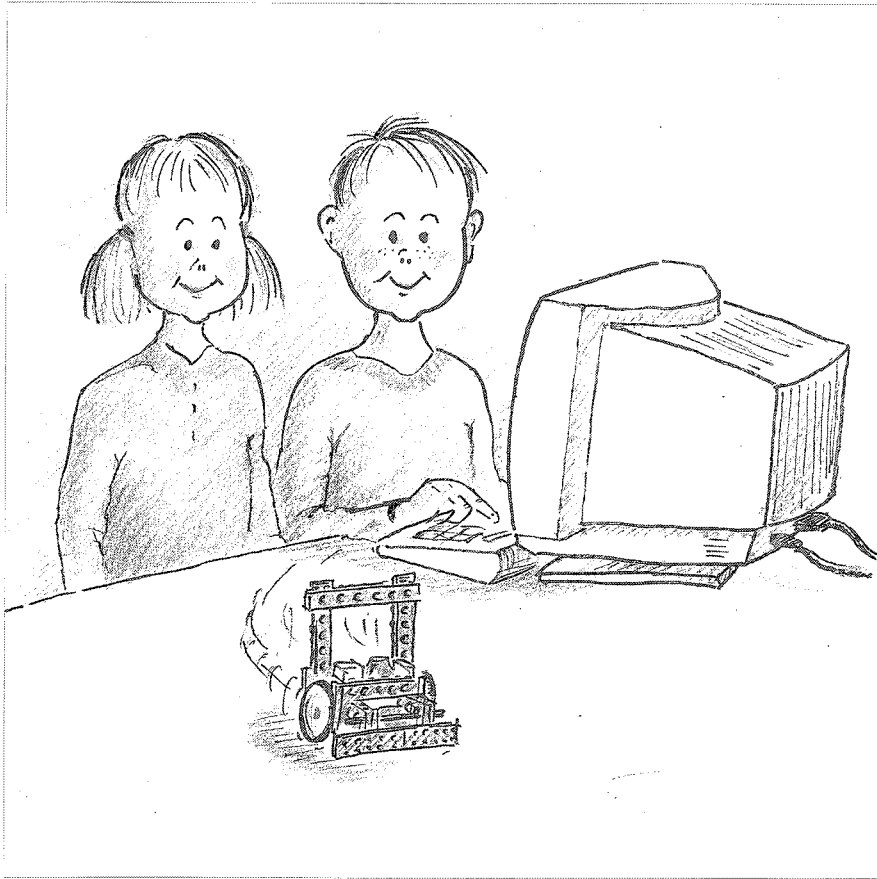


# Students' Problem Solving in the LEGO/Logo Learning Environment



Jyrki Suomala

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Students' Problem Solving  
in the LEGO/Logo  
Learning Environment

Esitetään Jyväskylän yliopiston kasvatustieteiden tiedekunnan suostumuksella  
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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 1999



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## ABSTRACT

Jyrki Suomala

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Finnish summary

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The study examines fifth-grade Finnish students' problem-solving in the LEGO/Logo learning environment. LEGO/Logo integrates Lego building blocks with the Logo programming language. The study analyses Seymour Papert's theoretical ideas underlying Logo and relates these ideas to current discussion of problem solving.

The subjects were students attending three primary schools (N = 198). The study consists of two parts. Part One studies the influence of LEGO/Logo learning on students' performance in tests that was built on Piagetian schemata, i.e., conserving of displaced volume, propositional reasoning, probabilistic reasoning, and mastering of permutation. The test arranged was a classroom test (Enkenberg 1989). Two research groups underwent different instructional procedures. The LEGO/Logo group (n = 103) participated in a 20-hour teaching phase, whereas the ordinary group (n = 95) participated in conventional teaching without the use of computers. Pre- to post test changes in test scores were compared for the LEGO/Logo group and the ordinary group. In this way it was possible to assess the influence of LEGO/Logo on the students' general, context-independent problem-solving skills.

Part Two studies the LEGO/Logo group's problem-solving processes. The LEGO/Logo group was divided into two learning groups. The mediated group (n = 48) received teaching according to the mediated model, whereas the discovery group (n = 56) was taught according to the discovery model. The 20-hour-long teaching programme consisted of the *merry-go-round* - and the *robot* projects. After the teaching period a section of the students in the mediated LEGO/Logo group (n = 42) and in the discovery LEGO/Logo group (n = 46) participated in the experiment phase, which consisted of an open LEGO/Logo problem-solving task. The task involved programming the Lego robot to follow a certain route. The students' problem-solving processes were videotaped and the subsequent analysis was based on measures developed by Clements and Nastasi (1988). This analysis focuses on the occurrence of *cognitive conflict solving*, *cooperation with teacher* and *explicit planning*. In addition, the relationship of problem solving to prior experiences of Logo and to the students' school achievement and gender was studied. The study also reports on the analyses of the Logo programs developed by the students during the experimental phase and their relationship to the students' problem solving.

The development of Piagetian thinking was independent of the instructional model, gender and school achievement. However, the results of the study indicated that learning model, gender, and thinking level, as well as interaction between the learning model and prior experience, accounted for group differences in LEGO/Logo problem solving among students. Overall the results were interpreted as supporting the validity of the discovery learning model, when students are solving problems in a progressive learning environment. The student's role as an active learner during progressive problem solving should be respected by the teacher but, at the same time, the teacher should provide appropriate support in those situations where students encounter insuperable problems during problem solving.

Key words: LEGO/Logo, problem solving, learning environment, computers in education, educational psychology

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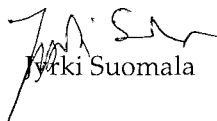
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# 1 INTRODUCTION

The present dissertation discusses children's problem-solving in a LEGO/Logo learning environment. LEGO/Logo integrates Lego building blocks, controllable motors, and interactive sensors with the Logo programming language (Harel & Papert 1991; Papert 1993). Although Logo<sup>1</sup> is a programming language, it was developed by Papert especially as a learning environment for children (Papert 1980; 1993). Logo is intended as a suitable tool to learn problem-solving skills. With Logo Papert tries to combine children's natural activity with the higher-order thinking process. This book describes some current issues in research on learning problem-solving skills in school.

The acquisition of the problem-solving ability has been regarded as a primary goal of general education in the information society (DeCorte 1990; Palumbo & Palumbo 1993). Learning of the problem-solving skills is, along with cognition, a complex social and motivational process (Pintrich, Marx & Boyle 1993). In this process, success is composed of both the cognitive skills of problem-solvers and the problem-solving environment (Berg & Calderone 1994; Ceci & Roazzi 1994; Chi, Glaser & Rees 1989). The principle that cognition interacts with contextual factors has been allowed in general, but there are few studies of this interaction (L.B. Resnick 1989). This complexity of the learning situation sets new demands for educational research and practice.

Traditional problem-solving research is concerned with individuals' cognitive processes derived from well-defined experiments (Bereiter & Scardamalia 1993; Simon 1994). Most studies of problem solving attempt to minimize - at

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<sup>1</sup> LEGO/Logo includes traditional Logo primitives (*if*, *repeat*, etc.) and 20 new primitives suitable for the LEGO environment (such as *on*, *off*, and *talkto*). The old "floor turtle" and "screen turtle" have been replaced with legopieces, which gives more opportunities for students to create programming objects. Papert has developed LEGO/Logo with his colleagues Martin Resnick and Stephen Ocko (M. Resnick 1996). However, despite differences between the old Logo and LEGO/Logo, both learning environments are based on the same theoretical ideas, presented by Papert (1980, 1993). The newest product of "Logo family" is LEGO Mindstorm (see: <http://www.legomindstorms.com/>).

every stage of the discovery process - the mutual influence of cognition and context for the sake of experimental rigor (Dunbar 1997; Klahr & Dunbar 1988; Salomon 1993). In addition, the tasks are usually very artificial. However, this "traditional " strategy has yielded many important findings about problem solving, but much remains to be learned about how different parts of the problem solving interact and about how the interaction is influenced by educational prompts. In authentic, open problem-solving experiments the variables concerning the learner, the social interaction and the situational variables (material, the problem, the tools, etc.) shape the complex combination of the situation (Järvelä & Enkenberg 1995; Klahr & Dunbar 1988; Perret-Clermont 1993; Salomon 1992; Schneider & Pressley 1989; Snow 1994). Learning in an open problem-solving situation depends on cognitive skills and also on the students' motivational and social skills (Järvelä & Enkenberg 1995). In the open learning situation the problem space is large (Holyoak 1991; Newell & Simon 1972) and the learners can choose many different sets of operators, which change the problem situation from the initial state to the goal state (Newell & Simon 1972). In the unstructured problem-solving situation the learner can decide also what is the initial state and what is the goal state.

The goal of the work described in this dissertation is to extend earlier studies by investigating problem solving in a context that requires a rich interaction among the processes of the social, motivational and cognitive parts of problem solving. Based upon the analysis of subjects' problem-solving behavior in this situation, I propose a framework that integrates the problem solving processes, and then I try to use it as a basis for reinterpretation of some important issues in the area.

Papert's main arguments concerning the Logo learning environment are, first, that it is possible to learn according to the principle of natural learning in the Logo learning environment and, second, that this natural learning process develops children's problem-solving skills (Papert 1980; 1993). Papert's arguments have been studied by many researchers and it is not clear what children really learn with Logo (DeCorte 1993; Lehrer & Littlefield 1993; Verschaffel 1989; Watson, Lange & Brinkley 1992). A question which has arisen is: what kinds of instructional mediation promote success in problem solving in the Logo environment? The origins of the answer to this question come from two expressed sources.

First, the original idea of Logo is that the self discovery approach and the solution of cognitive conflicts leads to the development of problem-solving skills (Papert 1980; Papert 1993; Harel & Papert 1991). Second, there are researchers who hold that the primary mechanism for the development of problem-solving skills is interaction between the teacher and students. Through this interaction the teacher mediates the right way to solve problems to the students. This assumption is based on both Vygotsky's theory of cognitive development (Lehrer & Littlefield 1993; Lehrer & Randle 1987; Miller & Emihovich 1986; Volet & Lund 1994; Watson et al. 1992) and modern cognitive science, which emphasizes the meaning of the mediation of expert's knowledge and strategies for children (DeCorte 1993; Enkenberg 1993; 1994; Verschaffel 1989). In these cases, experts' knowledge and strategies are based on mental models of how different heuristic methods are

used, such as means-ends analysis, global planning and problem decomposition (Holyoak 1991; Mayer 1992a). While both of the above groups of Logo studies have shown the beneficial effects of students' problem-solving skills upon a structural problem-solving situation, little is known at present of the effect of a different learning model in the open problem-solving situation.

The purpose of the present study is therefore to compare the effects of the mediated model of learning and the discovery model of learning on students' problem-solving processes in the open LEGO/Logo problem situation. Previous research has shown that the learning processes of students in a Logo learning environment include more desirable features of problem solving, such as cognitive conflicts, cooperation and effectance motivation, than in a structured CAI (Computer Assisted Instruction) learning environment (Clements & Nastasi 1988; Clements & Nastasi 1992; Nastasi & Clements 1993). The goal of this study is to test Papert's theoretical ideas in a Finnish primary school, but at the same time to supervise the effects of Logo programming in a systematic way in the open problem-solving situation using a systematic observational procedure.

The basic presupposition of this study is that the LEGO/Logo learning environment exemplifies the dynamic learning environment, in which students can learn to work at the limit of their own competencies. This means that continually during the learning process students encounter novelty problems, in which their current cognitive competencies do not match the demands of the task. In other words, students first learn to encounter cognitive conflicts and, second, to solve those cognitive conflicts in adequate ways. Bereiter and Scardamalia (1993) call the process in which learners work at the limit of their competencies progressive problem solving. Progressive problem solving requires extensive domain knowledge, understanding when to use the knowledge, and metacognitive monitoring and control. Bruer (1993) argued that students who are capable of applying progressive problem-solving skills to the novelty problem situations are intelligent novices and expert learners<sup>2</sup>. In a research sense, this starting point opens a new problem space for the researcher, in which dynamic student-teacher and student-student interaction can be studied.

The essential idea concerning LEGO/Logo is that this learning environment includes so many concrete, familiar components for children that at the beginning of the learning process, children do not feel the learning to be demanding. However, the Logo programming language has demanding features similar to other computer languages. Those demanding components are, for example, the repeat command, the use of subprocedures, the idea of recursions and the use of variables. A very topical question is whether students can profit from the

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<sup>2</sup> One of the most essential research areas during recent decades in the cognitive learning psychology has been novice-expert studies. However, the problems of expert-novice studies are, that they give very static picture of the nature of expertise. In addition, these studies do not clarify how the novice develops to the expert and what is the role of education in this process. The new concepts "intelligent novice" and "expert learners" emphasize the need for continuous learning as determinant of coping behaviour in novelty problem situations (Bereiter&Scardamalia 1993; Bruer 1993; Eteläpelto 1998). Because the LEGO/Logo is a combination of simplicity and complexity, it can be supposed, that this learning environment is one possibility, in which students can learn cognitive skills essential for intelligent novices.

familiarity and concreteness of LEGO/Logo in acquiring those demanding components in the LEGO/Logo learning environment?

This dissertation studies the problem-solving processes of fifth-grade Finnish students in the LEGO/Logo learning environment. The study includes two parts. Part one studies the influence of LEGO/Logo learning on students' ability as revealed in a test designed on the basis of Piaget's theory. In this way it was possible to assess the influence of LEGO/Logo on the students' general, context-independent problem-solving skills.

Part two studies the LEGO/Logo group's problem-solving processes. In this case students were given either mediated LEGO/Logo teaching (the mediated LEGO/Logo group) or discovery LEGO/Logo teaching (the discovery LEGO/Logo group). After the teaching period students participated in the open LEGO/Logo problem-solving situation. In this situation the students' problem-solving processes were videotaped and the analysis focuses on what kind of behavioral features significant for problem solving can be discerned in the learning processes. In addition, the connections of the problem-solving processes to prior experiences of Logo and to the students' school achievement and gender are studied. Finally, the study reports on the analyses of the students' Logo programs and its relationship to the students problem solving process.

## **2 LEGO/LOGO-LEARNING ENVIRONMENT**

In this chapter I begin by describing the features of the LEGO/Logo learning environment in practical terms. I then proceed to examine Papert's main hypothesis concerning learning with Logo and then I conclude by presenting the results of Logo research.

### **2.1 The Features of LEGO/Logo**

LEGO/Logo is a combination of LEGO building blocks and the Logo programming language. The LEGO/Logo learning environment consists of LEGO building materials, an interface box with interface card, a transformer, a personal computer and the Logo computer program (See Fig. 1). In addition, it is possible to provide a teacher's guide, student booklets and a student activity card. The LEGO building materials comprise various technical LEGO building blocks, beams, gears, axles, wheels, controllable motors and interactive sensors. The LEGO robot in Figure 1 includes two motors, one controllable touch sensor and two lights. The transformer is connected to the interface box and it provides electrical power for the LEGO motors and lights. By means of Logo programming it is possible to control the LEGO machines. (M. Resnick, Ocko & Papert 1988).

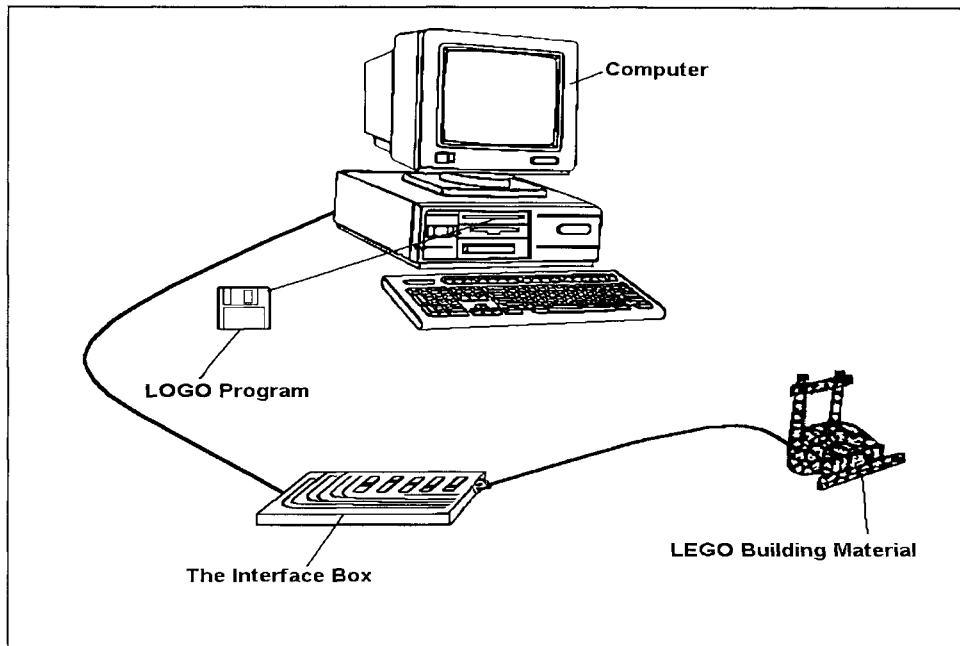


FIGURE 1 The LEGO/Logo learning environment

TABLE 1 An example of a Logo program which controls the LEGO robot

LINES	COMMANDS	EXPLANATION
Line 1	TO PETER	Name of the programme
Line 2	TALKTO [4 5]	Talk to both lights
Line 3	FLASH 1 2	The lights begin to flash
Line 4	TALKTO [A B]	Talk to both motors
Line 5	ON	Turn on the motors
Line 6	LISTENTO 6	Listen to the touch sensor
Line 7	WAITUNTIL [SENSOR?]	Wait until sensor is pressed
Line 8	OFF	Turn off the motors
Line 9	TALKTO [4 5]	Talk to both lights
Line 10	OFF	Turn off the lights
Line 11	TONE 262 1	Play note C 0,1 second
Line 12	TONE 294 2	Play note D 0,2 second
Line 13	TONE 330 3	Play note E 0,3 second
Line 14	END	End of programme

The program *Peter* controls the LEGO robot, presented in Table 1, in the following way. The robot has two lights built into it, which are connected to the computer via port 4 and port 5 of the interface. Two motors have been connected to the computer via port A and port B of the interface. Ports 4 and 5 have first been opened with the command TALKTO [4 5]. After this the command FLASH

causes both lights to flash until they are stopped (Lines 9 and 10). The command TALKTO [A B] opens the line to both motors, after which the line is open for the command ON and the motors begin to operate until they are stopped (Line 8). In line 6 the command LISTENTO 6 opens input port 6 and then the command WAITUNTIL[sensor?] is initiated and remains operative until the robot runs into a wall. After the robot crashes, the computer begins to read line 8 and the motors turn off. The lights then turn off and three notes are played at the end of the procedure.

This example comes from the teaching phase which is part of this study. This kind of problem context is multivariable in nature and it is easy to notice that the programming of this kind of Logo procedure is a very complex problem-solving process for eleven-year-old students. However, this procedure controls a concrete object - the robot - and this concrete object makes the programming process easier for the children than the multivariable context usually does. In addition, recent research has shown, that students at this age begin to develop skills to cope with problem-solving environments, which are multivariable in nature (Kuhn, Schauble & Garcia-Mila 1992; Klahr, Fay & Dunbar 1993).

The robot has been constructed by children and they immediately see the effect of their own program. Thus, the demanding thinking process and hands-on experiences are connected in the LEGO/Logo learning environment. Students get visible feedback from the action of their procedures and this makes a revision cycle possible, if it is necessary. Unlike problem-solving tasks in schools, in the LEGO/Logo environment problem solving has a concrete goal. In this project-oriented work Papert's learning theory should be realized. For example, even 4-year-old children can learn 10 Logo commands in the screen Logo version and they can move the "turtle" almost anywhere on the screen (Watson et al.1992).

The LEGO/Logo learning environment is considered to be based on learning ideas of constructivist and situated cognition (Enkenberg 1993; Järvelä 1996a; Järvinen 1998; Suomala 1993; 1997). According to this point of view the LEGO/Logo learning environment is an example of a complex learning environment where thinking, learning and exploration are connected with one another in a creative way (Enkenberg 1993; Järvelä 1996a). It is reasonable to assume that the LEGO/Logo learning environment is an example of a dynamic learning environment, in which progressive problem solving is possible (Futschek 1997a, 1997b; Järvinen 1998). How, then, is the activity in the LEGO/Logo learning environment different from traditional school lessons? In the next section I try to answer this question with regard to the main ideas of Papert's hypothesis.

## 2.2 Papert's hypothesis concerning learning

Although Logo is a programming language, it was developed by Papert principally as a learning environment for children (Papert 1980). From a broad perspective, Papert's learning theory can be regarded as one interpretation of the general constructivist view of learning. The general constructivist perspective assumes that learning is always based on one's current cognitive resources (von



Glaserfeld 1989) and one's own interpretation of the situation (L.B. Resnick 1989). Papert calls his approach constructionism (not constructivist), because he emphasizes the learner's own participation in the meaningful learning projects more than the general constructivist point of view does (Papert 1991). One essential feature of the constructionism aspect of learning is that students are actively involved in creating and constructing meaningful products. In the LEGO/Logo learning environment - as in any other constructionism learning environment - students can work like "real" scientists and "real" inventors. Learning in the authentic situation helps students to care about their own work, in contrast to the normal situation in a conventional classroom (Martin & M. Resnick 1990).

Many researchers have regarded Papert's ideas behind Logo more as anecdotes and assertions than as an explicit learning theory (Pea & al. 1987; Yusuf 1995). Logo is a thinking tool especially for general school education, not for experimental psychology. The holistic point of view in Papert's books and articles is expressed in such a way that it is sometimes difficult to know what Papert really intended. When Papert emphasizes the holistic nature of learning, he at the same time criticizes traditional psychological tests. Papert asserts that the essential mental changes occur outside experimental test situations. He based this argument on his own childhood experiences. In his childhood he often played with an old discarded car. He remembers his childhood experiences of the gearbox:

... , I remember that my first encounter with them was in my second year. If any "scientific" educational psychologist had tried to "measure" the effects of this encounter, he would probably have failed. It had profound consequences but, I conjecture, only very many years later. A "pre- and post- test" at age two would have missed them. (Papert 1980, viii).

