings, C., Thijssen, A., & Vermetten, Y. (in press). Het effect van procesgericht natuurkunde-onderwijs. *Tijdschrift voor Didactiek der β-wetenschappen.*

Brown, A.L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the learning sciences, 2,* 141-178.

Brown, D.E. (1992). Using examples and analogies to remediate misconceptions in physics: Factors influencing conceptual change. *Journal of Research in Science Teaching, 29,* 17-34.

Byrnes, J.P. (1996). *Cognitive development and learning in instructional contexts.* Boston: Allyn and Bacon.

Canada, K., & Pringle, R. (1995). The role of gender in college classroom interactions: a social context approach. *Sociology of Education, 68,* 161-186.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Carey, S. (1986). Cognitive science and science education. *American Psychologist, 41*(10), 1123-1130.

Chinnappan, M., & Lawson, M.J. (1996). The effects of training in the use of executive strategies in geometry. *Learning and Instruction, 6* (1), 1-17.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 52,* 66-71.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching, 30* (10), 1241-1257.

Commissie Toekomst Natuur- en Technische Wetenschappen (1997). *Wetenschap en Techniek. Welvaart en Welzijn. Een verkenning van de oorzaken en gevolgen van de sterke doling van het aantal studenten in de natuur- en technische wetenschappen.* Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen.

De Klerk Wolters, F. (1989). *The attitude of pupils towards technology.* Eindhoven: Eindhoven University of Technology.

De Raad, B. (1996). Personality traits in learning and education. *European Journal of Personality, 10,* 185-200.

De Vries , M. (1988). *Techniek in het natuurkunde-onderwijs.* Eindhoven: Technische Universiteit Eindhoven.

Dijkstra, S. (1997). Theoretical foundations of Instructional Design: Introduction and overview. In: R.D. Tennyson, F. Schott, N. Seel, & S. Dijkstra (Eds.), *Instructional Design: International perspectives. Volume 1: Theory, research, and models* (pp. 19-24). Mahwah, New Jersey: Lawrence Erlbaum.

diSessa, A (1985). Learning about knowing. In: E.L. Klein (Ed.), *Children and computers. New directions for child development* (pp. 97-124). San Francisco: Jossey-Bass.

Dochy, F.J.R.C. (1992). *Assessment of prior knowledge as a determinant for future learning.* Heerlen: Open Universiteit.

Doomekamp, G. (1997). *Probleemoplossen binnen het vak techniek. Een studie naar effectieve domeinspecifieke ontwerprichtlijnen voor onderwijsleerpakketten.* Enschede: Universiteit Twente.

Driver, R., & Easley, J. (1978). Pupils and paradigms: a review of literature related to concept development in adolescent science students. *Studies in Science Education,* 5, 61-84.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23,* 5-12.

Dudley Herron, J. (1996). *The chemistry classroom. Formulas for successful teaching.* Washington, DC: American Chemical Society.

Eraut, M. (1994). *Developing professional knowledge and competence.* London: The Falmer Press.

Ferguson-Hessler, M.G.M., & De Jong, T. (1993). Het leren van exacte vakken. In: W. Tomic, & P. Span (Red.). *Onderwijspsychologie. Beïnvloeding, verloop en resultaten van leerprocessen* (pp. 331-351). Utrecht: Lemma.

Gagné, R.M., & Briggs, L.J. (1979). *Principles of instructional design.* New York: Holt, Rinehart & Winston.

Gauvain, M. (1998). Social context, mathematics, and cognitive development: a promising research direction. *Learning and Instruction, 8* (6), 561-566.

Glynn, S.M., Yeany, R.H., & Britton, B.K. (Eds.) (1991). *The psychology of learning science.* Hillsdale, New Jersey: Lawrence Erlbaum.

Greeno, J.G., Collins, A.M., & Resnick, L.B. (1996). Cognition and learning. In: D.C. Berliner, & R.C. Calfee (Eds.), *Handbook of educational psychology* (pp. 15-46). New York: Simon & Schuster MacMillan.

Hattie, J., Biggs, J., & Purdie, N. (1996). Effects of learning skills interventions on student learning: A meta-analysis. *Review of Educational Research, 66 (2),* 99-136.