Papert has solved the problem of methodology by further developing the clinical method based on Piagetian and psychoanalytical theories (Turkle & Papert 1993). It includes case studies based on participant observation in real learning situations. Extensive descriptive documentations of children's learning provide a rich picture of Papert's ideas concerning learning with Logo. However, the problem with Papert's research method is that he based his own arguments on the observations collected in nonsystematic conditions. Especially students who are not interested in working with Logo, remain outside of Papert's descriptions (Hawkins 1987, Pea & al. 1987, Suomala 1996). The goal of this study is to test Papert's theoretical ideas in a real Finnish primary school, but at the same time to examine the effects of LOGO programming in a systematic way in an open problem-solving situation.

The main goal of Papert's ideas concerning the learning is to combine, by means of Logo, children's natural activity with the development of problem-solving skills. His learning theory has two main sources: first, the concepts of natural learning and, second, Papert's own experiences of programming in Artificial Intelligence (AI) projects in MIT in the 1960s.

Papert's first assumption is that educational interventions have to be based on the students' *natural learning*. Natural learning refers to a learning process in

which an individual adopts knowledge in his/her surroundings without systematic teaching. The essential point in natural learning is that children can themselves choose the object of learning and the use of learning material.

According to Papert, people learn an enormous number of things according to the principle of natural learning (Papert 1980). A typical example of natural learning is the learning of the mother tongue. It is typical of such learning that it is intertwined with emotional experiences, with a high level of motivation, and that it is very personal in nature. Natural learning often happens in a social situation. Papert elucidates the significance of culture in learning by means of the concept of "*Mathland*" (Papert 1980; 1986; 1987). In *Mathland*, mathematics is learned as easily as the French language is learned in France. The Logo environment is one example of a *Mathland* in which children learn the models of systematic thinking in a natural way. The teacher should not plan or give the learning task in too ready a form for the children. Papert supposes that in the LEGO/Logo learning environment, the learner has enough motivation and capacity to decide without conscious intervention what is a suitable goal of learning.

Papert's view of natural learning converges at several points with other approaches that emphasize the significance of culture in the learning process. For instance Cole and Cole suggest that the child's development has as its prerequisite the acquisition of models that operate within a culture (Cole & Cole 1989). According to Wartofsky, an individual constructs his/her own cognitive models of cultural artifacts (Wartofsky 1979). These artifacts include linguistic models, objects, tools, rules of behavior, and models of thinking. According to Papert the LEGO/Logo environment is an example of an environment in which students can learn thinking skills according to the principle of natural learning. In such a situation, Logo serves as a new cultural artifact produced by the information society - an artifact by means of which children can learn cognitive models according to the principle of natural learning. When many new interpretations of cognitive learning psychology (Collins, Brown & Newman 1989; Järvelä 1996a; Lehtinen, Vauras, Salonen, Olkinuora & Kinnunen 1995) emphasize, that learners' activity and orientation toward learning are developed by instructional actions, Papert's main assumption is that the children are active by nature. Natural activity in Papert's sense does not mean that the acquisition of higher order thinking is a short, or easy process. On the contrary, the process is long and for that reason the learning process has to be based on children's natural activity. According to Papert, the problem is that learning situations in schools do not give enough room for the children's natural activity and this could lead to inappropriate learning action.

It may be fruitful to consider the difference between naturally occurring learning and learning occurring by systematic education. In general, the goal of the whole public school system is an advance over what comes naturally. However, an advance over what comes naturally may be also a characteristic of the individual. Those individuals are experts who continually try to work at the edge of their competence (Bereiter & Scardamalia 1993). The problem is, how can we educate growing students so that each "natural" learning process includes expert like thinking in Bereiter's and Scardamalia's sense. When we observe

childrens' free playing in the sand box or when they build themselves a cabin, we can see how they take care of their "projects", how they can concentrate on long-term creative processes and how they solve problems which interest them. They make use of the environmental impetus in their "natural" problem-solving processes. But why are the same children not capable of behaving in the same way in the academic context? The idea of Logo is to provide students with an opportunity to achieve problem-solving skills which do not occur naturally without systematic educational arrangement. But we need information on what the psychological mechanisms concerning development are. Thus, Papert's view is that we can plan good learning environments, in which we can influence the "natural" psychological mechanism of the students' development. But the question concerning the nature of the natural psychological mechanism, is yet unsolved.

Natural learning can thus refer to two different interpretations. The first alternative is that effective thinking, learning, and problem solving are fixed at birth and that there is nothing one can do to change them (Vye, Delclos, Burns & Bransford 1991). The second interpretation is that people can be helped to improve their abilities to think, solve problems, and learn on their own. The latter interpretation is the starting point of this study. Also Papert's ideas concerning to Logo are based on the assumption that with suitable educational intervention children's development can be helped. But this intervention must give enough room for children's free discovery. Pea (1993) argued against Papert's natural learning assumption by saying that the LEGO/Logo learning environment includes so much "invisible" human intervention, that it is not realistic to say that students' "free-discovery" is possible in this environment. Pea means that designers of LEGO and Logo demand certain types of behavior from students (interlockable components of LEGO machines and the Logo primitive commands for controlling these machines). This means that LEGO/Logo constrains what actions are possible with the parts in combinations. Pea points out that it does not make sense to regard the teacher's intervention as a block to the child's free discovery when, at the same time, we overlook the impact of the designer (a kind of artifact-based intelligence contributing to the child's achievement of activity) on the child's activity in the LEGO/Logo learning environment (Pea 1993).

The second assumption in Papert's learning theory is that the correction of the errors during the learning process may facilitate the development of children's thinking. This assumption is based on Papert's own experiences of AI projects. Papert participated in various AI projects during the 1960s. In the projects he noticed that when he and his colleagues were programming, they also made errors. During the correction process they began to think about their own thinking. The programming process constrained them to use metacognition. Papert has applied these insights into the programming process in Logo. In the Logo learning environment, programming includes a great number of correcting processes ("debugging") and those processes encourage students to use metacognition, which is fruitful for the development of problem-solving skills (Papert 1980). Working with Logo makes the thinking process concrete. During the correcting process programmers can also discuss freely and in this way social interaction contributes to the development of problem-solving in a natural way.

With Logo, Papert aimed at bringing children's personal activity, social interaction and previous everyday experiences to bear in the learning of problem-solving skills.

Emphasis on the meaning of errors and on metacognition in the learning process combines Papert's hypothesis with many learning theories. Cognitive conflicts have been regarded as central to the developmental process (Dehn & Schank 1982; Piaget 1963). For example, the process of equilibration in Piaget's cognitive theory refers to the situation in which, an individual must change his/her mental structure so that it matches the demands of the environment. Markman (1977) also emphasizes the fruitful effect of errors for the use of metacognition (Markman 1977) and in Sternberg's triarchic theory of intelligence, the use of metacognition is a central part of intelligence (Sternberg 1985).

In addition, the discrepancy between learner's current understanding and new information, has been regarded as one of the most critical phases both in the scientific discovery process (Dunbar & Klahr 1989) as well as in the children's learning processes (Chinn & Brewer 1993; Niaz 1995; Vosniadou 1994). The solution of cognitive conflict, or debugging of the Logo program in this particular case, are, however, a very complex cognitive skills. Successful solution of cognitive conflict requires a mix of content-specific knowledge and general problem-solving skills (Klahr & Carver 1988). For example, in the Logo context, research has shown that when children are confronted with buggy programs, most children prefer to abandon them and start over rather than debug them (Klahr & Carver 1988). Contrary to the Papert's hypothesis, Klahr and Carver argued that it is not possible to achieve complex debugging skills without explicit teaching.

In summary, then, Papert's ideas on learning includes two suppositions. First, the supposition that children learn optimally according to natural learning and, second, that programming with Logo fosters the use of metacognition. The following chapter discusses the meaning of natural learning for the acquisition of problem-solving skills in the LEGO/Logo learning environment.

### **2.3 The programming process in the LEGO/Logo learning environment**

The LEGO/Logo learning environment offers many opportunities for approaching programming. Turkle and Papert (1990) divide programming styles into two categories: formal and concrete. *The formal programming style* refers to the traditional scientific approach to solving problems. Turkle and Papert (1990) describe this programming style as rule-driven programming, which includes clear control through structure and planning. The content of programming is regarded as abstract knowledge, which can be handled with the help of formalized rules (M.Resnick & Ocko 1991). In Western science this kind of thinking is regarded as the most effective and highest level of knowing. In programming terms, this style means that the programmer divides the problem into clear modules and subprocedures. M.Resnick and Ocko (1991) call this kind of style analysis. The formal style is well known as a goal of schooling. Polya's

(1973) rule for problem-solving - divide and rule - is a famous slogan that refers to this kind of style. Turkle and Papert connect the formal style to individual work and a clear plan for eliminating errors during the programming process. Previous research concerning the differences between expert and novice programmers has found that the expert problem solver concentrates his/her attention on the whole problem (Andersson 1995; Vessey 1985). Vessey (1985) calls this approach a *breadth first* planning strategy and this strategy leads to high-level modules in planning.

One example of formal programming style is from the Austin School Logo project, described by Turkle (1984, 98-102). Students used screen Logo in this project. One of the student who took part in this project was Jeff. He had a typical formal programming style. He was in the 4th grade of an elementary school and he was an expert with the computer. Jeff was precise in all of his actions and he wanted to use the formal style when working with the computer. The starting point of Jeff's programming was a detailed and precise plan for a space-shuttle. It included a rocket, boosters, a trip through the stars and a landing. Jeff then divided this plan into several subplans and systematically carried out each subplan using Logo. Jeff's formal programming style resembles the top-down method and he represents the common conception of the mathematically oriented student.

*The concrete programming style* does not include clear planning and decomposition during programming. Turkle and Papert (1990) use Claude Levi-Strauss' people type "bricoleur" to describe this kind of programming style (Levi-Strauss 1968). Levi-Strauss calls a bricoleur a scientist of the concrete in primitive culture. The bricoleurs construct theories by arranging and rearranging, by negotiating and renegotiating with a set of well-known materials (Turkle & Papert 1992). Usually this concrete approach has been regarded as an inferior way of knowing and this style has been considered a necessity by those who have not yet mastered the formal style. But Turkle and Papert give bricolage the same value as they give the formal style. Programming the computer using the bricolage way can be done as effectively as in the formal way. Turkle and Papert have found this kind of style typical of many students in their Logo projects. The student who uses the concrete programming style desires to play with the elements of the program like a painter with colours. In this case programming is a conversation between the programmer and the computer and errors are part of the essence of this kind of navigation. M. Resnick and Ocko (1991) call this kind of style design. When Turkle and Papert describe the problem-solving strategy of bricolage, they make analogies between bricoleurs and cooks as well as between bricoleurs and painters. They describe: "We have defined bricolage as a style of organizing work that invites descriptions such as negotiational rather than planned in advance, what Warren McCulloch called "heterarchical" rather than hierarchical." (Turkle & Papert 1990, 144).

Second example describes the concrete style of nine-year-old Alex. He took part in an experiment using LEGO/Logo in the Hennigan Elementary School in Boston (Turkle & Papert 1993). Alex used wheels to make flat shoes for his robot. One motor was allowed to vibrate, thus moving the robot forward. When Alex programmed in Logo, he liked to keep things similarly concrete. Turkle and

Papert describe Alex's concrete style in following: "While the structured programmer starts with a clear plan defined in abstract terms, Alex lets the product emerge through a negotiation between himself and his material." (Turkle & Papert 1993, 50).

Previous research has found that the novice programmer uses a local planning strategy, in which s/he begins to write a new code before understanding the whole problem (Andersson 1995; Vessey 1985). Vessey calls this planning strategy *depth first* and typical of this strategy is that it leads to unfocused and accidental planning.

Whereas Papert regards both programming styles - concrete and formal - as equally efficient, studies in cognitive sciences have found that the concrete style (*depth first*) is an essential characteristic of the novice problem solver, whereas the formal style (*breadth first*) is characteristic of the expert problem solver (Andersson 1995; Vessey 1985)<sup>3</sup>.

Most case studies described both by Papert (1980, 1993) and Turkle and Papert (1990, 1992, 1993) illustrate the concrete style. Subjects were both children and adults. They also compare the programmer with a concrete style to the writer who starts with one idea, associates it with another, and discovers a connection with a third. According to Papert the difference between bricoleurs and planners is not the quality of the product; it is in the process of creating it. Papert contends that bricolage is a way of organizing work, not a stage. The style refers rather to personality than to developmental level. Similarly formal reasoning is not a stage, but a style, suitable for a certain personality-type (Turkle & Papert 1990). According to Papert it is important that people can choose different ways of approaching the same object. Object-oriented programming and closeness to object makes concrete and associational styles possible, but it does not exclude the possibility of using a formal one (Turkle & Papert 1990). In addition, Turkle and Papert (1993) assert that the programming style of females resembles the concrete style more than the programming style of males, which accordingly more resembles the formal programming style (Turkle & Papert 1993).

In the LEGO/Logo environment students can solve programming tasks in their own way. It is possible to program using both a formal style and a concrete style. In Papert's case studies all children and students had a very high level of motivation to program with Logo. Does Logo really interest all students? Papert does not give a clear teaching method for teaching Logo. But he gives the teacher ideas on how to organize Logo working in classes so that children can learn in an optimal way.

Papert's conception of optimal learning does not include problem-solving rules (Papert 1993). The problem situation should be planned in such a way that

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<sup>3</sup> Papert describes different ways of programming by calling them 'styles'. In contrast, most other studies of different programming methods - or at a more general level problem-solving - call these different routes 'strategies'. 'Style' refers more to the individual's personality than cognitive capability, whereas the term 'strategy' refers in cognitive science more to the individual's cognitive capability. The problem from Papert's point of view is, that he regards programming style as an indicator of personality, but he has not tested this idea with any personality test.

students' problem solving fosters their thinking. This kind of learning refers to the concept of mathematics. Papert explains this as follows:

What is mathetic here is the shift of focus from thinking about whether the rules themselves are effective in the immediate application to looking for multiple explanations of how working with the rules can contribute in the longer run to learning. (Papert 1993, 87).

Papert suggests some general preconditions for optimal learning in the LEGO/Logo learning environment: The possibility to choose the goal of learning, the possibility to play with learning material and the possibility for social interaction during learning. *The possibility to choose the goal of learning* oneself means that students can themselves create the problems and the programming method to solve those problems. With their own goal and own method it is possible that students can learn with a suitable personal style. Perkins (1993) also argues that the big failing of the educational system is that students can seldom, if ever, select problems in the school themselves. In addition, Bereiter and Scardamalia (1993) have analyzed the action of different types of teachers in relation to the student's learning process. The traditional teacher religiously chooses the content, method and goal of the students' learning, whereas the new teacher gradually gives the students responsibility for these cognitively demanding tasks. Bereiter's and Scardamalia's idea of the new role of teachers in the classroom is mainly consistent with Papert's idea. But there is a considerable difference between ideas concerning the moment when the child is ready to take responsibility for the learning process. According to Papert natural learning means especially that children are capable of choosing the content and method as well as the goal of their learning process by nature, if they feel the learning to be meaningful.

*The possibility to play with learning material* means that students can take their time with LEGO material and a Logo-programming task (Papert 1993). In this case Papert applies Polya's first problem-solving rule, in which Polya advises the student to remember previous known problems when they encounter a new problem (Polya 1973). When Polya's rule has usually been applied in schools in such a way that the teacher has taught students to compare different problems with one another, Papert's interpretation of Polya's first problem-solving rule is very unconventional, because the comparison between the new problem and the old problem happens through playing.

*The possibility for social interaction* during learning means that children can freely discuss together and also with the teacher (Papert 1980; Papert 1993). Harel and Papert describe the phenomena of optimal learning:

A narrow description of our intention in doing this is that we wished to turn the usual tables by giving the learner the active position of the teacher/explainer rather than passive recipient of knowledge; and the position of designer/producer rather than consumer of software. This idea is in line with Constructionism's use of "building", "constructing," or "knowledge-representing" as central metaphors for a new elaboration of the old idea of learning by doing rather than by being told ("Constructionism" rather than "Instructionism").(Harel & Papert 1991, 41).

The three preconditions for optimal learning described above lead to a conflict situation, which is important for the development of problem-solving skills. Papert regards the child as active and goal-oriented, if the learning environment is suitable.

## 2.4 The results of Logo studies

The results of Logo studies give contradictory answers to the question of whether Papert's hypothesis on the development of the problem-solving skills and children's natural learning in open Logo situations has actually been confirmed. Some of the studies seem to show clearly that Logo facilitates the use and development of higher-order thinking processes (Battisa & Clements 1986; Clements 1986a, 1986b, 1990, 1991; Clements & Gullo 1984; Genishi 1988; Hughes, MacLeod & Potts 1985; Kull 1988; Lehrer & Randle 1987, Littlefield, Delcos, Bransford, Clayton & Franks 1989; Mayer & Fay 1987; Nastasi & Clements 1993). However, there are also several studies, which seem to refute Papert's argument (Geva & Cohen 1987; Hawkins 1987; Nielsen 1986; Pea & Kurland 1984; Pea et al. 1987; Siann & MacLeod 1986). At the same time there are also studies showing that children's problem-solving skills develop, if children get suitable support from the teacher (Emihovich & Miller, 1988a, 1988b, 1988c; Klahr & Carver 1988; Lehrer, Guckenberger & Lee 1988; Lehrer, Guckenberger & Sancilio 1988; Miller & Emihovich 1986; Versachaeffel 1989; DeCorte, 1993). Instead of supporting the student's self-discovery in Logo learning, these studies suggest the use of more directed teaching in the Logo environment. For example, King suggests direct instruction for Logo teaching, because in this way, the teacher can assist students in the use of suitable problem-solving strategies and contribute to developing students' skills to ask task-related questions during Logo programming (King 1989).

Palumbo and Palumbo (1993) have shown that students who learn to program in the LEGO/Logo learning environment made significant gains on the Raven's Progressive Matrix measure. This test measures the ability to form comparisons, to reason by analogy, and to organize spatial perceptions into systematically related wholes. All these abilities are essential parts of the problem-solving ability (Palumbo & Palumbo 1993).

In Lai's study (1993), students increased their metacognitive awareness during LEGO/Logo learning period. Younger students (8-9 years old) increased their metacognitive awareness more than older students (10-11). In addition, the same study showed that learning in a LEGO/Logo learning environment increases students' higher-order thinking skills, such as self-monitoring and evaluation (Lai 1993). It is noteworthy that in Lai's study students learnt to program in Logo using the discovery learning model. In addition, girls and boys increased their higher-order thinking score by the same amount during the LEGO/Logo period. Attitudes of different genders to the use of computers changed toward more equality during the treatment period (Lai 1993).



Papert regards children as active and as self-directive in the Logo environment. The teacher's role is to support children's own discovery and projects. Children can use different styles during programming, but the differences are not between quality of process, but between the different personalities. On the one hand, the case studies of students' learning processes in the Logo environment described by Papert and his colleagues provide a picture - maybe one-sided - of active students in the open Logo learning environment. On the other hand, Logo studies which have used a carefully chosen sample of students have not analyzed the students' learning process in an open learning situation. However, programming with Logo is, like problem solving in general, more a set of activities that search for a solution, and not merely an outcome (Palumbo & Palumbo 1993). In the next chapter I try to clarify the meaning of the concept of problem solving and the relationship between the development of problem-solving skills and different kinds of instructional interventions.

### **3 HUMAN AS A PROBLEM SOLVER**

This study considers Logo programming as a problem solving activity. In chapter 2 I described the two main hypotheses of Papert with regard to learning with Logo. First, Logo provides an opportunity for natural learning and, second, that natural learning leads to the development of problem solving skills. The assumption that problem solving skills progress in the Logo learning environment is based on the following idea. The natural learning process leads students to situations in which there is a discrepancy between their current understanding and the demands of the task. These discrepancies are caused especially when students make errors during their Logo programming processes. Thus, the concept of problem solving is fundamental when trying to answer questions concerning the benefit of LEGO/Logo in school learning.

This chapter begins with a description of the concept of problem solving. First, I describe the features of a problem solver in a problem situation and the features of a problem solving environment. Then I concentrate on the role of planning and the role of individual differences in problem solving. After that I deal with the relationship of learning and teaching in the school context.

#### **3.1 What does problem solving mean?**

##### **3.1.1 General background**

Problem solving has been regarded as the skill of finding a suitable way around difficulties when striving toward a goal which is not immediately attainable (Holyoak 1991; Mayer 1992a; Newell & Simon 1972; Polya 1973). Problem solving can thus be regarded as a search for a path from the initial state to the goal state. During this process the problem solver selects internal and external information and builds internal mental space, which control the searching process. Thus,

typical for problem solving is that it is a highly selective process. An essential criterion for selection is the functional role of the pieces of the information in the individual's thinking action (Saariluoma 1995; 1997). During this process a problem solver are using metacomponents, performance components and knowledge acquisition components of thinking (Sternberg 1985).

The ability to solve problems is one of the most essential features of a humans' skills (Holyoak 1991). Previously emphasis has been placed on context-independent general skills based on symbols structured in the problem solving (Newell & Simon 1972). This purely cognitive viewpoint tried to explain individual's problem solving behavior by information-processing, which can be implemented both with a computer and with a human. Currently, problem-solving research has emphasized the meaning of domain-specific knowledge, metacognitive skills, and general cognitive strategies in the problem-solving performance (Bruer 1993). However, the problem solving research is based on many different kinds of research traditions. The most recent is the movement of situated and distributed cognition, which emphasizes, that the performance of an individual problem solver is based on the social and the cultural determinant, not only on cognitive processes (Clancey 1993; Enkenberg 1994; Hatsch & Gardner 1993; Salomon 1993). However, when emphasizing only situational aspect of cognition, individual's prior experiences has been disregarded, and we can not achieve realistic conception of the learning of the problem-solving skills. Correspondingly, if we emphasize only human's mental processes, the nature of social part of human is overlooked. A complementary viewpoint comprising both the purely cognitive and the purely contextual has been emphasized in this study.

Problem-solving skills differ from other cognitive skills especially in two different aspects. First, with problem solving skills humans can encounter new, novel situations (Lesgold 1991). Even if encountering novel situations has been regarded as one of the most important feature of the problem-solving skill, empirical research into this feature has not been implemented much (Bereiter & Scardamalia 1993; Bruer 1993). At present it has been seen that the goal of school is to educate students to become intelligent novices and expert learners, who can encounter novel situations (Bruer 1993). In the same vein, the LEGO/Logo learning environment in this study has been regarded as an environment, in which students can learn to be expert learners. Second, in a problem-solving situation people have to apply all levels of knowledge (syntactic, semantic, schematic and strategic)<sup>4</sup>. Consequently the learner's prior knowledge and previous experiences have an essential role in the learning process concerning to problem solving. Mayer (1992a) has divided knowledge concerning program-

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<sup>4</sup> The concept of knowledge has many different meanings. Very often in cognitive learning psychology concepts like declarative knowledge, procedural knowledge and metacognitive knowledge have been used (Andersson 1995; Bruer 1993). In this study, it is convenient to use Mayer's knowledge classification (Mayer 1992a; Fay & Mayer 1994), because he has used it especially in his Logo studies. In fact, Mayer's classification includes the content of previously mentioned concepts. For example, strategic knowledge in Mayer's sense includes also metacognitive knowledge.

ming languages into four types. The following description is based on Mayer (1992a) and Fay and Mayer's (1994) explanation, as applied to LEGO/Logo. *Syntactic knowledge* refers to the lexical units and rules which combine programming language units. In LEGO/Logo programming language, the lexical units include keycommands (e.g. TALKTO, ONFOR and FLASH), letters (e.g. A, B and C) and numbers (e.g. 50 and 80). Combination rules include rules for ordering lexical units within a line such as, "TALKTO must be followed by a space and a number or a letter". They also include rules for ordering lines, such as "interface ports must be open before turning the motors or lights on". *Semantic knowledge* means that the programmer knows that, for example, TALKTO [A B] means that the computing system opens ports A and B of the interface but does not turn the motors on. *Schematic knowledge* refers to knowledge of types of subroutines, for example knowing several different ways of using music at the same time as the lights are on in LEGO/Logo programs. *Strategic knowledge* refers to knowledge of how to plan and monitor the LEGO/Logo program, such as breaking a program into modules. According to this classification, the problem solver has good planning skills, if he/she possesses a lot of strategic knowledge.

The combination of the problem solver and the environment appears in Newell and Simon's (1972) conception of problem solving. Newell and Simon's theory of problem solving has three main components: *the information-processing system*, *the task environment*, and *the problem space* (Newell & Simon 1972; Simon 1994). The information-processing system refers to an individual's cognitive resources, the task environment refers to the situation in which the problem solver works with the problem, and the problem space refers to the different possibilities for solving a given problem. Although Newell and Simon's theory of problem solving represents a purely cognitive viewpoint, the fact is, that the above-mentioned three basic concepts are still usable. In the following text, these concepts are described and reinterpreted by the writer. In this way, it is possible to relate Newell and Simon's problem-solving theory to the goals of this study and to the current viewpoint of situated and distributed cognition.

### 3.1.2 The information-processing system

*The information-processing system* refers to the problem solver's mental resources (Simon 1994). The structure of the information processing system includes three main parts, *sensory memory (SM)*, *short-term memory (STM)* and *long-term memory (LTM)*. SM is a temporary store and it duplicates the sensory inputs from the sense organs. A piece of information in SM can not be consciously processed until it is transferred to STM (Mayer 1993). In STM, a person can hold and/or manipulate several pieces of information in active consciousness (Mayer 1993). STM has been regarded as part of working memory<sup>5</sup> (WM). STM has a very limited capacity and this means that a person can actively think of only five to eight digits, symbols or other items at the same time (Mayer 1987, Simon 1974, Simon 1994). This limitation concerns both duration and capacity (Simon 1974).

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<sup>5</sup> The concept working memory (WM) emphasizes the control processes of STM. However, both concepts are used currently.

LTM is a permanent storehouse of an individual's existing knowledge (Mayer 1993). The capacity of LTM is unlimited and a person can be aware of the content of LTM by transferring knowledge from LTM to STM, where it can be consciously reviewed (Mayer 1993).

The information processing system includes four main processes: *selecting*, *organizing*, *integrating* and *encoding* (Mayer 1993). *Selecting* means that a learner pays attention to pieces of information in the learning environment. Through selection, pieces of information in SM are transferred and occupy space in the learner's consciousness in STM. From an educational point of view, the meaning of this process is "that when material is made more interesting, students pay more attention, that is, they select more information for active processing." (Mayer 1993, 262). By *organizing* a learner builds internal connections among the pieces of information that are in STM. From the learning point of view, the outcome of organizing "is to create logical links between pieces of information". (Mayer 1993, 262). By *integrating* individuals are building connections between incoming information and knowledge already in LTM<sup>6</sup>. The outcome of the integrating process is to find similarities between newly received knowledge and existing knowledge in LTM. From an educational point of view, the integrating process is more natural if the learner has domain-specific knowledge concerning the environment from which the new information is achieved. By *encoding* a learner transfers the knowledge constructed in STM into LTM for permanent storage (Mayer 1993). The information processing - selecting, organizing, integrating and encoding - can be done either consciously or automatically (Marcus, Cooper & Sweller 1996). With cognitive processes the learner builds an internal mental model from the environment. On the one hand, this mental model guides the learner's behavior and in this way influences selecting and organizing. On the other hand, this mental model is partially based on external information. The demanding question is what are the critical educational prompts which affect the cognitive processes in an appropriate way. The Piagetian research tradition and Vygotskian research tradition have given different answers to this question, a problem which will be returned to in chapter 3.4.

The contents of LTM, in which individual's prior knowledge is located, is a critical component in a problem solving situation (Marcus et al. 1996). For example, when people encounter a novel problem, they bring to bear a wide variety of prior knowledge in formulating their initial hypothesis about how to overcome the problem (Klahr & Dunbar 1988). In addition, the skill to solve problems depends on how the problem solver can select important information from the task environment in the STM. This skill develops as a child grows, but also experiences from similar situations can effectively develop skills to select and organize information by STM.

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<sup>6</sup> Ericsson and Kintsch (1995) have constructed concept long-term-working memory (LT-WM). LT-WM develops for experts and it includes a lot of domain-specific knowledge. In problem situation, an expert can "use" LT-WM automatically without conscious thinking.

### 3.1.3 The Task Environment

*The task environment* refers to the domain of problems. The features of the task environment evoke specific knowledge structures, activate context-specific strategies, and influence the subject's interpretation of the task itself. At present it is emphasized that the task environment and the individual's information processing system form an integrated system in which the cognitive skill becomes part of the context (Ceci & Roazzi 1994).

The task environments can differ from each other according to 1) the structural level of the task (well-structured/ ill-structured), 2) the familiarity of the task (familiar/novel) and 3) the concreteness of the task (concrete/ abstract). The problems can be either well-structured puzzle-like tasks or fuzzy, ill-structured tasks of large magnitude encountered in real life (Simon 1994). Most studies concerning problem solving have treated problem solving in a well-structured problem situation (Newell & Simon 1972; Simon 1994). A good example of this kind of structured problem task is Newell and Simon's (1972) missionary-and-cannibals problem. Well-structured problems are often presented in a psychological laboratory and may take only 15 minutes or less to solve, whereas ill-structured problems presented in real life may occupy a substantial part of the problem solver's waking time for years (Simon 1994). Many school tasks are well-structured. Students are seldom engaged in a learning process in which they themselves have to specify the goal of learning and in which they have to consider different possibilities for solving problems. Often they have only two choices, right or wrong. Education presupposes more information about problem solving in ill-structured problem situations. Schools have tried to develop learning environments in which students can learn to acquire problem solving skills in complex life-like situations. In those situations, the learning environment should include possibilities for students to set personal goals, actively handle and gather meaningful information, monitor and evaluate their own problem solving process (Collins et al. 1989; Järvelä 1996d; Wilson 1995). In those situations, students can work for many hours and try themselves to construct problems which they feel are meaningful (Enkenberg 1994; Järvelä 1995).

According to Voss, ill-structured problems presuppose from the problem solvers more use of metacognition and planning than well-structured problems do (Voss 1988; Voss, Blais, Means, Greene & Ahwesh 1989). Also Papert (1980; 1993) emphasizes that ill-structured problems give much space for the problem solver to use different problem solving styles. Thus, according to Papert, ill-structured problems are more meaningful for the problem solver. In this case, it is possible to solve problems with either a formal or informal style.

The degree of the problem's novelty determines the use of the different components of intelligence (Sternberg 1985). Sternberg (1985) divides intelligence into three types of information-processing components in his triarchic theory of human intelligence. These components are performance components, knowledge acquisition components, and metacomponents. The components work in a different way depending on the degree of novelty of the problem. In the purely novel problem-solving situation, the problem solver uses performance

components and knowledge acquisition components of intelligence. However, the role of the use of metacomponents is important in novel problem situations because metacomponents control the use of performance components and knowledge-acquisition components (Sternberg 1985). In a familiar problem solving situation, the problem solver copes by using metacomponents and performance components. According to Sternberg (1985), in familiar situations, the use of metacomponents and performance components is automatic and metacomponents control the use of performance components (Sternberg 1985). Thus, metacomponents have an important role both in a novel and in a familiar task environment. They serve as a strategy construction mechanism, orchestrating the knowledge acquisition components and performance components.

The novelty of the problem requires solutions that cannot be simply retrieved from memory (Gardner & Sternberg 1994). A problem solver should discover a new solution from existing mental resources, find an analogy between the existing new problem situation and relevant past experience, or obtain instruction about a suitable solution (Andersson 1995; Gardner & Sternberg 1994). Voss et al. (1989) call this kind of solution indirect. In contrast, in a familiar problem situation, the problem solver can give the answer immediately if s/he knows the answer or has knowledge or an algorithm that will yield the answer. Voss et al. (1989) call this kind of solution direct.

It is possible that different problems with the same problem structures can produce different representations (Lesgold 1991). If the problem solver can base his/her representation on concrete and visual information, this kind of representation leads to better results than an abstract and symbolic representation (Kotovsky, Hayes & Simon 1985; Saariluoma 1988). Also the order of appearance of information and the elements of information influence learning (Sweller 1994; Marcus et al. 1996). In addition, symbolic and abstract problems can be easier to understand if the problem can be presented in a visual and concrete form (Andersson 1995; Mayer 1992a). This means that also problems with complex problem structure can be suitable for children, if the problem is presented to children in a visual and concrete form. Problem solving performance can improve, if it is possible to make concrete representations about the task environment, including illustrations and animations (Mayer 1993). If the problem includes features familiar to the problem solver, it is easier to solve than an unfamiliar problem.

The nature of the learning environment influence effectance motivation and self-perceptions of competence. Nastasi and Clements found that both Logo and CAI environments may provide opportunities for enhancement of effectance motivation and perceived competence although through different paths. CAI engenders effectance motivation through automatic external feedback whereas Logo does so through intrinsic means or reliance on elicited social feedback (Nastasi & Clements 1993). Although Logo may hold more promise for fostering intrinsic motivation and the development of self-reward systems, pupils in the Logo environment indicate the need for external feedback also (Nastasi & Clements 1993).

The new demand for the learning environment is that students can work in this environment at the limit of their competence (Bereiter & Scardamalia 1993).

Working at the limit of competence is an essential feature of progressive problem solving. In this process, students can continually reformulate problems at higher levels when lower levels are achieved (Bereiter & Scardamalia 1993). A learning environment, in which progressive problem solving is possible, is a dynamic learning environment. There are many reasons to assume that the LEGO/Logo problem solving environment exemplifies the dynamic learning environment. The Logo programming language as such gives many new challenges at every level to find new and more demanding tasks to solve, and endless applications in new LEGO projects. In the main source of Logo philosophy, *Mind-storms*, Papert (1980) describes many examples in which children discover their own goal and engage in the problem solving process and try to find optimal solutions to problems. Above in chapter 2.3 I gave a more detailed description of these kinds of discovery processes using Logo.

### 3.1.4 The representation of the problem

*The problem space* refers to the problem solver's internal mental representation of the task environment. According to Simon (1994), the simplest problem space for a task is the basic problem space. It consists of a set of states generated by all legal moves. The basic problem space may not be identical to a particular person's problem space, because an individual problem solver can generate a problem space that contains needless elements or errors. In that sense, it is fruitful to use the term mental space of the task, when it refer to the individual mental representation of the task. It can vary from one correct alternative to endless alternatives, depending on the nature of the problem solving environment. Individuals differ from each other in their mental spaces depending on their background knowledge.

The mental space control the problem solver's searching process during problem solving. With selection the problem solver identifies critical information about the task environment and builds a mental space. Especially children have two problems in selecting essential information from a task environment. First, they do not know what the important features are and, second, they do not know how to select important features efficiently (Siegler 1991). A good example of mis-selecting that leads problem solving to failure is McCloskey's and Kaiser's (1984) study concerning a ball's trajectory, when it falls from a moving flatcar. Over 70 percent of 4-to 11-year-olds predicted wrongly that the ball would fall straight down (McCloskey & Kaiser 1984).

The mental space consists of four parts: *The initial state, the goal state, intermediate states, and operators* (Holyoak 1991; Mayer 1992a; Newell & Simon 1972). The initial state is the representation of the starting conditions of the problem and the goal state is the representation of the final or goal situation of the problem (Mayer 1992a). Intermediate states consist of all states between the initial state and the goal state, and operators are the moves that are made from one state to the next (Mayer 1992a). Thus the mental space can consist of the set of all potential states that can be reached during problem solving. It is important to emphasize that the problem space and the task environment are not identical, because different people can understand a problem in different ways. The quality



of the mental space is important, because the problem representation influences problem solution (Berg & Calderone 1994; Enkenberg 1993; Mayer 1993; Sternberg 1991).

When an individual makes a mental space, it consists of two interconnected parts: cognitive and situational (Kozma 1991). The cognitive part evokes the individual's cognitive resources stored in memory in previous learning situations. The situational part benefits from situational resources in the actual problem solving situation. The situational resources include the task-environment itself (well-structured or ill-structured; familiar or novel; concrete or abstract) and the social situation. For example, the mental space of an expert in physics includes information both from the situation and from the expert's own cognitive resources. The mental space correspond to the physical objects mentioned in the problem, as well as, entities that correspond to the formal constructs of physics. The formal constructs of physics concern, for example, force, vectors, friction and velocity and they have no direct, concrete referent in the real world. (Kozma 1991). Thus, problem solving is never purely cognitive or purely situational, but both aspects influence the interpretation of the problem. The problem of school learning is that students cannot often apply the knowledge that they have of situations in the real world. In addition, the knowledge that students acquire in the school is frequently stored in ways that it is not evoked in problem situations outside school.

In the LEGO/Logo learning environment, children can see the effect of their programming on a concrete machine. The object of programming is concrete, touchable and authentic. LEGO bricks are transitional objects (Papert 1980) because they represent at the same time the concrete and the abstract. Papert supposes (1980) that children can begin programming at the concrete level, but little by little this concrete action becomes more abstract. This enables children to handle also complex problems. When the level of abstraction increases, more planning is needed in problem solving. Thus, the nature of the problem influences the interpretation of the problem. The following chapter discusses the meaning of planning in problem solving.

### **3.2 The role of planning in problem solving**

The prerequisite of successful problem solving is that the initial planning of a solution is kept separate from the actual execution (Holyoak 1991; Siegler 1991). In addition, the problem solver has to possess the skill to think about his/her own thinking, i.e., use metacognition (Enkenberg 1994). The ability to distinguish between the initial planning of a solution and its actual execution requires that the problem solver has a suitable knowledge structure in his/her LTM concerning the domain of the task. Empirical expert-novice studies have shown that the development of expertise requires many years of intensive experience (Enkenberg 1993; Glaser & Chi 1988; Mayer 1992a). As a result of intensive experience, experts have saved a lot of highly structured knowledge in their LTM.

In a complex problem situation, humans have to find the optimal solution for a problem and, in this case, the planning skill is an important part of problem solving, especially in a novel situation and in an ill-structured task situation (Voss et al. 1989). The problem solver has a limited amount of processing capacity and memory is easily overloaded by requirements of an unfamiliar problem (Kotovsky et al. 1985). This overload of memory prevents the use of memory capacity for planning. Humans can overcome the problems of limited capacity of STM by chunking information and by automating the processing of information.

The advantage of planning is that in this way a problem solver can look ahead and find the optimal solution to the problem. Efficient planning includes looking for all important and non-important elements of the task environment. Often a problem task includes many elements which depend on each other. Young children notice only one or two elements of a task environment and they interpret the task based on these few elements (Siegler 1991). A skillful planner can take all important elements into account and build a representation in which those elements are in structural order.

In the following, I shall discuss in greater detail the features relating to effective planning in a problem situation. These features are *metacognition, automation and chunking*. All these mental processes have a crucial function in the planning process. The skill to use *metacognition* is a crucial prerequisite for planning and effective problem solving. Schön has emphasized that effective problem solving is based essentially in the problem solver's ability to reflect on his or her own actions (Schön 1987). An effective problem solver has to be conscious of different possible solution paths among the alternatives from the initial state to the goal state. Thus, planning requires the skill to think consciously of one's own thinking, i.e. to use *metacognition* (Flavell 1979; Meichenbaum, Burland, Gruson & Cameron, 1985).

The role of consciousness in planning appears to be important in Vygotsky's theory of the development of thinking. A child cannot be conscious of his/her own action before the age of 11/12 (Vygotsky 1978). Piaget calls the same development stage as the formal operational stage of cognitive development (Piaget 1963; Inhelder & Piaget 1958). According to Vygotsky, the development of thinking means the evolution of the meaning function from the understanding of an everyday concept to the use and understanding of the scientific concept as a part of the conceptual system (Vygotsky 1978). The meaning of everyday concept is subjective and diffuse and meaning is based on some directly observable property of the object (Vygotsky 1978). Scientific concepts again refer to words that have a generalized and hierarchical meaning in a child's mind. In this case the meaning of a word is no longer connected to a directly observable property of an object, but a child has become able to incorporate the word into a conceptual system and this means that the child is competent to use words as a genuine tool. The skill to use words as a genuine tool enables action in which planning is used in goal determination, as well as in the analysis of one's own action and in error elimination. The conscious control of phenomena that is characteristic of scientific concepts presupposes that the phenomena are related to each other as parts of a general and hierarchical conceptual system (Vygotsky 1978). According to Vygotsky, the creation of such general and hierarchical conceptual systems is not

possible without the use of metacognition. Both Vygotsky and Piaget connected this kind of thinking with 11/12-year-old children.

Also Enkenberg notices that it has been suggested that formal operational thinking is one of the best examples of metacognitive thinking (Enkenberg 1989). Carey (1991) argues that an essential limitation of young children's memory is the lack of skill in the use of metacognition. This means that young children are not capable of explicit analysis of their own memory processes (Carey 1991). This limitation is reflected in children's problem solving processes, where their attention is directed at detail and they cannot concentrate on an analysis of the whole problem situation. Young children's thinking is very spontaneous in nature, but after metacognition has developed, conscious planning and problem solving is possible.

The idea of Papert's views on learning is that with suitable social and environmental effects metacognition can be developed also in younger children. The LEGO/Logo learning environment is one example of this environmental effect. In this way also younger children can be skilful planners and problem solvers. The idea that children's metacognition can develop considerably earlier than Piaget and Vygotsky have proposed has been confirmed by research in general developmental psychology as well as in Logo studies. For example Wertsch has shown, that the quality of verbal interaction between the child and his/her parents influences the use of metacognition in a child under school age (Wertsch 1979, 1980, 1985). Furthermore, Logo programming has been found to facilitate the use of six-year-old children's metacognition (Clements & Gullo 1984; Clements & Nastasi 1985).

A second important technique in overcoming the limit of STM is the *automatization* (Marcus et al. 1996; Mayer 1987; Sweller 1994). According to Sternberg, the use of metacomponents can become automatic too. This does not mean that spontaneous thinking fully gives way to conscious thinking. Things which are consciously learnt become automatic<sup>7</sup> and in an intuitive way influence other problem situations (Kolligian & Sternberg 1987).

The use of metacognition is important in novel problem situations when the problem solver begins to acquire new information about a task situation. If this situation is familiar, it can be supposed that the problem solver applies his/her experiences and solves problems quickly and without conscious thinking. Experts' planning skills are often tacit because they have acquired a lot of knowledge during their training in the domain of their expertise (Soloway & Ehrlich 1984). The familiarity of the problem releases memory capacity for effective planning because the use of lower-level knowledge can be applied in an automatic way (Marcus et al. 1996; Sweller 1994). Thus, the automation of the use of knowledge is a necessary precondition for effective planning in a problem solving situation (Case 1978; Kotovsky et al. 1985).

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<sup>7</sup> Clancey (1993) has criticized a pure cognitive approach because it deals with human action based only on phenomena which can be explained with clear concepts. Clancey has been emphasized that prelinguistic actions play a very important role in human problem solving.

Sternberg has described the role of automatization in his triarchic theory of intelligence (Kolliagian & Sternberg 1987; Sternberg 1984; 1985). When we speak about the effect of intelligence in the task situation, we have to clarify, how familiar the task is for the problem solver. Consequently, the degree of the familiarity of the task environment has a relationship to the degree of the automaticity of the problem solving process.

Experience of certain type of problem is a crucial component of intelligence. A person who has a lot of experiences of certain problems can solve such problems in an automatic way and thus cope with the situation. The automatization process has thus two meanings. First, young child's problem solving is unconscious and spontaneous. The action of a child looks automatic because s/he does not deliberate on his/her action. This kind of automatic behavior is caused by lack of experience and knowledge concerning the domain. Second, an expert's problem solving is often tacit. This kind of automatic behavior is caused by a lot of experiences in the domain of expertise. An expert's LTM includes many different types of knowledge concerning the domain and s/he is able to search for essential information in LTM to STM in an automatic way. His/her behavior could appear spontaneous too, but this spontaneity is qualitatively different from children's spontaneous behavior. In the case of experts, automatic information processing releases memory capacity for planning and effective problem solving. In education, a critical aspect concerning the teaching of problem solving skills is how to provide children with essential knowledge for novel situations.