Havita, N., & Lesgold, A. (1996). Situational effects in classroom technology implementations: Unfulfilled expectations and unexpected outcomes. In: S.T. Kerr (ed.), *Technology and the Future of Schooling* (pp. 131-171) Chicago, Illinois: National Society for the Study of Education.

Hoek, D., Terwel, J., & van den Eeden, P. (1997). Effects of training in the use of social and cognitive strategies: An intervention study in secondary mathematics in cooperative groups. *Educational Research and Evaluation, 3,* 364-389.

Hoek, D., Van den Eeden, P., & Terwel, J. (1999). The effects of integrated social and cognitive strategy instruction on the mathematics achievement in secondary education. *Learning and Instruction, 9,* 427-448.

Hofer, B.K., & Pintrich, P.R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67,* 88-140.

Huber, G.L., & Sorrentino, R.M. (1996). Uncertainty in interpersonal and intergroup relations. An individual-difference perspective. In: R.M. Sorrentino, & E.T. Higgins (Eds.). *Handbook of Motivation and Cognition, Volume 3: The Interpersonal Context* (pp. 591-619). New York: Guilford.

Kelly, G.A. (1955). *The psychology of personal constructs.* New York: Norton.

Kramers-Pals, H. (1994). *Leren oplossen van verklaringsproblemen in het scheikunde-onderwijs.* Enschede: Technische Universiteit.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge: Cambridge University Press.

Leechor, C. (1988). *How high and low achieving students differentially benefit from working together in co-operative small groups.* Stanford: Stanford University, School of Education (ph. dissertation).

Lintsen, H. W. (Ed.) (1998). Techniek in Nederland in de twintigste eeuw. Deel 1. Stichting Historie der Techniek/Walburg pers.

Mayer, R.E., & Wittrock, M.C. (1996). Problem-solving transfer. In: D.C. Berliner, & R.C. Calfee (Eds.), *Handbook of educational psychology* (pp. 47-62). New York: Simon & Schuster MacMillan

Merrill, M.D. (1983). Component Display Theory. In: C.M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status* (pp. 279-334). London: Erlbaum.

Mettis, C.T.C.W., & Pilot, A. (1980,). *Over het leren oplossen van natuurwetenschappelijke problemen.* Enschede: Universiteit Twente.

Montague, W.E. (1988). Promoting cognitive processing and learning by designing the learning environment. In: D.H. Jonassen (Ed.), *Instructional designs for microcomputer courseware* (chapter 4, pp. 125-149). Hillsdale, NJ: Erlbaum.

Ng, E., & Bereiter, C. (1992). Three levels of goal-orientation in learning. *The Journal of the Learning Sciences, 1,* 243-273.

Nussbaum, J., & Novick, S. (1982). Alternative frameworks, conceptual conflict, and accommodation: Towards a principled teaching strategy. *Instructional Science, 11,* 183-200.

Pfundt, H., & Duit, R. (1991). *Bibliography: Students' alternative frameworks and science education* (3rd edition). Kiel, West Germany: IPN.

Pfundt, H., & Duit, R. (1994). *Students' alternative frameworks and science education* (4th edition). Kiel: University of Kiel.

Pintrich, P.R., Marx, R.W., & Boyle, R.A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63,* 167-199.

Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66,* 211-227.

Prawat, R.S. (1989). Promoting access to knowledge, strategy, and disposition in students: A research synthesis. *Review of Educational Research, 59,* 1-41.

Prosser, M., Walker, P., & Millar, R. (1996). Differences in students' perceptions of learning physics. *Physics Education, 31,* 43-48.

Reigeluth, C.M. (1987). Lesson blueprints based on the Elaboration Theory of Instruction. In: C.M. Reigeluth (Ed.), *Instructional theories in action. Lessons illustrating selected theories and models* (pp. 245-288). Hillsdale, New Jersey: Lawrence Erlbaum.

Roelofs, E. & Terwel, J. (1999). Constructivism and authentic pedagogy: State of the art and recent developments in the Dutch national curriculum in secondary education. *Journal of Curriculum Studies, 31* (2), 201-227.

Salomon, G. (1998). Novel constructivist learning environments and novel technologies: Some issues to be concerned with. In: M. Vauras (Ed.), *Research Dialogue in Learning and Instruction* (pp. 3-12), Vol. 1.No. 1.