A third important technique which helps to overcome the limitations of STM is the *chunking strategy* (Mayer 1987). Actual STM capacity may be constant after age four or five. The development of the efficacy of STM after this age is based on the extent to which people have learned to use more efficient strategies for handling information in STM (Mayer 1987). Skillful problem solvers can store information about a task situation in an effective way. The memory span capacity is the same for novices, but an expert's information unit is larger than a novice's (Andersson 1995). On the one hand, their memory advantage is based on larger patterns; on the other hand, their ability to search for information in LTM is more effective than novices' or childrens'. For example, in Adelson's study (1981), experts created chunks that were about 50 percent larger than novices' chunks in the programming task. However, automatization process and chunking techniques develop only in the domain of expertise (Andersson 1995).

The skill to divide the problem into parts presupposes conscious planning. Skillful problem solving presupposes an adequate amount of conceptual and strategic knowledge applicable in a problem-solving situation. If a learner does not have enough knowledge, s/he should at least have motivation to acquire new knowledge to solve the problem.

Studies consider problem solving from an expert's point of view. These studies give us a good picture of an expert's problem solving and also of the difference between a novice's and an expert's execution in a task situation. The shortcoming of these studies is that they often consider problem solving purely in cognitive terms. Motivational and social factors have not been taken into account alongside cognitive factors (Pintrich et al. 1993; Salomon 1993).

The criterion for optimal problem solving has been taken from expert thinking. This viewpoint covers an individual's own interpretation of the learning situation outside of the problem solving situation. If we consider an individual's behaviour in problem solving situations in school, we can see a lot of off-task behavior, a lot of interpretation which is meaningless from cognitive point of view, but is meaningful for the individual him/herself. Lehtinen and others describe this situation in the following way:

The original motivational tendencies—sense of control, self-efficacy, and mastery motivation (Dweck & Elliott 1983; Harter 1978; Schunk 1989) - thus interact with the initial basic process to produce task-oriented coping behaviors like exploring, recognizing and (mental) transformation of the task elements, as well as systematic planning (Diener & Dweck 1978; Dweck & Wortman 1982; Moriarty 1961). In Piagetian terms, an assimilation-accommodation process leads to a partial new balancing (or equilibration); task-related structures of thought and action are reorganized, which produces a partial fulfillment of expectations and reinforces the student's sense of self-efficacy with regard to the task. (Lehtinen et al. 1995, 22).

Studies of the information processing system give us a good model of humans in terms of cognitive processes and structures but have little to say about cognitive skills in relation to the individual's external world (Sternberg 1984). Sternberg (1985) has developed the triarchic theory of human intelligence in which he also describes the contextual and experiential part of intelligence (Sternberg 1985). Sternberg divides intelligence into contextual, experiential and componential parts. He defined metacomponents as executive-level cognitive processes used in planning, monitoring, and decision-making during problem solving and task execution (Sternberg 1985). Because the componential part of intelligence (metacomponents) controls the other parts of intelligence, this part is central in problem solving.

The problem solver has to take all important elements of the task environment into account and build a representation, in which those elements are in structural order. Thus, efficient planning of the problem solving process includes looking for all important elements of the task environment. Education has an important role in the development of problem solving skills. The information-processing system is similar for all humans, and it is common to us all that our memory capacity is limited, both in the amount of information that can simultaneously be attended to and in the speed of memory processes (Siegler 1991; Mayer 1992b).

### 3.3 Individual differences concerning problem solving

From the cognitive point of view, cognitive resources denote fundamental processes, such as encoding and searching from memory. These resources have been regarded as essential components of the cognitive architecture. Based on the assumption that the limitations of STM govern much of reasoning and problem solving, Lehrer and Littlefield established that it is important to account for individual differences in the efficiency of STM in order to better understand

individual differences in Logo programming skill (Lehrer & Littlefield 1993). In the following I try to clarify how previous research has dealt with differences between experts and novices, between different ages, between high and low achieving students, between high motivated and low motivated students and between females and males.

### 3.3.1 Differences between novices and experts

Chase and Simon (1973) have shown that the primary factor distinguishing novices from expert chess players is the experts' extensive store of board configurations learned during real chess games. In a test situation experts can thus recall immediately the most suitable configuration from their LTM. Thus during their thousands of hours of experience in the domain of their expertise, experts have removed a lot of information through their STM and they have stored this knowledge in their LTM. Thus, the main differences between novices and experts concern cognitive resources (both knowledge structures and processes). Expert-novice differences in computer programming have been found both on a very basic level (syntactic and semantic knowledge) and on a higher level of thinking (schematic and strategic knowledge).

Wiedenbeck (1985) arranged recognition tests for studying the differences between experts and novices concerning syntactic knowledge of programming languages. Ten expert and ten novice FORTRAN programmers participated in this study. The experts made 40 per cent fewer errors and responded 25 per cent more rapidly than novices in this recognition test, in which they had to recognize incorrect grammar in the FORTRAN programming language. Wiedenbeck argues that experts have automated their lower-level programming skills and therefore they can detect a grammatically incorrect code with minimal conscious attention. In the same situation, novices must concentrate a great deal of their conscious capacity on acquiring lower-level programming skills (Wiedenbeck 1985). Thus, it looks as if the automatization of syntactic processing reduces the cognitive load, and that cognitive capacity is sufficient for focusing attention on the meaning and structure of the program.

Experts and novices also differ from each other in the semantic knowledge area. Typical features of novice computer programmers' semantic knowledge are that they do not have useful mental models of the computing system (Bayman & Mayer 1988). Computer courses which emphasize the use of a concrete model of the computer increase student's understanding of the computing system (Mayer 1992a). In a LEGO/Logo environment, children can see the effect of a Logo procedure in a real 3-dimensional environment, and for that reason it can be supposed that children acquire a suitable model of the computing system in this environment.

Expert-novice differences in schematic knowledge have been studied with recall (Adelson 1981; McKeithen, Reitman, Rueter & Hirte 1981) and sorting tasks (Weiser & Shertz 1983). In a recall test, subjects first study a computer program for a given time. After that they have some time to recall the program. Experts outperformed novices, if the lines of programming code were presented in normal order, but the results of experts and novices were similar if the lines were

presented in random order (McKeithen et al. 1981). In Adelson's (1981) study, novices based their search on a syntax-based organization, whereas the experts based their search on principles of program function. Mayer (1992a) explains this result in the following way:

Like expert chess players who can chunk pieces into meaningful configurations, expert programmers seem to have a large storehouse of typical configurations of programming statements. This schematic knowledge helps experts to see a thirty-one-line program as a collection of five or six chunks of programming statements, with each chunk consisting of several statements that are meaningful related to a specific function. (Mayer 1992a, 402).

Novices try to understand the problem on the bases of easily noticeable features of the problem, whereas experts understand the problem with the aid of structural schemas (Mayer 1992a). As far as schematic knowledge in programming is concerned, experts have learnt more chunks concerning different types of routines than novices (Mayer 1992a).

Experts and novices also differ a lot in strategic knowledge. Andersson (1995) noticed that novice and expert programmers both developed programs in a so-called top-down manner (Andersson 1995; Andersson, Farrell & Sauers 1984). However, experts divided the problem into subproblems in a more sophisticated and systematic way than novices. In Vessey's (1985) study, both novices and experts presented a general solving strategy, but experts had more alternatives. The difference in strategic knowledge between novices and experts is also reflected in the planning strategy (Mayer 1992a). Experts used a global planning strategy, which means that they become familiar with the problem before they write new code. This strategy can be called *breadth first* because the attention of experts in the planning process focuses on the whole problem (Andersson 1995, Vessey 1985). In contrast, novices used a local planning strategy, which means that they begin to write new code before they understand the problem. This planning approach can be called *depth first* because novices' attention focuses on small items at the bottom (Andersson 1995, Vessey 1985). In addition, experts used high-level modules in planning, whereas novices had an unfocused approach and their planning included more modules. Mayer (1992a) draws the following conclusion:

In summary, research using thinking-aloud protocols shows that both in program generation and program debugging tasks, experts possess higher-level plans than novices. (Mayer 1992a, 405).

Relating the main procedure to subprocedures is a very demanding task for the novice programmer. Enkenberg (1994) has shown, that some 13/14-year-old students learn to use subprocedures in an effective way if the teaching phase concentrates especially on teaching these skills to students. However, only 3 out of 13 pairs learnt to produce LEGO/Logo subprocedures during a 10-hour teaching phase. The rest ten pairs of students wrote Logo code without subprocedures (Enkenberg 1994).

It can be seen that the difference between novices' and experts' knowledge appears in the area of the very basic level of knowledge as well as the higher level

of knowledge. A common inference of expert-novice studies is that the high quality of knowledge that experts possess is based on the plentiful experience of the experts in the domain (Andersson 1995; Chi 1978; Enkenberg 1993; Glaser & Chi 1988; Mayer 1992a). In other words, the knowledge which experts possess is very domain-specific in nature.

Experts in a domain are distinguished from novices both by the nature of their mental models and the way they use them to solve problems (Kozma 1991). The essential feature of problem solving in this particular situation is that the problem solver uses all types of knowledge. From this point of view, the problem of school learning is not only the too abstract knowledge or too concrete/practical knowledge, but the failure to use all levels of knowledge in dynamic and complex learning situations.

The research concerning the differences between experts and novices in problem solving has, however, some limitations from an educational point of view. When the mission of the public school system is to arouse students' learning processes, expert-novice research gives a static picture<sup>8</sup> of expertise (Bereiter & Scardamalia 1993). The second shortcoming of this research is that the problem-solving tasks used in the studies are too easy for the experts and too difficult for the novices (Bereiter & Scardamalia 1993). The same problem also occurs also in conventional schools. Often the tasks are too easy for good students and too difficult for poor students. It is not easy to develop learning situations in which all students could work at the limit of their own competencies.

In regard to expert-novice studies the degree of prior experience has a central role in success in problem solving. This conclusion can be seen as consistent with the general point of view concerning constructionism, which emphasizes, that learners' personal learning history affects how s/he sees the learning situation (see von Glaserfeld 1989). Learning in school concerns so many different subjects that it is not possible to achieve such an amount of knowledge to enable comparison of school students' knowledge and experts' knowledge. However, it is important to know in what way previous school learning experience of Logo programming affects the acquisition of new problem solving skills in the LEGO/Logo learning environment.

It is difficult for novices to learn concepts concerning programming language because novices are normally taught those programming concepts in a static, abstract manner (Rajan 1991). In the practical programming situation, the programmer has to translate this static, abstract information into a dynamic form (Rajan 1991). Rajan (1991) emphasizes that concrete examples which are related to particular programming task may facilitate novices' understanding of concepts of programming language. Thus, at a general level, the ability to understand programs depends on construction, which includes two sides: the construction of what the program does and the construction of how it does it.

In the LEGO/Logo learning environment, students can make experiments with every programming command (Järvinen 1998). Thus, the combination of "what the program does" and "how it does it" is implemented all the time.

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<sup>8</sup> Eteläpelto (1998) has pointed out that also experts differ from each other in their design processes. Thus, the picture of expertise is multidimensional.



### 3.3.2 Developmental differences

Research on problem solving has concentrated on comparing the performance of expert and novice problem solvers. These studies do not explain the differences between novices in the same age. However, knowledge concerning individual differences in the learning situation is important from the point of view of school learning.

Piaget and Vygotsky described stages of reasoning such as syncretic thinking (Vygotsky 1978) and formal operations (Inhelder & Piaget 1958) to characterize strategies in problem solving in all subject matter domains. In the past especially Piaget's stage theory has predominated the discussion of child development (Linn 1986; Siegler 1991). In both theories the main explanation for the development of thinking is age. According to present understanding, children have a much richer cognitive capacity for problem solving than Piaget has asserted (Siegler 1991). There is no single age at which the acquisition of certain concepts and problem-solving skills occurs. Siegler explains the possibility of children's acquisition of problem solving skills in the following manner:

Given the complexity of cognitive development, it often will prove impossible to provide a meaningful statement about the age at which children acquire a cognitive capability. Models that specify both how children think and the conditions under which they think in various ways seem needed to deal with this complexity. (Siegler 1991, 352).

In the same vein, Klahr and Robinson (1981) describe children's thinking skills in the following:

Young children appear to have rudimentary forms of many of the problem-solving processes previously identified in adults, but they may differ in encoding and representational processes. (Klahr & Robinson 1981, 114)

However, children have a smaller memory span than adults and this is reflected in success in problem solving (Mayer 1987). But the age only does not explain success in the problem situation. For example, expert chess players of average age 10.5 years outperformed adult novices in a recall task in which content belonged to a real chess situation (Chi 1978). Adults again outperformed young chess players in a digit span test (Chi 1978). This means that experiences in certain domains - in this case, chess - develop the skills of chunking strategies concerning this domain. Based on his study, Chi (1978) argues that the age differences in memory span reflect differences in children's familiarity with the material rather than differences in children's memory capacity.

Also young experts (age 10-11) in baseball could better recall a list concerning baseball than young novices of the same age (Gaultney, Bjorklund & Schneider 1992). In another study, young experts in soccer, but with low-aptitude in school, outperformed novices in soccer, but with high-aptitude in school, in memory and comprehension tests concerning soccer. Children in the soccer recognition test were in grades 3, 5 and 7, and the effect of expertise was much greater than the effect of grade level (Schneider, Körkel & Weinert 1989). Siegler (1991) describes the development of problem solving skills in the following way:

The development of problem solving involves children's efforts to overcome obstacles and attain goals. It involves the orchestration of a large number of other processes toward this end. Much of children's problem solving reflects the structure of the task. How well children encode the critical information in the task and how well they can use the encodings to form mental models are among the key determinants of their success on many problems. Their success also depends critically on the ability to integrate general and specific knowledge, and their selection of the right process in the right situation. (Siegler 1991, 285 - 286).

Social and motivational factors also affect cognitive execution. Especially the development of planning skills has a strong relationship with the self-regulatory process (Ellis & Siegler 1994). According to Harter (1975), children have mastery or effectance motivation, but in different ages this motivational force appears in quite a different way when children try to solve tasks. Older children (10 years) were clearly motivated to produce a successful outcome (correct answer), whereas younger children (4 years) wanted to successfully produce an effect on the environment focusing mainly on sensori-motor effects. According to Harter (1975), both age groups have the same central motivating force, but the behavioral manifestation was clearly quite different.

One of the major differences in reasoning strategies between adults and children is the skill to evaluate experimental evidence (Dunbar & Klahr 1989). Adults can profit from the information they obtain by empirically experiencing their existing knowledge structures, whereas children interpret the given information by means of their preinstructional belief. Thus, in children the cognitive conflicts during problem solving may not lead to cognitive reorganization processes as often as is the case among adults. In Dunbar's and Klahr's study (1989), adults were more capable of profiting from the results of an experiment for inducing a new frame, whereas children interpret the results of their experiments with the aid of an old frame (Dunbar & Klahr 1989).

### 3.3.3 Aptitude Treatment Interaction (ATI)

Previous studies (Snow 1994; Snow & Lohman 1984) have shown that children's general ability to learn from instruction varies from case to case. This diversity of ability in learning means that different children can profit from instruction in different ways. For that reason, low-ability learners need more teacher guidance than high-ability learners. The ability to learn is also related to general school achievement (Snow 1994; Snow & Lohman 1984). A relationship has also been found between problem-solving success in a LOGO environment and academic achievement in reading and mathematics (Bradley 1985; Suomala 1996).

ATI means that the instructional approach that is best for an average student is not best for all students (Cronbach & Snow 1977). Students with low capacity for problem solving need more guidance than pupils with high capacity (German 1989; Mayer 1987; Snow 1994; Snow & Lohman 1984; Suomala 1996). Snow and Lohman (1984) state that the existence of individual differences in cognitive aptitude for learning from instruction is the most long-standing fact in educational psychology.

King (1989) showed that in screen Logo problem solving high academic ability pupils did use significantly more long statements and fewer short

statements concerning task-solving than did average ability students. However, there was no relationship between the level of academic ability and success in the Logo task itself. King's conclusion is that pupils at a higher cognitive level use more verbal interaction in general, although the result of Logo programming is similar (King 1989).

### 3.3.4 Motivational differences

Research concerning the differences between novices and experts has clearly shown that novices make different cognitive representations of the same task than experts. This diversity has also been found in the LEGO/Logo learning environment (Järvelä 1995). Various interpretations of the learning situation does not reflect only the difference in the quality of cognitive resources among students; rather, the question is that students have different ways of coping with a challenging learning and performance situation (Järvelä 1995, Lehtinen et al. 1995).

The reason for this socioemotional diversity is that students' learning history may dominate in the new learning environments (Lehtinen et al. 1995). Recently it has been shown that individual's learning history has an important role also in the experts' action in task situations requiring thinking (Eteläpelto 1998).

### 3.3.5 Gender differences

In general, the domains of problem-solving, computer programming, mathematics, as well as science education, have traditionally been associated with boys rather than girls (Edwards, Coddington & Catarina, 1997). Also, Legos itself as a play material is dominated by boys more than girls (Edwards et al. 1997). Although females' attitudes towards computers are more negative than those of males and this is reflected in females' unwillingness to participate in computer courses (Edwards et al. 1997), no differences have been found in how females and males perform in computer courses (Webb 1985).

The following gender-related differences have been found in the LEGO/Logo learning environment. Turkle and Papert have found that females' programming style is concrete, whereas boys' programming style is formal (Turkle & Papert 1992). Despite the difference in programming style, the quality of the results concerning programming has been found to be similar. Edwards and others have obtained the following results concerning the differences in boys' and girls' problem solving processes in the LEGO/Logo learning environment (Edwards et al. 1997). First, boys called for help from the teacher more frequently than girls did. Thus, girls tended to work more autonomously than boys (Edwards et al. 1997). This result contradicts the results of previous research on boys' and girls' mastery motivation in general. In previous research boys were found to demonstrate significantly intrinsic mastery motivation, whereas for girls the need for adult approval was the more important motivational determinant (Harter 1975). Second, girls showed greater persistence than boys when a conflict occurred during programming. And finally, girls talked about what they would

do or should do before acting, whereas boys tended to act before discussing (Edwards et al. 1997).

According to Lai's study (1993), the level of metacognitive awareness was similar with boys and girls after a four-week LEGO/Logo period. Also all students showed much willingness to cooperate with others in problem solving during the LEGO/Logo period. Thus, the effects of LEGO/Logo programming on willingness to cooperate was similar for boys and girls (Lai 1993).

Turkle and Papert (1993) assert that females' style of programming is more of the concrete programming style than that of boys (Turkle & Papert 1993). The present study looks at 11-12 year-old girls and boys, and will examine how males and females of that age differ in their style of programming.

### 3.4 The different modes of learning problem solving skills

The main idea of this study is that, with suitable instructional adjustment, it is possible to influence students' cognitive development. In addition, the assumption is that LEGO/Logo serves as a potential example of dynamic learning environment, in which many of the problems affecting the conventional school could be overcome. LEGO/Logo serves also as good learning environment in which it is possible to study students' learning processes in actual and progressive situations. This authenticity of LEGO/Logo provides good opportunities for studying students' problem solving in an ecologically valid way. The following section discusses at a general level, and considers the advantages and disadvantages of the mediated and discovery learning method.

#### 3.4.1 Learning in general

Cognitive learning theory can be regarded consistent with the general learning view of constructivism<sup>9</sup>. According to constructivism, people are builders of knowledge structures rather than recorders of information (L.B. Resnick 1989, Mayer 1992b). This means that learning is a constructive process, where students actively construct their knowledge and skills through interaction with the environment and through reorganization of their mental structures (Chi & Bassok 1989, Collins & al. 1989, DeCorte 1990). The essential role of human in this process is that s/he is a sense maker (Mayer 1996). At this general level, researchers concur. But inside this general understanding there are different emphases.

In cognitive science, learning has been regarded as largely cognitive and symbolic in nature in the past decades (Norman 1993). This pure cognitive approach emphasizes that thinking is mainly symbol manipulation (Norman

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<sup>9</sup> In cognitive science, the concept of mental representation is essential. With mental representation, we understand something as something. The formation of this understanding is not simple perception, but a creative and constructive process (Glenberg 1997, Mayer 1996, Saariluoma & Hohlfield 1994).

1993). In addition, this symbolic point of view emphasizes the meaning of decontextual and abstract knowledge in learning. Thus, the events inside the brain are the most important part of learning. For example, Newell and Simon's problem solving theory described above emphasizes the meaning of the information processing system inside the learner's head (Newell & Simon 1972).

However, in recent learning research, the limitations of cognitive approaches have been stressed frequently. Many researchers have expressed the need for better theoretical and methodological approaches to the analysis of learning in realistic situations (Järvelä 1996b). According to these studies, the quality of learning cannot be adequately described in purely cognitive terms; the social and motivational aspect of learning should also be considered (Pintrich et al. 1993). This *situated cognition* approach emphasizes the meaning of social interaction and motivational dispositions of the learner in addition to cognition. According to the situation cognition approach, knowledge that is acquired in a learning process is situated in the learning environment in which that knowledge has been acquired. Thus, knowledge is anchored to the learning situation and is not by itself transferred and used in a new situation (J.S.Brown, Collins & Duguid 1989; Clancey 1993; Järvelä 1996b; Lave & Wenger 1991; Norman 1993; Perkins & Salomon 1989; L.B.Resnick 1989). Thus, the situated cognition approach as well as the contextual approach in general, emphasize the structures of the environment and how they guide human behavior (Lave & Wenger 1991, Norman 1993). The features of the environment are as important as the cognition processes and structures in the learner's head during the learning process. Whereas the symbolic approach emphasizes the meaning of decontextual and abstract knowledge, the contextual approach emphasizes the meaning of contextual and concrete knowledge. In addition, this approach emphasizes the essential meaning of individual's prelinguistic sensorimotor processes in his/her learning (Clancey 1993).

The problem of school learning is that some of students do not feel learning as meaningful. The contextual perspective tries to solve this "inert knowledge problem" by making school teaching more concrete and more authentic (Kozma 1994). The content of learning is in most of the cases very complex. It includes both situational and theoretical aspects. For that reason, learning in school could not be based only on concrete, authentic situations or only on theoretical knowledge, but it has to be a progressive process, in which the situational and theoretical aspects integrate into the same entity.

Thus, learning problem solving skills is, along with cognition, a complex social, motivational and cultural process (Pintrich et al. 1993). In this process, success is composed of both the cognitive skills of problem-solvers and the problem-solving environment (Ceci & Roazzi 1994, Chi & al. 1989, Berg & Calderone, 1994). Kozma (1994) characterizes this combination in the following way :

However, as we have come to understand, learning is not the receptive response to instruction's "delivery". Rather, learning is an active, constructive, cognitive and social process by which the learner strategically manages available cognitive, physical, and social resources to create new knowledge by interacting with information in the environment and integrating it with information already stored in memory (Shuell

1988). From this perspective, knowledge and learning are neither solely a property of the individual or of the environment. Rather, they are the reciprocal interaction between the learner's cognitive resources and aspects of the external environment. (Kozma 1994, 8).

In conventional school learning, the teacher's role as an external cognitive resource has been essential. The teacher has decided the content of learning, the learning method and the social forms in the classroom. Papert's main idea is that children learn best if they have a lot of freedom in the learning situation. Computers can change the form of the learning processes and the role of teachers so that they are different from conventional school learning. The role of the teacher has changed from the knowledge presenter to the guide of students' learning processes<sup>10</sup>.

The big question is what is a suitable amount of teacher's guidance in the learning process? In the following, I have divided learning models according to the degree of teacher's guidance in the problem solving situation. First model is called as mediated and second as discovery model.

Discovery is the process by which the learner uses his/her mind to acquire, organize and internalize the concepts and principles of the domain (Carin & Sund 1989). Many empirical studies have suggested the use of a mediated method. A new wave of interest in the discovery method sprang up during the 1980s, when new information technology began to spread. Especially Papert's learning theory had the effect that the discovery process again became interesting. During the 1990s new interest has arisen in the mediated method when teaching higher-order thinking skills to students in a complex problem solving situation (Collins et al. 1989, Enkenberg 1994, Järvelä 1995). In the following I describe the main features of the mediated and the discovery model of learning.

### 3.4.2 Learning based on the mediated model

The mediated model of learning is based on a sociocultural account of learning (Vygotsky 1969). It is possible to consider the sociocultural account of learning from a constructivist perspective, where it is called social constructivism. The Vygotskian research tradition assumes that the primary explanatory constructs in the individuals cognitive development are the individual's participation in culturally organized practices and face-to-face interactions (Järvelä 1996c; Newmann, Gridffin & Cole 1989; Vygotsky 1978; Wertsch 1985). According to Vygotsky (1969) the essential psychological mechanism which engenders cognitive growth when learners participate in culturally organized practices, is imitation. The focus of imitation is the language and the activity of the other people surrounding the developing human. The imitation is not mechanical, but it focuses on the potential possibilities for the human. The concept of the *zone of proximal development* (ZPD) refers to the development area in which the potential

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<sup>10</sup> Bereiter and Scardamalia represent the new teacher type, who tries to give students tasks which are gradually more difficult. They suppose that the Computer Supported Intentional Learning Environment (CSILE) is an example of this kind of progressive learning environment (Bereiter & Scardamalia 1993).

possibilities of the child can be realized, first, together with other people and then alone.

In the mediation process the role of the teacher is important because the teacher presents the information to students directly. The information contains the explicit presentation of facts and processes in the subject matter (Linn 1986). The mediated model involves an emphasis on ready-made problems given to the students, and often mediation is used in an attempt to raise questions which evoke the student's prior knowledge. When the teacher uses a mediated model, s/he decides the mode, pace and style of exposition (Bruner 1961). According to the social constructivism, the cognitive responsibility is with the teacher at the beginning of the learning process. The assumption is that, during the learning process, the degree of the student's cognitive responsibility increases, and ultimately, the learner will be a self-regulating, autonomous problem solver.

The child constructs his/her view of the world by interacting with adults or with other more competent people (Vygotsky 1969). Instruction is one important form of social interaction and the major strength of instruction is to mediate scientific concepts, conceptual systems and scientific theories for students (Vygotsky 1978). Especially the acquisition of the higher order thinking and scientific concepts is not possible without the teacher's mediation of these concepts (Vygotsky 1978).

Learning based on a mediated teaching method is suitable in situations in which students try to acquire domain-specific knowledge and knowledge about hierarchical relationships among items of information (Linn 1986). Domain-specific knowledge is an important element in all disciplines in the school. In addition, one role for the mediated method is to foster effective use of limited processing capacity (Linn 1986). With the mediated method it is possible to present information in a form which does not exceed the processing capacity of the learner (Linn 1986; McInterney, McInternay & Marsh, 1997). The use of the mediated model does not take as much learning time as does the use of the discovery model. In the case of mediated learning, the results of learning can be as good as when using the discovery or guided discovery model. However, the mediated model is effective when we want to ensure that the principles and rules have been learned (Mayer 1987). This is the reason, why the mediated method has usually been regarded as suitable for young children who do not have enough domain specific knowledge of the area being taught (Carin & Sund 1989). However, Mayer (1987) pointed out that if the goal of instruction is long-term retention and transfer, then the mediated method seems inferior to guided discovery.

The weakness of the mediated model of learning is that students may feel learning as boring and irrelevant. In the same vein Bruner criticizes the mediated model because students are "bench-bound listeners" and this kind of situation is not optimal for learning. Most recent textbook material in schools is based on the mediated mode of learning. Carin and Sund (1989) give a list of examples of typical learning situations in which the mediated model is used: telling, demonstrating, using scientific apparatus, carrying on a discussion, reading to children, showing a film or TV presentation. In this situation it is not necessary to

encourage the student to actively think about the rule or principles and they fail to learn metacognition in problem solving and planning (Linn 1986).

The capacity to organize the knowledge presented differentiates high- and low-ability students (Linn 1986). High ability students can often exploit their own organization of knowledge, whereas medium and low ability students have difficulties to benefit from having a knowledge organization presented to them (Doyle 1983). For this reason, the emphasizing of knowledge organization is important for low and medium ability students, and this can be guaranteed with the mediated method. On the other hand, the emphasizing of knowledge organization in a learning situation prevents high-level-ability students from applying their own knowledge in learning situations. Students who lack domain knowledge are more likely to benefit from teaching methods that explicitly provide a familiar context for learning than students who possess domain knowledge (Mayer 1993). Thus, mediated instruction can be effective for some students but not optimal for others (Linn 1986).

In the spirit of the *Act of discovery*, Bruner (1975) developed the concept of *scaffolding* to describe a mother's effort to limit the degrees of freedom in the task that the child is not able to control alone. Mothers who use scaffolding interpret children's activity as an intention to carry out some action and by means of scaffolding the mothers try to help the child to achieve this outcome. Bruner's term *scaffolding* has been used as one mediation tool in modern cognitive learning psychology (Enkenberg 1992, Järvelä 1996c). In these cases the meaning of mediation in learning is the mediation of an expert's cognitive models with interaction between the teacher and students (Enkenberg 1994; Järvelä 1996a; Kozma 1991; Wertsch 1985).

Some studies of Logo have found the mediated model of learning to be fruitful. King (1989) suggests the use of direct instruction when teaching Logo to 10/11-year-old students. In this way, it is possible to foster the verbal interaction and problem solving behavior which appear to promote success in group computer learning. With direct instruction, the teacher can demonstrate and coach students to ask task-related questions. In addition, direct instruction and coaching is suitable when guiding pupils to use time on plans (King 1989).

In Lehrer's, Guckenberg's and Sancilio's study (1988) the teacher presented problems and asked leading questions and s/he also helped children to apply strategies appropriately and helped them to overcome misconceptions. According to Lehrer and others, third-grade children in a mediated learning group developed far fewer misconceptions about the syntax and semantics of Logo than children in a less mediated group. In addition, the mediated group demonstrated higher metacognitive capabilities and showed a greater understanding of geometric concepts when compared to a less structured group (Lehrer et al. 1988).

Vygotskian theory tries to explain cognitive change in a collaborative situation in which interpersonal conflicts are not apparent (Vygotsky 1978). Based on Vygotsky's idea of collaboration, Nastasi & Clements (1991) have pointed out that reciprocal sense-making denotes an ideal interaction of Vygotskian interaction. In this process, individuals attempt to extract meaning, generate ideas, or solve problems through discourse. In a collaborative situation, people



take complementary roles in which partners provide scaffolding for each others making it possible for them to solve problems together which they could not solve alone (Vygotsky 1978). This kind of collaboration requires individuals to synthesize their actions with those of others (Nastasi & Clements 1991). Also recent research supports the idea of the advance of reciprocal sense-making. If collaboration and concurrence seeking are essential in cooperation, cognitive change is promoted (Nastasi & Clements 1991).

### 3.4.3 Learning based on the discovery model<sup>11</sup>

The discovery model of learning is based on the Piagetian tradition of learning (Bruner 1961, Piaget & Inhelder 1961). It is possible to consider the Piagetian tradition of learning from a constructivist perspective, where it is called individual constructivism. One of the basic assumptions of this tradition is that goal-directed activities lead subjects to conflict situations and the solution of conflicts is the main reason for cognitive development (Piaget & Inhelder 1975, Saxe 1991). A new interpretation of Piaget's approach, the social-cognitive approach, emphasizes the meaning of collaboration where individuals must resolve discrepant viewpoints to achieve cognitive growth (Perret-Clermont 1980). Those discrepant conflicts can be either interindividual or intraindividual. Interindividual conflicts refer to opposing egocentric viewpoints between two individuals. Intraindividual conflicts mean that the cognitive discrepancy occurs between an individual's current understanding and new demands.

According to Bruner (1961), learning through discoveries can be put under four headings: the increase in intellectual potency, the shift from extrinsic to intrinsic rewards, learning the heuristics of discovering, and the aid of memory processing. The discovery model of learning allows students to discover new rules and ideas, rather than simply memorize rules and ideas that the teacher presents (Bruner 1961; Mayer 1987). The results of the discovery model of learning can be good because the learner can organize the material in a useful way and the learner can practice information processing (Bruner 1961). In addition, with discovery, the student's motivation to learn is more intrinsic than extrinsic in nature (Bruner 1961).

In the discovery model, the students have cognitive responsibility at the beginning of the learning process and the teacher does not control pupils' work during learning if they do not ask for advice. In the discovery model, the teacher and the student are frequently in a cooperative position (Bruner 1961). When students learn with the discovery model, they can identify problems, generate hypotheses or possible solutions, test these hypotheses in the light of available data, and attempt to apply their conclusions to new data, new problems, or new situations (Carin & Sund 1989).

In discovery learning, the focus is on processes rather than on products. The discovery model of learning refers to the presentation of opportunities for learners to discover important scientific principles by interacting with scientific

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<sup>11</sup> The concept discovery model refers in this study both to the discovery and guided discovery approach to the learning.

material (Linn 1986). The discovery model helps students acquire knowledge that is uniquely their own, because they discover it themselves (Linn 1986; Carin & Sund 1989).

The discovery model of learning is frequently associated with a hands-on approach in which students can conduct experiments in order to identify scientific principles (Linn 1986). In this situation, the testing skills of students develop. Linn emphasizes that the discovery model of learning is undoubtedly the best approach for helping students to gain metacognitive skills and deep understanding. This deep understanding means that students can acquire all levels of knowledge from syntactic to strategic knowledge. If their solution is incorrect, they often get feedback when they see that their choice was wrong. Based on feedback they can then apply a better solution to the problem. Thus the discovery model of learning is good for students to practice and learn problem solving skills (Linn 1986; Carin & Sund 1989).

The shortcoming of the discovery model of learning is that it is inherently time consuming (Linn 1986). In spite of using a lot of time, students in the discovery group have inferior performance on transfer and long-term retention (Mayer 1987). Despite the fact that discovery students' intellectual power will increase, this method fails to ensure that they acquire the rule or principle to be learned. All students cannot exploit discovery learning because they do not have enough knowledge for this (Carin & Sund 1989). Mayer (1987) emphasizes that some learners simply may not be able to discover the underlying principles without some direction from the teacher. Chinn and Brewer (1993) explain the possibilities of the discovery method in education in the following:

When teachers want to focus less on helping students learn particular theories and more on helping them understand that science is a process of developing and evaluating theories, they can follow much the same procedure. However, instead of making sure that students have the alternative theories available and that the anomalous data converge to support the accepted theory, teachers might give students more freedom in constructing their own alternative theories and in designing their own series of experiments to test their theories. (Chinn & Brewer 1993, 38).

In a LOGO learning environment, all children cannot profit from the freedom that the discovery model of learning gives. Some children have difficulties in learning even the fundamentals of LOGO programming under discovery conditions (Kurland & Pea 1985; Pea & Kurland 1984; Pea & Kurland 1987; Suomala 1996). Kurland and Pea (1985) suggested, that instead of Papert's idealistic outlook, self-guided discovery needs to be mediated within an instructional context. Similar results have been found with BASIC programming (Mayer 1987). The results concerning instructional programs show that discovery teaching does not always lead to meaningful learning of programming commands. The probable reason for this is that students lack the appropriate prerequisite knowledge concerning programming.

### 3.4.4 Conclusion about different teaching/learning methods

A good learning environment provides several opportunities for students to attain learning goals and no single method of teaching is best for all children. Dynamic learning environment is characterized by a good balance between discovery learning and personal exploration on the one hand, and systematic instruction and guidance on the other (DeCorte 1990). Thus, the versatility and flexibility are characteristics of a good learning environment. Linn (1986) emphasizes that in a learning situation the teacher has to be conscious both of the initial state of the students and of the mechanisms which will enhance student learning (Linn 1986). From the teacher this requires sensitivity to the response of the learner.

However, the criticism of school learning has indicated that in school, teaching is rarely optimal for learning. Logo has been developed especially on the basis of the hypothesis that in school there are not enough opportunities for free discovery. However, the idea that children are incapable of profiting from an open learning environment is the main reason for using the mediated method in the school. Carin and Sund describe this view as follows:

The younger the children, the more you must present information and guide them; the older the children, the less you present, and the more they will initiate work with you as a facilitator, resource person, encourager, and guide. (Carin & Sund 1989, 93).

This view is in contradiction to Papert's view. He emphasizes that children are naturally eager to know and they can work a long time with suitable learning tools and discover in an open environment.

Because, children differ from one another in their general ability to learn from instruction, different children need different kinds of instruction. The low-ability learners need more teacher guidance than high-ability learners (Snow & Lohman, 1984; Mayer, 1987; German, 1989). The ability to learn is related to general school achievement (Snow & Lohman, 1984). Thus, both the mediated and the discovery model of learning have a place in the curriculum (Linn 1986). A relationship has also been found between the success of problem-solving in a Logo environment and academic achievement in reading and mathematics (Bradley, 1985). Linn describes the role of the different models of learning in the following way:

Combining discovery learning and direct instruction can provide a balance. Overemphasis of either side will lead to incomplete understanding of scientific problem solving and ultimately will detract from the important societal objective of providing scientifically literate as well as scientifically expert individuals. (Linn 1986, 187).

If the goal of instruction is understanding phenomena and long-term retention and transfer of learned principles, then the teacher ought to give enough guidance for the student to find out the principle to be learned, but not so much guidance that it discourages students from using their own thinking actively. Most of the studies concerning the effects of different teaching methods have been conducted in well-structured situations. The nature of the goal of learning in such studies has

often been very limited compared to complex problem solving tasks or authentic learning.

The main criterion for optimal learning is that students feel it to be meaningful. In rote learning students only learn to mechanically apply a formula, whereas in meaningful learning students understand the phenomena and their relationships. Understanding is important especially in problem solving. In the above, two learning models have been described and the conditions under which meaningful learning takes place with each method have been discussed. Hiebert, Carpenter, Fennema, Fuson, Human, Murray, Oliver and Wearne (1996) describe the teacher's role in a problem solving learning situation in the following way:

Our position is that the teacher is free, and obligated, to share relevant information with students as long as it does not prevent students from problematizing the subjects (Hiebert et. al 1996, 16).

The combination of students' free discovery and the teacher's direct guidance in the problem-solving situation is difficult to carry out. However, numerous results of studies concerning school learning have pointed out that the biggest hazard is that school teaching prevents the development of students' self regulation. Another problem is how to study a student's problem solving in a learning situation which is based on the student's responsibility.

The role of the teacher in open learning classrooms is problematic and still largely uncharted (A. Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993). A. Brown and others (1993) have realized that students' free discovery in the science class leads to misconceptions and often students overdetermine the cause of some phenomenon in science. Thus, the task of the teacher is not to give the problems, or answer directly, but the teacher should support students' free discovery in the right direction.

### **3.5 Conclusion about human problem solving and learning of problem-solving skills**

The general theory of problem solving (Newell & Simon 1972) provides a suitable conceptual framework for the description of human problem solving. Problem solving is a searching process in which the problem solver tries to cope from the initial state through intermediate states to the goal state. The essential feature of problem solving is that the goal state is not immediately available. However, this theory sees mental activity mainly as cognitive in nature, as do most other theories in cognitive science in the past decades. Despite the fact that Newell and Simon's theory takes into account the task environment and its structure, they also emphasize the role of the human internal mental activity. Other contextual factors of learning, such as the social interaction and motivational orientation of the student in problem solving have been omitted from this theory.

The theory of situated cognition, as well as other contextual approaches, tries to extend the explanation of human mental activity to the interaction

between contextual factors and cognitive factors. In this case, human behaviour, like problem solving, is part of larger goal-oriented activity (Lehtinen et al. 1995, Pintrich et al. 1993). From the point of view of situated cognition, the use of cognition is a part of the system, which includes social interaction, cultural conventions, social organization, evaluation systems and features of the task (Lehtinen et al. 1995). In addition, socioemotional and motivational features are important in mental activity. Thus, the learning of problem solving skills should be seen as a long-term process in which students not only acquire knowledge concerning the domain, but also learn to adopt a certain attitude to the learning situation (Lehtinen et al. 1995).

The following conclusion can be drawn with regard to individual differences in problem solving. First, the differences between problem solvers are not only differences of personal style, as Papert asserts, but the differences are messages about the different degrees of cognitive capacity the problem solvers possess. This has been expressed clearly in novice-expert studies (Anderson 1995, Chi 1978, Enkenberg 1993, Glaser & Chi 1988, Mayer 1992a), but also children of the same age differ from each other with regard to problem solving skills. This difference has been revealed in ATI studies (Snow 1994; Snow & Lohman 1984).

Second, the difference between a poor problem solver and a good problem solver concerns all levels of knowledge. For example, if a programmer is skillful in the area of strategic knowledge, s/he is skillful in the area of syntactic knowledge, too. On the other hand, if a programmer is skillful in the area of syntactic knowledge, it does not guarantee that s/he is good in the strategic area of programming. The acquisition of low-level knowledge is a necessary condition for the learning of the high-level knowledge, but it is not a sufficient condition. Especially, the problem of school learning is that children in schools do not have enough opportunities to train their schematic and strategic knowledge. Conventional forms of teaching are rarely optimal for developing higher-order thinking, such as problem solving skills (L.B. Resnick 1989). Rarely can students apply school knowledge in a real functional context (J.S. Brown et al. 1989, Järvelä 1996c).

Third, suitable learning environments can support young children and help them to become experts in certain domains earlier than Piaget's and Vygotsky's theories have assumed (Siegler 1991). For that reason, we have to arrange suitable learning environments also for young children - environments in which they can practise acquiring and applying all levels of knowledge in real problem-solving situations.

It is, however, not clear how to connect children's natural activity to higher-order thinking. Expert-novice studies give us a clear picture of effective problem solving, but it cannot be assumed that the path from novice to expert is easily mediated to children (Sweller, Mawer & Ward 1983; Sweller 1994). The difficulty in using the problem solving method is that it requires the learner simultaneously to handle many elements of the problem (Sweller 1994). If the elements are unfamiliar, the cognitive load increases and the problem solver cannot solve the problem.

According to the general constructivist point of view, learning is not simply perception, but its nature is constructive. Learner tries to make sense of the

situation by reconstructing his/her mental structures. The conceptions of the mediation and discovery models of learning emphasizes different things. The mediated model emphasizes the meaning of the teacher in students' learning processes, whereas the discovery model emphasizes the meaning of the interindividual conflicts between learners during learning processes.

## **4 CLEMENTS AND NASTASI'S THEORY OF PROBLEM SOLVING**

### **4.1 The connection of the contextual and cognitive components of problem solving**

The main problem with Papert's hypothesis concerning learning is that on an empirical level it is very difficult to verify the relationship between students' natural activity and the development of problem solving skills. In natural learning and problem solving cognition interacts with contextual factors. Although this idea has been allowed in general there are few studies of this interaction (Littlefield & al. 1989; L.B.Resnick 1989). The idea of combining natural learning with the development of problem solving skills links Papert's theory to current theories which emphasize the combination of context with cognition (Lave & Wenger 1991; Salomon 1993). From another point of view, most studies in cognitive learning psychology have studied children's thinking in a socially isolated and structured task environment. However, the cognitive science research tradition has given us a good understanding of human's cognitive components but only a very limited understanding of situational components. In these studies, the contextual factors of learning have been rejected or at least, the contextual factors have been relegated to the role of external sources of stimulation (Salomon 1993).