Schliemann, A.D., Carraher, D.W., & Ceci, S.J. (1997). Everyday cognition. In: J.W. Berry, Y.H. Poortinga, & J. Pandey (Eds.), *Handbook of cross-cultural psychology* (vol. 2, pp. 177-216). Boston: Allyn & Bacon.

Schoenfeld, AH. (1985). *Mathematical problem solving.* New York: Academic Press.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*, 498-504.

Schommer, M. (1994). An emerging conceptualization of epistemological beliefs and their role in learning. In: R. Gamer, & P.A. Alexander (Eds.), *Beliefs about text and instruction with text* (pp. 25-40). Hillsdale, New Jersey: Erlbaum.

Selka, R., & Conrad, P. (1987). *Leittexte - ein Weg zu selbständigem Lernen.* Berlin: BIBB.

Shayer, M., & Adey, P. (1997). *Large scale, long term effects of a cognitive intervention in the science curriculum on academic achievement in mathematics and English.* Paper presented at the 7th European Conference for Research on Learning and Instruction in Athens (august 26-30).

Slaats, A, Lodewijks, J.G.L.C., & Van der Sanden, J.M.M. (1999). Learning styles in secondary vocational education: disciplinary differences. *Learning and Instruction, 9,* 475-492.

Slaats, A, Van der Sanden, J.M.M., & Lodewijks, J.G.L.C. (submitted). *De samenhang tussen leerconcepties en verwerkingsstrategieën bij leerlingen in het middelbaar beroepsonderwijs.*

Sorrentino, R.M., Short, J.C., & Raynor, J.O. (1984). Uncertainty orientation: Implications for affective and cognitive views of achievement behavior. *Journal of Personality and Social Psychology, 47,* 1505-1518.

Slodolsky, S.S., Salk, S., & Glaessner, B. (1991). Student views about learning math and social studies. *American Educational Research Journal, 28,* 89-116.

Storey, R.D. (1992). Textbook errors and misconceptions in biology: Cell physiology. *American Biology Teacher, 54,* 44-47.

Strike, K.A, & Posner, G.J. (1985). A conceptual change view of learning and understanding. In: L.H.T. West, & AL. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 211-231). Orlando: Academic Press.

Strike, K.A., Posner, G.J. (1992). A revisionist theory of conceptual change. In: R. Duschl, & R. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147-176). Albany, NY: Suny

Taconis, R. (1995). *Understanding Based Problem Solving. Towards qualification-oriented teaching and learning in physics education.* Eindhoven: Technische Universiteit Eindhoven.

Taconis, R., & Ferguson Hessler, M.G.M. (1994). Het belang van probleemoplossen voor het onderwijs in de technische en exacte vakken *Tijdschrift voor Didactiek der ß-wetenschappen, 12,* 172-194.

Terwel, J. (1997). Grenzen aan de groep? Een onderwijspedagogisch perspectief op leren in contexten [Social contexts for learning]. Amsterdam: Vrije Universiteit (Inaugural lecture Free University Amsterdam).

Terwel, J. (1999). Constructivism and its implications for curriculum theory and practice. *Journal of Curriculum Studies, 31*(2), 195-200.

Terwel, J., Gillies, R., Van den Eeden, P. & Hoek, D. (1999). *Opening the black box: Processes in cooperative learning from a longitudinal multilevel perspective.* Paper presented at the Annual Meeting of the American Educational Research Association (AERA). Canada, Montreal, 1999, April 19-23.

Teurlings, C.C.J., & Van den Berg J. (1995). The Leittext PLUS method. In: J.M.M. van der Sanden, & F.J.J. van Bussel (Eds.), *Atrium in Europe. The development of learning abilities in youth training* (pp. 66-73). Bielefeld: W. Bertelsmann Verlag.

Teurlings, C.C.J., Van der Sanden, J.M.M., Simons, P.R.J.., & Lodewijks, J.G.L.C. (submitted). *Effects of a process-oriented learning environment based on cognitive apprenticeship: a study on learning to use a word processor.*

Tobias, S. (1976). Achievement-treatment interactions. *Review of Educational Research, 46,* 61-74.

Van den Akker, J.J.H. (1996). *Het Studiehuis: ook een leeromgeving voor docenten?* Amsterdam: Vrije Universiteit.

Van den Eeden, P., & Terwel, J. (1994). Evaluation of a mathematics curriculum: differential effects. *Studies in Educational Evaluation, 20,* 457-475.