The probable reason for the lack of research on interaction between cognition and contextual components in research settings is that variables concerning learners' cognition, cultural situation, social interaction and motivation form a situation of great complexity (Perret-Clermont 1993; Salomon 1992; Schneider & Pressley 1989; Snow 1994). The problem is how to connect environmental factors to human cognition in a task situation and also in a research setting. The solution is not the rejection of the "pure cognition"

standpoint, but the devising of a research setting in which also contextual factors have been taken into account. Andersson, Reder and Simon (1996) have pointed out that there is too little empirical evidence to explain the interaction in students' learning in authentic socially open situations. Clements (1986) emphasizes that Papert's hypothesis are fruitful as a general structural framework, but the problem with these hypothesis is that they are not sufficiently organized to serve the needs of practical research (Clements 1986).

The goal of this chapter is to describe the observational procedure in which both cognitive and contextual factors of learning problem solving skills have been taken into account. This procedure is mainly based on Clements and Nastasi's (1988) observational procedure, but it has been amplified with some important features concerning problem solving learning. Thus, the nature of this chapter is to combine the main aspects of the previously described features of Papert's learning approach (Chapter 2) and general problem solving theory (Chapter 3).

According to Clements and Nastasi (1988), problem solving includes areas concerning social problem solving, effectance motivation and information processing. Social problem solving and effectance motivation can be regarded as contextual factors and information processing can be regarded as a cognitive factor.

## 4.2 Social problem solving

The limitation of problem solving theories is that they do not take into account the role of social interaction in the development of problem solving skills. According to social cognitive theory, the use of knowledge has been motivated, organised and gets meaning in social interaction (Bearison 1982; Bearison & Zimles 1986; Doise & Mugny, 1979). Thus, the source of cognitive development is social interaction. This theory is based on several theoretical perspectives. Both Vygotsky (1978) and Piaget (1963) emphasize the social construction of knowledge. But both describe the nature of social interaction from different points of view. When Piaget emphasized the role of cognitive conflicts in the development of cognition, Vygotsky stressed more the role of interaction without cognitive conflicts.

The Vygotskian perspective on social cognitive theory tries to explain cognitive change in collaborative situations in which interpersonal conflicts are not apparent (Vygotsky 1978). In collaborative situations complementary roles are taken in which partners provide scaffolding for each other (Vygotsky 1978). In these situations, individuals integrate their task conceptualizations into a mutual plan without perceived cognitive conflict. The reciprocal sense-making is essential in the interaction. In this process, individuals attempt to extract meaning, generate ideas, or solve problems through a process of discourse. This kind of collaboration requires individuals to synthesize their actions with those of others (Nastasi & Clements 1991). If collaboration and concurrence seeking are essential in cooperation, cognitive change is promoted (Nastasi & Clements 1991).



The intraindividual conflicts may be engendered within one or several of the individuals via the exchange of ideas. In such cases, the resolution of the discrepancy occurs internally, within the individuals, rather than externally, between individuals. These kinds of intraindividual conflicts and their resolution may be fruitful for cognitive growth (Nastasi & Clements 1993).

Bandura (1969) has stressed peer modelling as an important source of cognitive development and Bearison (1982) has further developed this idea based on the social constructivist point of view. King explains this idea in the following way:

During peer interaction, students are exposed to new strategies, terminology, and ways of thinking about problems; these experiences can restructure their own thinking, which may in turn affect their problem-solving behavior. From the social modeling perspective, peer interaction provides opportunities for imitation of successful problem-solving behaviors. (King 1989, 2).

The Piagetian perspective on social cognitive theory is based on concepts of *equilibration* and *disequilibration*. When Piaget emphasizes the role of the environment in general as the source for disequilibration, social cognition theory emphasizes the role of social interaction as the source for disequilibration. These concepts in Piaget's cognitive theory emphasize the meaning of cognitive conflicts in learning (Dehn & Schank 1982; Piaget 1963). Disequilibration leads to pressure for change in human cognitive structures and processes (Beilin 1989). Disequilibration is caused when human conception comes into conflict in the social interaction process with another person's conception (Bearison & Zimiles 1986). In this conflict situation, humans use accommodation, in which the previously acquired conceptions change. Thus, social interaction that requires coordination of actions or thoughts facilitates cognitive development (Perret-Clermont 1980). Piaget has also emphasized that insofar as humans are thinking only for themselves, they have no need to be aware of the mechanism of their reasoning (Piaget 1928). Based on social cognitive theory, Clements and Nastasi (1988) underline that metacognition in problem solving has origins in such social interaction, too. The emphasis on the meaning of cognitive conflicts for the development of metacognition in the problem solving process combines Papert's learning theory with social cognition theory described previously. In the same vein Markman emphasizes the fruitful effect of errors for the use of metacognition (Markman 1977).

In addition to social cognitive theory Papert's view of natural learning converges at several points with approaches that emphasize the significance of culture in the learning process. Granott and Gardner (1994) describe the insight of the Soviet school as following:

Another line of critique questioned Piaget's focus on the isolated child, with little regard to the child's social environment. Following Vygotsky (1962, 1978) and the Soviet school, many researchers viewed cognitive change as an interpersonal process rather than a process related to the individual in isolation. (Granott & Gardner 1994, 172).

According to Vygotsky, cognitive development is initiated by adult-child interaction, and is later internalized by the child (Vygotsky 1978). The content of

this interaction is composed of cultural models. The view of the Soviet school has been regarded as contradictory to Piaget's indication of cognitive conflict (Granott & Gardner 1994). Instead of studying the individual's cognitive conflicts in the environment, these studies analyze the shared meaning that evolves between the child and a more capable partner.

Also Cole and Cole (1989) and Wartofsky (1979) emphasize the role of culture in cognitive development. Cole and Cole (1989) assume that the child's development has as its prerequisite the acquisition of models that are in force within a culture (Cole & Cole 1989). According to Wartofsky, an individual constructs his/her own cognitive models of cultural artifacts (Wartofsky 1979). These artifacts include linguistic models, objects, tools, rules of behaviour, and models of thinking. When Papert (1980) emphasizes the meaning of culture for cognitive development, he points out that Logo serves as a new cultural artifact produced by the information society - an artifact by means of which children can learn cognitive models according to the principle of natural learning.

At an empirical level, studies have shown that child-child interaction during the learning process is effective (Granott & Gardner 1994). Studies have also shown that especially in the computerized learning environment pupils exhibit higher levels of cooperative work than in off-computer learning environments (Clements & Nastasi 1985). Furthermore, programming in pairs has been found effective (Borg and Dickson 1986).

In addition, research has shown that pupils prefer the social use of the computer (Clements & Nastasi 1992, Kari & Nöjd 1991, Kontinen & Korhonen 1987). It has also been consistently shown that the amount of cooperation is at the same level in the CAI/CBI<sup>12</sup> and Logo learning environment (Clements & Nastasi 1985; 1988; Nastasi et al. 1990). However, the Logo groups demonstrated cognitive conflict more frequently than the CAI group, but this difference has concerned social conflict (Nastasi & al. 1990). The amount of cognitive conflict is also related to the number of attempts to resolve the cognitive conflict and success in the resolving it. The Logo group had more previously described types of behavior than the CAI group (Nastasi & al. 1990). Thus, Logo engenders especially cognitive conflicts and their resolution, which is fruitful for cognitive growth (Nastasi & Clements 1993; 1994).

In Nastasi's and Clements' study (1994) students in the Logo environment experienced more failure and difficulty during problem solving than students in the CBI environment. However, this difficulty in the projects was not reflected in the students' expressions of displeasure or negative self-evaluations (Nastasi & Clements 1994). Thus, consistent with Papert's learning theory concerning Logo, empirical studies have showed that computer environments appear to facilitate the cooperative learning process. This cooperation promotes cognitive conflicts and metacognitive experiences. Cognitive conflicts thus have a mediational role in facilitating problem-solving performance (Nastasi & al. 1990, Nastasi & Clements 1994). This occurs especially when children are working with self-

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<sup>12</sup> CAI = Computer Assisted Instruction; CBI = Computer Based Instruction. CAI programs in Clements and Nastasi's studies consisted either drill-and-practice material on arithmetic. CBI consisted word processing program with graphic software (Nastasi & Clements 1993).

selected Logo projects and they engage at every step in the problem solving process in which they define the problem and select the problem solving strategies (Clements & Nastasi 1988). According to Clements and Nastasi (1985), child-child interactions during Logo programming are as significant for cognitive development as are the child-computer interactions (Clements & Nastasi 1985). Clements and Nastasi (1988) summarize the meaning of social interaction for cognitive development in the following way:

Thus, cognitive growth cannot be accounted for solely on the basis of solitary reflections. Metacognitive components of problem solving also may have origins in such interaction; Piaget (1928) has stated that insofar as they are thinking only for themselves, children have no need to be aware of the mechanism of their reasoning. (Clements & Nastasi 1988, 89).

Cox and Berger have shown that students work better in teams than alone when using the computer during problem-solving (Cox & Berger 1985). Especially dyads and four-student groups work in an adequate way with the computer (Cox & Berger 1985).

In school it is important that students encounter cognitive conflicts. But the occurrence of conflicts and the students' own satisfaction with the solutions are not a sufficient condition for conceptual change. The first problem is, that in school learning it is a very common that students' preinstructional beliefs about the knowledge presented in the school conflict sharply with many of the accepted scientific theories taught in school (Chinn & Brewer 1993; Driver, Guesne & Tiberghien 1985; Perkins & Simmons 1988). Thus, the encounter with contradictory information is at the heart of learning (Chinn & Brewer 1993). The second pedagogical problem is that students rarely abandon or modify their preinstructional beliefs in the face of new, conflicting data and ideas. On the contrary, students often staunchly maintain the old ideas and reject or distort the new ideas. In addition, in the history of science, anomalous data have played an important role in scientific revolutions (T. Kuhn 1962).

#### **4.2.1 Social problem solving measurement in this study**

Based on the idea that social interaction during learning, and especially during LEGO/Logo problem solving, is fruitful for cognitive growth, observational procedures to serve the aims of this study have been developed with respect to social problem solving. The observational procedure is based principally on Clements and Nastasi's observational procedure (Clements & Nastasi 1988, Nastasi et al. 1990, Nastasi & Clements 1993) and has been used in this study in the experimental phase. According to Clements and Nastasi (1985, 1988), social problem solving means the capability of effectively applying problem solving skills to real-life social situations. They incorporate in social problem solving the capability to work in a cooperative fashion and the capability to successfully resolve conflicts without adult intervention. It is important to notice that the source of cognitive conflicts is the task and the different interpretations of the task. If the student feels the situation to be conflicting, it does not necessarily mean that the source of these conflicts is cognitive. As social-cognitive-oriented

theory has explained, many students have social or emotional conflicts in the task situation (Lehtinen & al. 1995). In these cases, students first have to solve social and emotional conflicts, and after that they are capable of dealing with cognitive conflicts.

Clements & Nastasi (1988) subsume under social problem solving *Cooperative work, Conflict and Resolution of conflict*. In their later work, they made some changes for their social problem solving measurement (Nastasi, Clements & Battista 1990; Nastasi & Clements 1993). First, they disconnected cognitive conflicts from social conflict. This disconnection is based on the empirical finding (Clements & Nastasi 1988) that students in the CAI group and Logo group have the same degree of conflict, when conflict refers to both social conflict and cognitive conflict. In their 1990 study they find that especially the Logo group has more cognitive conflicts. Second, they add the variables *Attempt to resolve conflict, Success in resolving conflict* (Nastasi & al. 1990) and *Failure in resolving conflict* (Nastasi & Clements 1994) to their procedure. These supplements are consistent with Papert's idea that not only the conflicts, but especially the processes after the conflicts, are important for cognitive growth (Papert 1980). Clements and Nastasi's description of social problem solving includes the main part of Papert's theory concerning AI. Cognitive conflicts and their solutions are an important part of problem solving according to Papert (1980; 1993).

Clements and Nastasi have developed their measurement mainly based on Papert's and Piaget's theory. Therefore they emphasize the role of students' work without adult intervention and the role of cognitive conflict for the development of problem solving skills. The Vygotskian tradition and cultural school emphasizes the role of the adult in the learning process. In addition, as was noted previously, pupils at a low level of academic achievement need more help from the teacher in the instructional situation than pupils at a high academic level (Snow 1994; Snow & Lohman 1984; Suomala 1996). In this research, the respective roles of the teacher in the students' problem solving were studied by means of adding the research component *cooperation with the teacher assistance* to the procedure of Clements and Nastasi (1988). This idea is consistent with the Vygotskian tradition in which reciprocal understanding and shared meaning between students and the teacher, as well as between student and student, has been regarded as an important source for cognitive development. This kind of interaction does not necessarily include transparent cognitive conflicts. Table 2 (p. 60) presents the observational scheme for social problem solving in this study.

The observational procedure presented in Table 2 includes important aspects of social-cognition theory. First, the variable *cooperation with another child*, describes childrens' cooperation, which includes the extraction of meaning, the generation of ideas or work through a process discourse without apparent cognitive conflict. This kind of interaction is fruitful for learning, according to Vygotskian tradition (Vygotsky 1978). During this kind of process, children can take complementary roles, in which pairs provide scaffolding for each other and together try to increase reciprocal sense-making. Second, the variable *cooperation with the teacher* describes the child's or children's cooperation with the teacher. In the experimental phase in this study the suggestion for cooperation was made by the child/children or by the teacher if the child had experienced the same difficulty over a longer period.

TABLE 2 Observation scheme for social problem solving

Behavior	Definition
Cooperation with another child	Child works with another child on an academic task without conflict and without teacher
Cooperation with the teacher	Child works with the teacher on an academic task. Interpersonal conflict can be apparent or not
No cooperation	Child does not work with another child or the teacher.
Cognitive conflict	Child engages in verbal or physical cognitive conflict with another child, or computer. Conflict concerning task conceptualization or solution. Also computer can cause mental conflict for the child (e.g. unexpected error message).
Attempt to resolve cognitive conflict	Child attempts resolution of conflict without adult intervention.
Success in resolving of cognitive conflict	Child reaches successful resolution of conflict without adult intervention.
Failure in resolving cognitive conflict	Child reaches no successful resolution of conflict without adult intervention.

However, all kinds of cooperation between the teacher and children during LEGO/Logo programming were coded in this class during an experimental phase. According to the Vygotskian tradition, cooperation between the teacher and students is a basic prerequisite for higher-order thinking. Third, the variable *no cooperation* describes childrens' behaviour in which either or both do not concentrate on LEGO/Logo working. This kind of "off-task behavior" is usual in conventional school working, but many studies have shown that working in a computerized learning environment decreases off-task behaviour. My previous study (Suomala 1996) made use of the observational classes *cooperative play* and *social conflict*. Cooperative play describes children's cooperation, but the cooperation is concentrated on some other area than the task itself. This variable was omitted from this study because in the experiment the occurrence of this kind of behaviour was zero. Social conflict means that children have an obvious disagreement which has no relationship to the execution of the Logo programming. Because the occurrence of this kind of behavior was also zero in this study, the variable *social conflict* was omitted from the observational procedure.

The variables *cognitive conflict*, *attempt to resolve cognitive conflict*, *success in resolving of cognitive conflict* and *failure in resolving cognitive conflict* all describe behaviour in which cognitive conflict and its solving process are transparent. Papert (1980) and also Clements and Nastasi (1988) based their theoretical ideas on the assumption that the occurrence of cognitive conflict as well as the solving

process concerning these conflicts increases children's effectance motivation and hence improves cognitive development.

It is worth noting that in this research the source of cognitive conflict can be the computer itself. This is reasonable because one basic idea in Papert's learning theory is that the Logo programming language itself can be the source of cognitive conflicts (Papert 1980). The observational technique will be described in more detail in chapter 5.

### 4.3 Effectance motivation

Problem solving consists not only of cognitive capability and social interaction, but also of emotional and motivational aspects. An essential question related to problem solving is what maintains the process. Csikszentmihalyi and Csikszentmihalyi (1988) have applied the term *flow* when they describe the activity of artists, athletes, scientists, mountain climber and others, who want to work continuously at the limit of their competences. Flow refers to an experience of sustained pleasure when people are working. Essential for flow experiences are total absorption in the activity, in which all mental resources are invested in the activity so that none are available for self-reflection (Csikszentmihalyi & Csikszentmihalyi 1988). The occurrence of flow requires balance between ability and challenge. If challenge exceeds capability, anxiety and frustration will arise instead of a flow experience. In contrast, if capability exceeds challenge, the result is boredom (Csikszentmihalyi & Csikszentmihalyi 1988). Thus, general performance forms both cognitive and motivational aspects of learning.

The natural activity of the learner is a basic assumption in Papert's learning theory. New interpretations of cognitive learning psychology (Collins & al. 1989; Brown & al.1989; Järvelä 1996b; Lehtinen & al. 1995) emphasize that the learner's activity and orientation toward learning are developed by instructional actions. In Papert's theory natural activity does not mean that the acquisition of higher order thinking is a short, or easy process. On the contrary, the process is long and for that reason, according to Papert, the learning process has to be based on children's natural activity. According to Papert, the problem is that the forms of learning situations in the schools do not take enough account of children's natural activity and this leads to inappropriate motivational orientations.

The general limitation of the theories of problem solving is that they do not take enough account of the role of motivation in the learning of problem solving skills. Most of the problem solving theories assume that learners are in a self-explanatory way motivated to carry out problem solving tasks. However, students' motivational orientations differ from each other (Lehtinen & al. 1995).

Because the acquisition of problem solving skills is a long term process, it is important in school learning that the student's motivational orientation develops in an adequate way. Thus, the criterion for relevant learning is not only how complete students' cognitive structures and processes are, but what attitude they adopt towards the tasks in school.

The goal of school learning should be that the learner possesses a task-oriented problem solving strategy (Järvelä 1996b; Lehtinen & al. 1995). But problem solving studies have not adequately discussed the role of the development of motivational orientation for problem solving skills. According to the systemic approach of learning, students have a different motivational orientation in the learning situation, and this orientation has developed during the learners' learning history in school (Olkinuora & Salonen 1992; Lehtinen & al. 1995). The student's own motivational orientation is gradually reinforced through learning situations in school, which increases the probability of a similar cognitive-emotional orientation in subsequent learning situations (Olkinuora & Salonen 1992, Lehtinen & al. 1995). The interpretation of the task situation can lead either to a progressive or to a regressive learning process (Lehtinen & al. 1995).

In a progressive learning process the learner is involved in the task in an intensive way and s/he wants to master the situation. The learner's interpretation of task clues and instructions consists of recognizing the task as intelligible (Lehtinen & al. 1995). Intrinsic motivation guides the learning process, and social clues or emotional fears concerning failure do not affect this coping strategy. Emotions like curiosity, interest, or enthusiasm arise and the learner enjoys doing the task and he/she expresses pleasure at succeeding in the task (Lehtinen & al. 1995; Olkinuora & Salonen 1992). Such progressive learning processes are likely to promote task-approaching behaviors.

On the contrary, a regressive learning process leads to a nontask-oriented coping strategy or social-dependence coping strategy (Lehtinen & al. 1995), in which learners concentrate their attention on social clues or the defence of their own egos. The characteristic of the task does not guide the learner's actions, but unessential circumstances. In the regressive learning process, a student's initial appraisal may lead to the lack of confidence in task success (Lehtinen & al. 1995). Anxiety, fear of failure, and other conflict-laden, inhibitory emotional states arise. The student does not aim at approaching and mastering the task but at relieving tension or conflict. Positive emotions are connected with the expected satisfaction of the teacher or with reward from the teacher. No inhibiting emotions arise (Lehtinen & al.1995).

Papert's learning theory emphasizes that children are by nature actively orientated toward the environment (Papert 1980; 1993). However, children's motivational orientation often develops toward other matters than those which school regards as important. Papert's criticism of school parallels the previously described systemic approach of learning (Järvelä 1996b; Lehtinen & al. 1995; Olkinuora & Salonen 1992), who criticize school because it develops children's motivation in a regressive direction. Children learn in school to copy from the learning situation, which is often not optimal for real learning. The descriptions of children's action in the Logo learning environment, presented by Papert, also include the basic presumption that children are orientated toward Logo-programming in a progressive way. Thus, Papert applies the concepts of natural learning in the LOGO environment in such a way that all children are motivated toward programming.

The goal of this study is to discuss students' different problem solving processes in the LEGO/Logo environment. Papert's concepts of natural learning refer to cognitive processes, but an essential parts of this concept are also social, motivational and emotional processes related to cognition. Papert supposes that in the LEGO/Logo learning environment the learner has enough motivation and capacity to decide without conscious intervention what a suitable goal of learning is. But it can be assumed that Papert overemphasizes the role of Logo as "an evocative program" for all students.

Effectance motivation means the ability to control or effect change in the environment (Clement & Nastasi 1985). In the learning context this means that children want to direct their own learning (Nastasi & Clements 1993). It has been shown that especially collaborative interactions in the computerized learning environment influence the development of effectance motivation (Nastasi & Clements 1991). Especially social factors, such as feedback, social comparison, and modeling, alter motivation toward a sense of competence (Harter 1982). According to Harter, competence motivation and an internal reward system develop when children successfully solve problems (Harter 1978). Success in the learning task develops students' sense of competence and this feeling serves as a mediator of subsequent mastery-oriented behavior (Harter 1978; Harter & Jackson 1992). In the same vein, Nastasi and Clements (1993) argued that students' sense of efficacy may influence their attempts at task mastery, the amount of self directive behaviour and their persistence in the face of difficulty or failure. Thus, effectance motivation has a central role in the problem solving process, when pupils try to achieve the goal and overcome difficulties.

Clements and Nastasi (1992) have shown in many different studies that Logo and CAI/CBI environments differentially engender effectance motivation. In their first study first- and third grade elementary school students working with screen Logo showed more evidence of increased effectance motivation than students of the same age, working with CAI/CBI (Clements & Nastasi 1985; 1988). This means that students working with Logo had higher frequencies of rule determination and showed more pleasure at intellectual discovery than those working with CAI/CBI drill-and-practice (Clements & Nastasi 1985, 1988). In addition, the Logo groups only showed self-directed work during programming. Clements and Nastasi did not found group differences in frequency of persistence (Clements & Nastasi 1988) or in assistance-seeking (Nastasi, Clements & Battisa 1990). When they compared pupils in the first- and third grades, first grades engaged in more approval seeking than others and third graders working with Logo exhibited the highest levels of rule determination behavior (Nastasi & Clements 1993).