Van der Krogt, F.J. (1995). *Leren in netwerken: Veelzijdig organiseren van leernetwerken met het oog op humaniteit en arbeidsrelevantie.* Utrecht: Lemma.

Van der Sanden, J.M.M. (1986). *Het leren van technische vaardigheden. Individuele verschillen bij het uitvoeren van praktijkopdrachten in het lager technisch onderwijs.* Den Haag: SVO.

Van der Sanden, J.M.M. (1994). Learning and instruction of motor skills. In: T. Husén & T. Neville Postlethwaite (Eds.), *The International Encyclopedia of Education* (pp. 3950-3953). Oxford: Pergamon Press.

Van der Sanden, J.M.M. (1997). *Duurzame ontwikkeling van leervermogen. Leren leren in het technische domein.* Intreerede. Eindhoven: Technische Universiteit Eindhoven.

Van der Sanden, J.M.M., & Van Bussel, F.J.J (Eds.) (1995). *Atrium in Europe. The development of learning abilities in youth training.* Bielefeld: W. Bertelsmann Verlag.

Van der Sanden, J.M.M., & Teurlings, C.C.J. (1998). *Developing competence during practice periods: the learners' perspective.* Poster presented at the European COST Conference on promotion of flexibility, transferability and mobility in vocational education and training. University of Newcastle, November, 1998

Van Merriënboer, J.J.G. (1997). Training complex cognitive skills. A four-component instructional design model for technical training. Engiewood Cliffs, NJ: Educational Technology Publications.

Van Oers, B. (1998). From context to contextualizing. *Learning and Instruction, 8,* 473-488.

Van Rossum, E.J., & Schenk, S.M. (1984). The relationship between learning conception, study strategy and learning outcome. *British Journal of Educational Psychology, 54,* 73-83.

Vermunt, J. (1992). *Leerstijlen en sturen van leerprocessen in het hoger onderwijs. Naar procesgerichte instructie in zelfstandig denken.* Amsterdam: Swets & Zeitlinger.

Vermunt, J.D. (1998). The regulation of constructive learning processes. *British Journal of Educational Psychology, 68,* 149-171.

Vosniadou, S. (1991). Conceptual development in astronomy. In: S.M. Glynn, R.H. Yeany, & B.K. Britton. (Eds.). *The psychology of learning science* (pp. 149-177) . Hillsdale, New Jersey: Lawrence Erlbaum.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and instruction,* 4, 45-69.

Vosniadou, S. (1996). Towards a revised cognitive psychology for new advances in learning and instruction. *Learning and Instruction, 6,* 95-109.

Vosniadou, S., & Brewer, W.F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24,* 535-585.

Vosniadou, S., & Brewer, W.F. (1994). Mental models of the day/night cycle. *Cognitive Science, 18,* 123-183.

Vosniadou, S, & Ioannides, C. (in press). From conceptual development to science education: A psychological point of view. *The International Journal of Science Education.*

Webb, N. (1984). Sex differences in interaction and achievement in cooperative small groups. *Journal of Educational Psychology, 75,* 33-44.

Webb, N.M., & Farivar, S. (1994). Promoting helping behavior in co-operative small groups in middle school mathematics. *American Educational Research Journal, 31,* 369-395.

Wigfield, A., Eccles, J.S., & Pintrich, P. (1996). Development between the ages of 11 and 25. In: D.C. Berliner, & R.C. Calfee (Eds.), *Handbook of educational psychology* (pp. 148-185). New York: Simon & Schuster MacMillan.

AFFILIATIONS

Johan van der Sanden, Tilburg University and Eindhoven University of Technology, Institute for Teacher Training, Den Dolech 2, 5612 AZ, Eindhoven, The Netherlands. E-mail: j.m.m.v.d.sanden@phys.tue.nl

Jan Terwel, University of Amsterdam, Graduate School of Teaching and Learning, and Vrije Universiteit Amsterdam, Faculty of Psychology and Education, Department of Educational Psychology, Van der Boechorststraat 1, 1081 BT, Amsterdam, The Netherlands. E-mail: j.terwel@psy.vu.nl

Stella Vosniadou, University of Athens, Department of Philosophy and History of Science, 37 John Kennedy Street, Athens 16121, Greece. E-mail: svosniad@compulink.gr