In Clements and Nastasi's second study concerning fourth and sixth grade students (Nastasi et al. 1990), the Logo group showed significantly more pleasure than those in CAI. In contrast, the CAI problem-solving group exhibited significantly more positive statements about themselves during working. Furthermore, the Logo group exhibited more rule-making behaviour and approval seeking from the teacher, compared to the CAI group. Nastasi et al. (1990) explain this paradoxical result on the basis of Harter's (1978, 1982) work. Students, according to Harter, judge their competence partly on the basis of the



external feedback. Nastasi et al. (1990) argued that CAI environment provides the external feedback and it is possible that working in the CAI environment evokes positive self-appraisals of performance (Harter 1978, Nastasi et al. 1990, Clements & Nastasi 1992). In contrast, the internally structured Logo environment does not provide the external feedback, but does provide intrinsically interesting phenomena, and “these might be more likely to evoke feelings of pleasure or satisfaction with the product of one’s efforts.”(Nastasi & al. 1990, 157). Thus, the need for external feedback is important even within the Logo learning environment. In the same vein Harter (1982) suggests that individuals rely on a combination of self-evaluation and social feedback in making judgments about their own competence. Thus, students need social support from the teacher even within an intrinsically-interesting, self-directed context (Nastasi & Clements 1994).

#### 4.3.1 Effectance motivation measurement in this study

Clements and Nastasi (1988) subsume under Effectance motivation the variables *Self-directed work*, *Rule determination*, *Persistence*, *Assistance seeking from the teacher* and *Expressing pleasure*. All these are characteristics of previously described features concerning the progressive learning cycle. These variables describe behaviour which is connected to the problem solving. Papert has suggested that this kind of self-directiveness occurs in the LOGO learning environment. Table 3 presents the observational scheme for effectance motivation used in the experimental phase of this study.

TABLE 3 The Observation scheme for effectance motivation

Behavior	Definition
Self directed work	Child initiates or engages in an independent work activity without teacher's coaxing or direction; includes constructive solitary or parallel work.
Rule determination	Child engages in self-determination of rules, for example, making plans. Includes the use of verbal heuristics for solving problems.
Persistence	Child persists with a task after encountering difficulty or failure without teacher's coaxing or encouragement.
Assistance seeking	Child seeks help or attention from teacher relevant to task solution.
Expressing pleasure	Child shows signs of pleasure at solving (i.e. mastering) a problem or at discovering new information (e.g., child cheers after reaching a solution).

The variables, *self-directed work*, *rule determination*, *persistence* and *expressing pleasure* in the observational procedure presented in Table 3 are identical to Clements and Nastasi's 1988 study. In their later study (Nastasi, Clements &

Battisa 1990) they added to the procedure the variables *approval seeking from the teacher* and *assistance seeking from the teacher*. Because the occurrence of approval seeking was zero in this study, I have only used the variable *assistance seeking*. Even so, this procedure mainly measures children's independent work, especially the variable *assistance seeking* gives us a picture of children who want or who must get support from the teacher. It is worth noting that the suggestion for asking comes in this case from the child, not from the teacher. Thus, this variable refers more to situations in which the child uses the teacher as resource person, than to situations in which the child is socio-emotionally dependent on the teacher.

The observational technique based on the observational scheme for effectance motivation will be described in more detail in chapter 5.

#### 4.4 Information processing

Social problem solving and effectance motivation are connected to Papert's conception of natural learning. An important standpoint in Papert's learning theory is the assumption that Logo fosters cognitive development, especially the development of higher-order thinking. The assumption is that learning processes in the Logo environment include the use of metacognition in the correction of programming. Clements and Nastasi (1988) agree with Papert when they write:

There is reason to hypothesize that certain Logo programming environments may engender social interaction that promotes conflict of concentrations and metacognitive experiences. When working with self-selected Logo projects, children engage in every step of problem solving, from problem definition to strategy choice to solution monitoring. (Clements & Nastasi 1988, 89).

In problem solving it is important to distinguish between the initial planning of a solution and its actual execution (Holyoak 1991; Siegler 1991). The precondition for this separation is that the problem solver can in a conscious manner, plan either his/her own action (metacognition) or task solution. Although the problem solver needs all levels of knowledge (syntactic, semantic, schematic and strategic knowledges), the central role is played especially by strategic knowledge.

As has been described in chapter 2, Papert considers the depth first approach as good a strategy as the breadth first approach. He calls these strategies the formal programming style and the concrete programming style. The students in this study are all novices, although they differ in their experiences of Logo programming. However, we can assume that the students differ from each other in problem solving processes. Thus, it is meaningful to study the differences in students' information processing in the logo-programming process.

Previous research has shown that students working with Logo exhibited more frequent use of metacomponential processing (*defining the nature of the problem, selecting and combining performance components, and monitoring solution processes*) than those working with CAI (Clements & Nastasi 1988). In the Logo group, 26 % of all verbalizations during the problem solving process reflected metacomponential processing, compared to 7 % of CAI-group. The result of

Nastasi and Clements' study supported the finding that Logo's effects on thinking are mediated to some extent by effects on motivation (Nastasi & Clements 1993). In addition, students in the Logo group spent more time engaged in reading plans and using material as resources, whereas the CBI-W group spent more time "taking turns" at the keyboard (Nastasi & Clements 1993).

#### 4.4.1 Information-processing measurement in this study

*Information processing* includes metacomponents and performance components. Metacomponents are executive processes utilized in planning and evaluating one's information processing (Clements & Nastasi 1988; Kolligian & Sternberg, 1987; Sternberg 1985). Performance components are used in the actual execution of tasks and they form a variable of their own (see Table 4). The scheme for categorizing metacomponents of problem solving is based on the study of Clements and Nastasi (1988), who in turn constructed it on the basis of Sternberg's (1985) triarchic theory of intelligence. Metacomponents include the variables *Deciding on the nature of the problem*, *Selecting performance components*, *Combining performance components*, *Forming a mental representation*, *Monitoring solution processes*, *Being sensitive to external feedback* and *Allocating resources*. The observational scheme of Clements and Nastasi (1988) was used in this research to describe the cognitive part of the children's problem solving when they used the LOGO programming language. The students' conversations during the problem-solving was categorized according the information processing categories described in Table 4.

The Information-processing scheme presented in Table 4 is identical with Clements and Nastasi's (1988) procedure, but lacks one variable. Because the occurrence of the variable *forming a mental representation* was zero in this study, this variable has been omitted. In chapter 5 I give a detailed overview of how I analyzed the students' problem solving processes from videotape based on the categories (Tables 2 - 4) described in this chapter.

TABLE 4 The Observation scheme for information processing components

Component	Definition	Examples
Deciding on the nature of the problem	Determining what the task is and what it requires	"We may program music whenever the robot turns. Thus we must use TONE commands together with RIGHT or LEFT commands."
Selecting performance components	Determining how to solve the problem	"First put LEFT 6 and then TONE 232, so that the music plays at the same as the robot turns."
Combining performance components	Sequencing the components selected	"First FORWARD 40 and then LEFT 7."
Allocating resources	Deciding how much time to spend on various components	"That's enough time talking. We should move it."
Monitoring solution processes	Keeping track of progress and recognizing the change of strategy	"The distance is more, I thought that FORWARD 30 is enough."
Being sensitive to external feedback	Understanding and acting upon feedback	Teacher: "What were you supposed to do now? Pupil: "Oh, yes, I should've put in another command after WAITUNTIL [SENSOR?]."
Performance components	Executing the task; include encoding and responding	"TONE 2-5-6, FORWARD 4-0, LEFT 9" (typing with the computer).
Other	Miscellaneous; includes off-task and uninterpretable verbalizations	"Did you see that programme last night?"

## 5 RESEARCH PROBLEMS AND DESIGN

Using Logo as an example, Papert tries to combine children's natural activity with higher-order thinking processes. In the Logo learning environment, according to Papert, children become engaged in their programming task in a motivated fashion. Papert has two main suppositions about learning: children learn optimally according to natural learning and the Logo computer language fosters the cognitive development of children. Essential in this learning process is the use of metacognition in the correction of programming.

Logo has been studied fairly extensively, but the results concerning its influence on children's cognitive development are contradictory. It seems that Logo itself does not develop problem solving skills. A much more detailed analysis is needed of the conditions under which the Logo learning environment would work in the way Papert meant it to work. It seems that the teacher's role is central.

This study tries to clarify the development of students' context-independent thinking skills in the LEGO/Logo groups and in the ordinary group based on Piaget's thinking experiment (Enkenberg 1989). In addition, this study tries to study, how students' problem solving processes in the LEGO/Logo learning environment differ from each other. The LEGO/Logo group (n = 103) attended the 20-hour-long teaching phase. During the teaching phase students learnt Logo commands relating to the merry-go-round project and robot project (see Table 6). The mediated LEGO/Logo group (n = 48) learnt Logo commands according to mediated model of learning whereas the discovery LEGO/Logo group (n = 56) learnt the command according to the discovery model of learning. The ordinary group (n = 95) attended conventional teaching without the use of computers. The research problems concerning the development of context-independent thinking are as follows:

1. Does LEGO/Logo learning influence the development of students' Piagetian thinking?

This problem divides into three subproblems:

- 1.1. Does the development of the Piagetian thinking of students in the LEGO/Logo group differ from the development in the ordinary group?
- 1.2. Does the development of the Piagetian thinking of students in the mediated LEGO/Logo group differ from the discovery LEGO/Logo group?
- 1.3. Is there any relationship between the development of Piagetian thinking and the learning model (ordinary/discovery/mediated), gender, school achievement and prior experiences of programming?

The research problems concerning the problem solving processes in the open LEGO/Logo environment are as follows:

2. Does the problem solving process of students who have learnt LEGO/Logo programming based on the discovery model differ from that of students who have learnt it through the mediated model?

Recent research on learning emphasizes that the learning environment as such - e.g., the LEGO/Logo learning environment - is not enough to develop individual students' learning (Järvelä 1996a). More knowledge is needed about individual differences in problem solving between students in order to develop pedagogically meaningful learning environments. In the next subproblem, I try to clarify individual differences in problem solving processes in the LEGO/Logo learning environment:

- 2.1. Is there any relationship between the problem solving process in the LEGO/Logo learning environment and the learning model (mediated/discovery), the level of Piagetian thinking in the pretest (Low/ high), gender and previous experience of Logo programming?

The third problem deals with the quality of the final LEGO/Logo program:

3. Does the final LEGO/Logo program of students who have learnt LEGO/Logo programming based on the discovery model differ from that of students who have learnt LEGO/Logo programming based on the mediated model?

There is one subproblem concerning problem 3:

- 3.1. Is there any relationship between the final LEGO/Logo program and the learning model (mediated/ discovery), the level of Piagetian thinking (in the pretest), gender and previous experience of Logo programming?

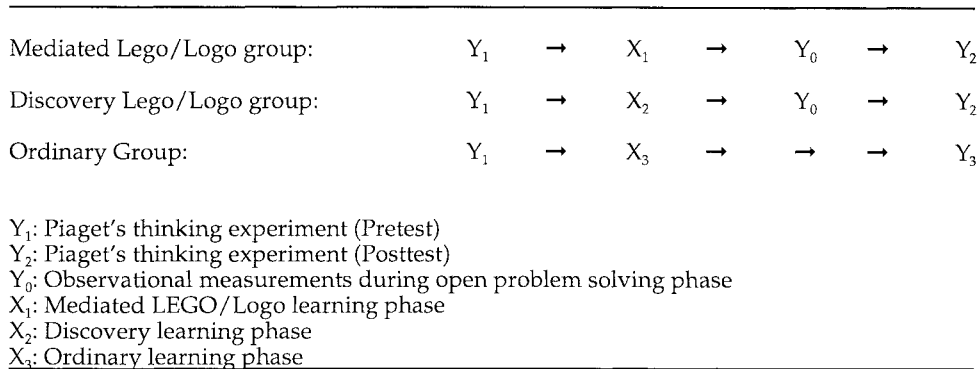


FIGURE 2 The design of the study

Figure 2 presents the design of the study. The development of context-independent thinking (research problem 1; 1.1. - 1.3.) was studied in the following manner. Piaget's theory offers a tool for evaluating of context independent thinking. According to Piaget, the essential operational schemata are combinations, proportionality, probability and permutations (Enkenberg 1989, Inhelder & Piaget 1958). Through these schemata Piagetian thinking is closely associated with the processes and contents of school learning as well as with problem situations occurring in everyday life (Enkenberg 1989; Shayer & Adey 1981). Piaget's thinking experiment in this study includes a test of the student's ability to pass the test of *displaced volume, proportionality, probability and permutation*. This same test has been arranged as the pretest ( $Y_1$ ) and as the posttest ( $Y_2$ ) for all three groups (Figure 2). Piaget's thinking experiment was arranged in Spring 1992, before and after the LEGO/Logo learning phase. The changes in test scores from the pretest ( $Y_1$ ) to the posttest ( $Y_2$ ) are compared between the LEGO/Logo group ( $N = 103$ ) and the ordinary group ( $N = 95$ ). In this comparison the LEGO/Logo group was formed from both the mediated LEGO/Logo group and the discovery LEGO/Logo group. In this way it is possible to assess the influence of LEGO/Logo on the students' context independent problem solving skills.

The students' problem solving processes (research problems 2, 2.1; 3, 3.1) in the open LEGO/Logo learning environment are studied by observational measurement ( $Y_0$  in Figure 2). This procedure has been presented in more detail in chapter 4. While with Piaget's thinking experiment it is possible to study students' thinking skills in a structured and socially isolated situation (paper-and-pencil test), with the observational procedure it is possible to study students' problem solving processes in an authentic programming situation. In this situation the students worked in pairs. According to Papert, unstructured problems are an important precondition for the development of problem solving skills of children in a LEGO/Logo learning environment (Harel & Papert 1991; Papert 1980; 1993).

In addition, 88 students from the LEGO/Logo group (42 from the mediated group and 46 from the discovery group) participated in the open LEGO/Logo experimental phase after the teaching period. The students' problem solving

processes were videotaped in the open problem solving phase arranged after the teaching phase, in which one pair of students at a time programmed the Lego robot to go through a certain route. On the basis of this material, the analysis focuses on what kind of behavioral features significant for the problem solving process can be discerned in the learning process (see chapter 4).



## 6 METHOD

### 6.1 Subjects

The subjects of this study are 198 eleven to twelve-year-old Finnish fifth-grade students at three primary schools in rural communities in central Finland. The number of girls was 96 (48.5%) and the number of boys was 102 (51.5%). Students in school 1 (n = 46) and school 2 (n = 57) attended the LEGO/Logo group and students in school 3 (n = 95) attended the ordinary group. The LEGO/Logo group consists of both the mediated LEGO/Logo group and the discovery LEGO/Logo group. The LEGO/Logo group (n = 103) participated in the 20-hour-long LEGO/Logo teaching phase, whereas the ordinary group (n = 95) participated at the same time in the conventional school program. In addition, 88 from the LEGO/Logo group participated in the open LEGO/Logo experimental phase. 42 of them have learnt programming based on the mediated model of learning and 46 have learnt it based on the mediated model of learning. Students were chosen for the experimental phase according to the following principles. Students who did not have a constant partner during the teaching phase for at least 16 hours, and students who worked alone during the whole teaching period were excluded from the experimental phase. This group includes eight students. In addition, eight students were omitted from the discovery group in order to make the mediated and discovery groups as similar as possible. 33 students of the LEGO/Logo group had 20 hours' experience of screen Logo programming before this study; other students had no previous experience of programming.

Students in the LEGO/Logo group came from four different classes and they were divided by class teachers into nine groups before the teaching period. Each group included 10 - 12 students. The teaching period was arranged in such a way that in four groups teaching was based on the mediated model of learning (n = 47) and in five groups on the discovery model of learning (n = 56). The learning model for each group was randomized by the present researcher.

Although the schools are a sample of convenience, there are no indications that they are in any way different from other primary schools in Finland. International comparisons (Linnakylä 1993, 1995) suggests that the between-school variance in Finland is small. There were no statistical differences between the groups in the Piagetian pretest. The mean test score on the Piagetian pretest in the LEGO/Logo and ordinary groups were respectively 16.22 and 16.74, [ $t(190) = 0.95, p = 0.95$ ]. In addition, the mean test score on the same test was 15.37 in the mediated LEGO/Logo group and 16.92 in the discovery LEGO/Logo group, [ $t(100) = 1.90, p = 0.061$ ]. Thus, there are no statistical differences between the three groups in this study and it is reasonable to assume that all groups represent typical students in this age group.

There were two reasons for choosing the students in this study. First, according to Piaget's theory, eleven/twelve-year-old students are transferring from the concrete operational stage to the formal operational stage (Inhelder & Piaget 1958). This means that students in this age are capable of taking into account of several different components in problem solving processes. Thus, it can be assumed that students can benefit from Logo programming in this age (Enkenberg 1989; Hautamäki 1984; Shayer & Adey 1981). Although the strict stage theory has been heavily criticized (Siegler 1991), recent research has also shown that students at this age begin to develop thinking skills for generating procedures in a multivariable context (Kuhn et al. 1992; Klahr et al. 1993). The skills to take into account many variables at the same time are necessary in the LEGO/Logo context used in this study. One can assume that some students can use a very developed problem solving strategy in the LEGO/Logo learning environment at this age.

The second reason was practical. This study is an extension of a screen-Logo study (Suomala 1996). The aim was to choose in part the same students who participated in the screen Logo study ( $n = 33$ ). In this way, it was possible to study how previous experiences of Logo-programming influence programming in LEGO/Logo. Table 5 describes subjects according to gender, school and teaching group.

TABLE 5 Subjects of the study by gender, school and teaching group

School	LEGO/Logo group				Ordinary group		Total
	Mediated Boys	Mediated Girls	Discovery Boys	Discovery Girls	Boys	Girls	
School 1	16	8	14	8			46
School 2	11	12	15	19			57
School 3					46	49	95
Total	27	20	29	27	46	49	198

## 6.2 Teaching phase

All students in the LEGO/Logo groups ( $n = 103$ ) participated in a 20-hour LEGO/Logo teaching period during spring 1992. During the same period the ordinary group ( $n = 95$ ) participated in standard lessons without computers.

Otherwise the lessons in all schools followed the official Finnish curriculum. Subjects in the discovery group learnt LEGO/logo programming according to the discovery model and subjects in the mediated group learnt programming according to the mediated model.

The essential difference between the mediated and the discovery group was that the goal was set by the teacher in the mediated group, whereas in the discovery group, students themselves set the goal. The purpose of the teaching phase was to familiarize students with the LEGO/Logo system so that they could function comfortably in the experimental phase.

The lessons were arranged in two elementary schools, both of which had a computer classroom with six PC computers. The size of the group taught at a time was 10-12 students and most of the students worked in pairs. Pair working makes sense, because research has suggested that collaborative interactions are more beneficial for promoting cognitive growth than individualistic endeavors in the computerized learning environment (Nastasi & Clements 1993). Nine groups were composed, four of which were mediated groups and five discovery groups.

The present researcher was the teacher for all the LEGO/Logo groups. In the first lesson, students chose their own partners. Each group was taught ten lessons, two hours at a time. The teaching consisted of *two projects*. These were the *merry-go-round* project and the *robot* project. The names of the projects refer to the devices to be built with LEGO components. Students built the merry-go-round and the robot according to LEGO/Logo guidebook. During building they could decide for themselves how many lights to place on the merry-go-round and the robot. Likewise they could decide how many "legopeople" used the device. However, the essential aspect concerning these projects is that they involve the programming of the device with the computer. During each project the following concepts were taught: *basic commands (how to use engines, lights and music), repeat command and writing a programme*.

The teaching phase followed these principles: Students learned during the teaching period about the syntax and semantics of the Logo commands and how to combine commands into a program to accomplish some goal. The assumption is that when the degree of complexity of programming increases, greater demands are placed on using planning skills.

During the teaching period there was an attempt to ascertain that students learned both how commands work and how these commands can be used in real programming. Thus, at every step, students had the possibility to combine "how-to-do-it information" with "how-it-works information" (Lesgold 1991, 207; Rajan 1991). The teaching period has been planned in this study in such a way that the complexity of the tasks increases during the lesson period. This means in practice that students learn to apply familiar programming concepts with new programming concepts. For example, when students learnt to program the merry-go-round with moving commands they then tried to combine the flashing lights with the moving commands. Thus, gradually, students prepared themselves to encounter novel situations (See Lesgold 1991).

Another goal of the teaching was that the students would learn to take into account the influence of at least three different factors in the operations, namely the device, lights and music. In the case of the robot, for instance, this means that

the students were supposed to write a programme in which they would use not only the basic movements but also the sensor, music, and lights. Table 6 shows contents of the teaching phase used in the study. Each block consists of two hours of teaching.

TABLE 6 Description of the LEGO/Logo teaching phase

Subject of lesson	Command to be learned	Function of command
1. Introduction to LEGO/Logo. Building the merry-go-round and connecting it to the computer. Starting and stopping the merry-go-round.	TALKTO "A, ON,OFF,ONFOR x	Opening the interface port, starting and stopping the motor.
2. Starting and running the merry-go-round for the desired period. Running the merry-go-round for regular intervals. Using the learnt commands in writing the program.	ONFOR x, IDEA OF PROCEDURE; TO name command1 command2 ... END	As above. Starting and running the motor for a period.
3. Running the merry-go-round exactly for the desired amount of revolutions.	LISTENTO, SENSOR? WAITUNTIL [SENSOR?]	Opening two interface ports at the same time. Message from the touch sensor.
4. Practicing the simultaneous use of three ports. Running the motor at the same time with two lights.	TALKTO [1 2 3] FLASH x y	Opening three interface ports at the same time. Switching the lamp on and off.
5. Further practice with the simultaneous use of three ports, combined with music. Planning and running the LEGO/Logo programme to make the merry-go-round run with lights and music.	WAIT x, TONE x y	Combining the music, the rotation of the motor, and the calculator in the self-made LOGO programme.
6. Building the Lego robot and testing it.	ON,OFF,ONFOR x, FLASH x y	Running the Lego robot by means of two motors.

(continues)

TABLE 6 (continues)

Subject of lesson	Command to be learned	Function of command
7. Testing the robot, combining lights and music with the robot movements. Using the Logo commands FORWARD (ETEEN), BACK (TAAKSE), RIGHT (OIKEALLE) and LEFT (VASEMMALLE).	SETEVEN, SETODD	Running the two motors of the robot to move the robot in different directions.
8. Running the robot in the "city". Writing the Logo program for running the robot for a desired distance. Combining lights and music for the "trip to the city".	SETEVEN, SETODD	Planning the robot's "trip to city" and carrying it out by means of lights and music.
9. Moving the robot. Using the touch sensor in controlling the robot. Writing a programme using the touch sensor.	IF SENSOR? [TFD x]	Using four interface ports at the same time in practicing the control of the robot.
10. Programming the robot by means of the concepts learned. Planning, writing and running the programme.		

The teaching phase described above was carried out with the mediated and discovery groups following different teaching methods. The lessons during which the LEGO device (Merry-go-round and robot) was built were the same for both groups. Students built both devices according to a guidebook. In addition, students in both groups could add lights and change the gearing. The difference between the mediated and the discovery group focused on the learning of programming.

The theoretical view of mediated and the discovery model of learning has been described in the chapters 3.4.2 and 3.4.3. The following describes at a concrete level what these learning models indicate in this LEGO/Logo learning program.

In the mediated group, students' learning was arranged according to problem solving, which referred to Turkle's and Papert's (1990) concept *formal programming style* and Vessey's (1985) *breadth first programming style*. Students were instructed in the mediated group, first by the teachers organizing students' programming tasks during the teaching experiment, and, second, with scaffolding

discussion<sup>13</sup> between the students and the teacher during the planning processes. The goal of the scaffolding discussion was that students learnt to cope with novelty situations by conscious planning of the LEGO/Logo program using a top-down method. This process was helped by questions given by the teacher. By answering the questions, students could think of subproblems. Then they wrote the program on paper before programming it with the computer. During (and after) the writing process they discussed the problems with other students and the teacher. The assumption was that students using this method develop into skillful planners, who can take important programming elements into account and build a representation in which those elements are in structural order. The second presupposition was that, after the teaching phase, students can concentrate on the whole problem before actual problem solving and in this way the problem becomes familiar to the problem solver before s/he begins to program. However, the scaffolding discussions during the teaching period should lead to situations where the student want to cooperate with the teacher as well as with the other student.

The teacher's role in the mediated group was twofold. First, in the planning process, he provided scaffolding for every pair to find a suitable solution to the programming task. Second, in the programming process, students were instructed to consult with the partner or other peers as well as the teacher. But, during programming, students could work together if they did not like to ask the teacher.

The next example describes the mediation in the mediated group. The last problem in the merry-go-round project included three components: motor, lights and music (Lesson 5, see Table 6). The problem was presented by the teacher to the mediated group in the following way.

The manager of the amusement park has a problem. "How can I develop my merry-go-round so that the lights flash and music plays as it goes round?" Try to help the manager! Create or discover and carry out this kind of program! You can discuss the matter with other students and with your teacher. First write the program on paper and show it to your teacher before you begin to make the program with the computer. Before writing the program on paper answer the following questions:

1. How many times does the merry-go-round rotate?
2. How many lights flash during rotation?
3. Do the lights flash all the time when the merry-go-round rotates?
4. When is the music heard?

In the discovery group, students' learning was arranged according to problem solving in terms of Turkle's and Papert's (1990) concept *concrete programming style* and Vessey's (1985) *depth first programming style*. In this group, students themselves chose what kind of program they made. A conscious planning process before programming was not necessary. This means that students could begin the programming before writing the Logo program. In the discovery group, the learning process was based on the Piagetian tradition, in which cognitive conflicts

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<sup>13</sup> Bruner's term scaffolding has been used as one mediation tool in modern cognitive psychology. These studies shape the theoretical ideas of Vygotsky (1978).

and the solving process concerning cognitive conflicts are essential for the development of problem solving skills.

The teacher's role was also different in the discovery group than in the mediated group. The teacher did not check students' work during programming if they themselves did not ask for advice. This means that the level of the structure of the problem was lower in the discovery group than in the mediated group. The goal of the discovery group during the teaching phase was that they learnt to deal with new situations by solving the cognitive conflicts during the programming processes. A conscious planning process before programming was not necessary, but it was possible. This means that students could begin programming before or without writing the Logo program. In the discovery group, students became familiar with the problem during the actual programming process. In addition, students' learning was arranged in such a way that they tried to find solutions for the given task during the actual programming process. The idea was that interindividual cognitive conflicts as well as cognitive conflicts between students and computer may facilitate students' learning with self-discovery. Thus, the presupposition was, with regard to learning in the discovery group, that the self-discovery process that engenders social interaction and requires coordination of actions or thoughts, facilitates cognitive development (Perret-Clermont 1980). The other presupposition was that the skill of using metacognition develops especially during cognitive conflict solution (See Clements & Nastasi 1988; Markman 1977).

The following example describes the task given by the teacher to the discovery group in the fifth lesson:

The manager of the amusement park has a problem. "How can I develop my merry-go-round so that the lights flash and music is played as it goes round?" Try to help the manager. Discover, create and carry out this kind of program! You can discuss the matter with other students and your teacher.

The ready-made task by the teacher was the starting point for the programming process in the mediated group. Students in the mediated group had been encouraged to identify the necessary part of the problem given by the teacher. Thus, conscious planning and discussion with the teacher and other students were the mediation tools during lessons in the mediated group. By contrast, students in the discovery group had been encouraged to discover themselves both the goal and the method of solving the programming task. In this way it was possible to compare the effects of the different learning methods on the problem solving process.

### 6.3 Piagetian test of formal operations

The criterion for the development of students' context independent thinking was the students' improvement in their test scores for the Piagetian thinking experiment from the pretest to the posttest. This thinking experiment includes the tests that was built on Piagetian schemata, i.e., *conserving of displaced volume*,

*propositional reasoning, probabilistic reasoning, and mastering of permutation* (Appendix 2). These tests are closely related to Piaget's theory of formal operations. According to Piaget's theory formal operations are significant tools of thinking (Inhelder & Piaget 1958; Karplus, Lawson & Wollman 1978). In addition, these schemata are important in problem solving in school and in life outside school (Enkenberg 1989). In addition, Enkenberg (1989) points out that this class test has been developed in such a way that it is comparable with Piaget's clinical interview (Shayer & Adey 1981).

The Piagetian thinking experiment was developed by Enkenberg (1985, 1989) based on Piaget's theory. In this study, the same test served as the pretest and the posttest. Every student had his/her own answer sheet with four pages (Appendix 2). The researcher demonstrated each subtest to the class. The researcher read the problem aloud and it was also written on the answer sheet. After that students wrote their solution on their own paper. The test of conserving of displaced volume consisted of one part while the other three tests consisted of two parts. Students thus had seven different subtasks. The range of possible scores for the different tests is as follows: *displaced volume*, 1 to 4; *proportionality A*, 1 to 5; *proportionality B*, 1 to 5; *probability A*, 1 to 4; *probability B*, 1 to 5; *permutation A*, 1 to 5 and *permutation B* from 1 to 5. Thus, the personal scores of students on the whole Piagetian test could vary from 7 to 33.

The interpretation of students' answers was based on both the answer and the explanation of the answer (Enkenberg 1989). The criterion for scoring each subtask is described in Appendix 2.

The main constraint on this kind of test is that it can test childrens' thinking only in a structured test situation and it does not give information about how children can solve problems in self-selected test situations. However, the construct validity of the Piagetian group test can be judged to be good in the area of context independent thinking.

The reliability of the group test of Piagetian thinking was evaluated by its internal consistency (Cronbach's alpha =  $\alpha$ ). The reliabilities of the pretest ( $\alpha = 0.67$ ) and the posttest ( $\alpha = 0.74$ ) were satisfactory, and they were mostly at the same level as in the original study (in Enkenberg's 1989 study alpha was 0.78 in the pretest and 0.82 in the posttest). The reason for a somewhat lower reliability coefficient in this study than in Enkenberg's study could be that the test in this study included two subtests fewer than Enkenberg's study. In addition, the intercorrelation between the pretest and the posttest was 0.78, thus the constancy of the Piagetian test measurement was satisfactory.

To improve the external reliability of the thinking test, the same person (the researcher) conducted the tests. In assigning scores to students' answers, the tasks were assessed one at a time. The answer sheets of the LEGO/Logo group and the ordinary group were mixed (Enkenberg 1989). The interpretation of the answers (Appendix 2) was based on Enkenberg's study (1989).

The test score of the Piagetian pretest has been used to study students' problem solving processes in the open problem solving situation. Students with scores from 8 to 16 belong to the *low achiever* group (n = 43) and students with scores from 17 to 26 belong to the *high achiever* group (n = 45).



#### 6.4 Video recording of students' problem solving processes in the open LEGO/Logo situation

After the LEGO/Logo learning phase an open LEGO/Logo problem solving situation was arranged for 88 LEGO/Logo group students. The construction of the problem phase was based on the idea that one of the most important goal of school learning is that students learn to encounter open problem situations. Thus, after the learning phase, an attempt was made to examine whether the mediated method or the discovery method is better from this point of view? The open problem solving situation is presented in Figure 3.

The students were asked to program the robot. Students worked in pairs, which were the same as during the teaching period. The researcher introduced the problem to the students in the following way:

Here you see a board with obstructions on it. Your task is to plan a route for the robot on the board. Write a program that moves the robot from area A to area B. In addition to movement, you can also use lights and music if you wish. During the task you may discuss freely. You may also ask me for advice if you like. Here is a piece of paper you can use in planning, if needed. You can also test the various stages of the program during the planning. Any questions? You can start.

The whole problem solving process of each pair was videotaped using on-line techniques. A video camera was used to record students' behavior. A VGA/PAL-video-transfer-card was used to record students' programming code from the computer screen on to the other videotape during the programming process. Later, both videotapes were combined into one videotape so that both students' behavior and the programming code from the screen could be observed from one tape. Subsequently students' problem solving processes were analyzed from this real-time video material. The behavior of students was assessed by means of the observational procedure described in chapter 4. To assess social problem solving and effectance motivation, observations for each pair of students were conducted from the videotape. The occurrence of behavioral features was assessed at intervals of 10 seconds. The frequencies of each variable in the areas of social problem solving and effectance motivation were counted. Because the duration of the problem solving processes varied from pair to pair, these frequencies were converted into percentages of occurrence for each variable in the areas of social problem solving and effectance motivation during students' problem-solving processes.

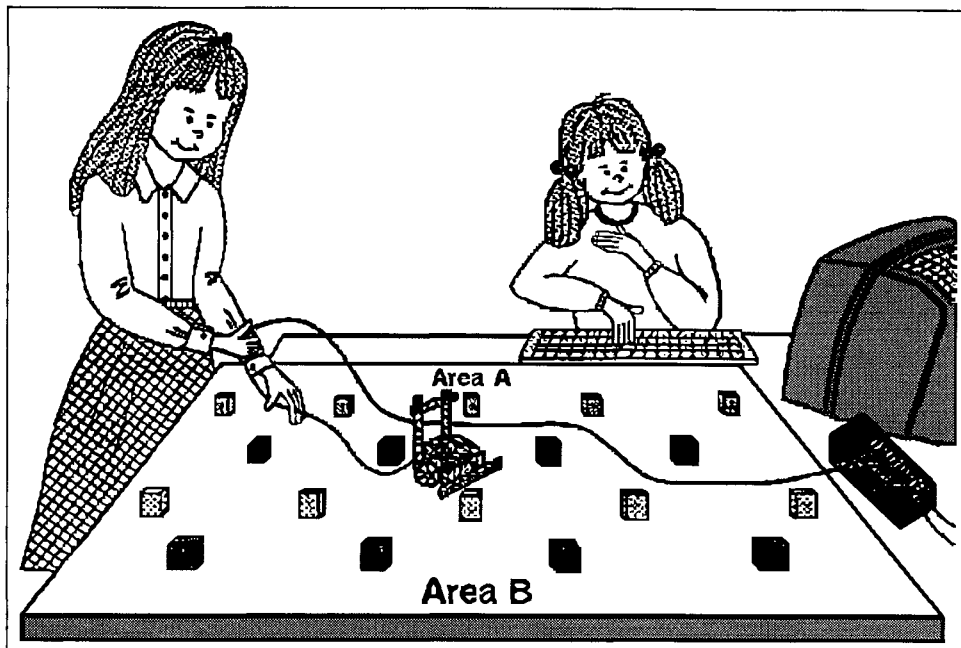


FIGURE 3 The open LEGO/Logo problem solving situation

Students' conversations during the problem-solving process were categorized according to the observation scheme for information-processing components described in chapter 4. Every sentence was categorized into one information processing category. The frequencies of each variable in the area of information-processing were counted and changed into percentages of occurrence.

An observational procedure was used because "traditional" tests excluded contextual factors of thinking. Thus, in the open problem solving situation, an effort was made to develop a research method, in which both internal and external factors of problem solving have been taken into account. The main assumption in this study is that the construct validity of the study will be better if students are observed as they solve self-selected problems. The content of the observational procedure comes from the social, motivational and information-processing part of problem solving. Thus, we can assume that the observational procedure used in this study gives a diversified picture of children's problem solving in an open problem situation. In this kind of measurement, the picture of problem solving skills based on crystallized thinking is amplified through the addition of problem solving skills based on fluid thinking (Eysenck & Keane 1990; Bereiter & Scardamalia 1993). The patterns of relationships among variables of social problem-solving, effectance motivation and information processing were studied by means of factor analysis, described in the next chapter.

The reliability of the observational procedure relating to the *social problem solving* (Table 2) and *effectance motivation* (Table 3) was tested by the amount of

agreement between two raters (interrater reliability). The present researcher first observed the whole observational data. To calculate the interrater reliability, 20 student pairs were chosen randomly, half from the mediated group and half from the discovery group. From the problem solving process of those students, 30 intervals were taken from the beginning, 30 from the middle and 30 from the end of the problem solving process. A parallel rater observed this part of the material, i.e., a total of 1800 intervals. Using the simple matching similarity measure (Anderberg 1973), the agreement of the two independent observers in respect of all variables was 95 %

Students' speech during the problem solving process was analysed in such a way that each spoken sentence was placed into some *information processing category* (Table 4). The present researcher first classified the whole material. To calculate interrater reliability, the parallel rater analysed the same part of the material as she observed. Interrater agreement of the two independent observers was 80.6%.

#### 6.4.1 Derivation of variables concerning students' problem solving processes

The explorative factor analysis with oblimin rotation was conducted to investigate patterns of relationships among variables of social problem-solving, effectance motivation and information processing.

The reason for using factor analysis was that the variables in social problem solving, in effectance motivation and in information processing did not correlate in a one-dimensional way (see correlation matrix in Appendix 3). The oblimin rotation is suitable in this study because the factors could correlate with each other. On the basis of the correlation matrix it is possible to come to the conclusion that the features of the problem solving process do not form clear social, motivational and information processing areas.

The variables *No cooperation* ( $x = 0.18\%$ ) and *Allocating resources* ( $x = 0.67\%$ ) were excluded from the factor analysis. The reason for this was that the distributions of both variables were very skewed. 78 out of 88 students had the value zero in the variable *No cooperation* and 68 out of 88 students had the value zero in the variable *Allocating resources*.

Several factor analyses were carried out with the remaining 18 problem solving variables in order to find a factor solution with meaningful contents. In this connection it became obvious that the communality of two variables *Other* (Communality 0.03) and *Being sensitive to external feedback* (Communality 0.05) was very low and therefore these variables were omitted from the final factor analysis.

Subsequently, an attempt was made to find a suitable factor model with different factors using 16 variables. The three factor solution was selected. On the basis of the eigenvalues (see Appendix 4) it would have also been possible to use the four or five factor solutions, but then it would have been difficult to interpret the outcome of extraction in terms of content.

In the later analyses, a standardized factor score of all three factors is used as a new variable. In addition, the time students spent on their problem solving processes has been calculated from the videotapes.

#### 6.4.2 The analysis of the final Logo program

The last Logo programs constructed by each student pair during the experiment phase were analyzed. The quality of the computer program can be evaluated by various criteria. For example, Fay and Mayer (1994) have classified the quality of a Logo program using the following criteria: *Program length*, *program flexibility*, *the local efficiency* of the program, *the global efficiency* of the program and *program modularity*. The number of commands in the program indicates *the program length* and the number of variable inputs indicates *program flexibility*. The number of times a repeat command appears in the program shows *local efficiency* and the number of same procedures used in the program as subprocedures denotes the *global efficiency* of the program. And, finally, the *program modularity* describes how many distinct modules are included in the program (Fay & Mayer 1994, 202).

In this study operational measures of high quality software have been developed on the basis of such observable program characteristics as the *program length* and the *diversity of the program*. In spite of the fact that the idea of using variables and subprocedures was taught to students during the teaching phase, none of them used variables during the experimental phase, and only four pairs used subprocedures during the experimental phase. Due to this fact, program flexibility and program modularity have not been evaluated in this study. In addition, local efficiency has been replaced by the variable *program diversity*. Because the complexity of the programming tasks increased during the teaching period from the beginning to the end of the phase, it makes sense to discover how much students applied all of the components learnt during the teaching phase in the experimental phase. These components were moving commands, lights commands and music commands. In addition, the repeat command, waituntil command and subprocedures were included in this component. However, there were no differences between the mediated and discovery groups or other subgroups in the amount of use of the repeat command, waituntil command or the amount of subprocedures. The only differences were found in the use of music commands in the final program. Thus, the value for *program diversity* is the same as the number of music commands in the final Logo program.

#### 6.5 School achievement

Students' school achievement was calculated on the basis of their school term mark in mathematics, Finnish and English. In the Finnish school system a scale of 4-10 is used in the school subjects. The information about students' school achievement was given by class teachers. In the analysis, a sum variable of all three school terms ( $\alpha = 0.78$ ) was used, and in this case, the range of this *school achievement* variable was 12 to 30, on which basis students were divided into three groups. Students with scores from 12 to 22 were assigned to the *low achiever* group ( $n = 58$ ), students with scores from 23 to 25 belong to the *moderate achiever* group ( $n = 76$ ) and students with scores 26 to 30 belong to the *high achiever* group ( $n =$

61). This classification is used when studying the development of students' Piagetian thinking.

## 6.6 Statistical analyses

The analyses of the development of students' Piagetian thinking is based on three repeated Multivariate Analyses of Variance (MANOVA) with different combinations of group variables (*instructional model / learning model, gender, prior programming experience, school achievement*). The MANOVAs tested for within-subject change over time between the *pretest of Piagetian thinking* experiment and the *posttest of Piagetian thinking* experiment with a different combination of group variables. Three separate MANOVA models were necessary because the repeated measure MANOVA model with four between-subject variables reduces the number of subjects in cells to the point where MANOVA was not possible. The advantage of the MANOVA model appears especially when the change from the pretest to the posttest is measured because the MANOVA model compares this change in every subgroup. Thus, we get results on the change in general (the main effect of the change) and also on the interaction effects of the change with each independent variable.

The analyses of the effect of the learning model (mediated/discover) and other grouping variables (*gender, prior programming experience, thinking level*) on the students' problem solving processes is based on two between-groups Analyses of Variance (ANOVA).

The homogeneity of variances assumption in MANOVA and ANOVA models was tested with Box's M test. The variances in the cells were homogenous because there were no statistical differences between the distributions in cells. Thus multivariate analysis of variance is possible with this material. The list of variables is presented in Appendix 1.

## 7 RESULTS

This section deals with the results in two main sections. Section 7.1 deals with the development of students' Piagetian thinking, first in the ordinary and LEGO/Logo groups, and second in the mediated and discovery LEGO/Logo groups. Section 7.2 deals with students' problem solving processes in the mediated LEGO/Logo group and in the discovery LEGO/Logo group. Both sections also deal with the role of *gender* and *prior programming experiences* in the development of students' Piagetian thinking and in the nature of the problem solving process. In addition, the ATI (Aptitude Treatment Interaction) effect on the development of students' Piagetian thinking is studied on the basis of *school achievement*, and on the development of students' problem-solving processes on the basis of the test score in the pretest. In addition, the analysis of the students' *final Logo program* is presented.

### 7.1 The development of Piagetian thinking from the pretest to the posttest

#### 7.1.1 The effect of the instruction model and its relationships to gender, school achievement and prior experience.

The MANOVA 1 model is the 2(*Instructional model*<sup>14</sup>: Ordinary/ LEGO/Logo) by 3(*school achievement*: low/moderate/high) by 2(*gender*:girl/boy) and by 2(*time*: pretest/posttest) design for repeated measures on Piagetian thinking experiment. In MANOVA model 1 *the learning model*, *gender* and *school achievement* serve as between-groups variables and *the Piagetian thinking experiment* (pretest and posttest) as a within-subject factor.

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<sup>14</sup> The variable *Instructional model* refers to two groups: Ordinary group and LEGO/Logo group. The variable *Learning model* refers to two groups within the LEGO/Logo group: mediated LEGO/Logo group and discovery LEGO/Logo group

Table 7 shows the mean scores and standard deviations of the LEGO/Logo and ordinary groups and their subgroups for Piagetian thinking in pre- and posttest. Furthermore, Table 8 shows the result of the MANOVA 1 model.

TABLE 7 Mean scores and standard deviations of the LEGO/Logo and ordinary groups and their subgroups for Piagetian thinking in pre- and posttest

Instruction group	N	Piagetian thinking experiment			
		Pretest		Posttest	
		$\bar{x}$	sd	$\bar{x}$	sd
<i>LEGO/Logo</i>	96	16.16	4.04	16.89	4.35
Ability x Gender					
High	29	18.79	3.65	19.58	3.65
Boy	6	17.00	3.89	17.66	4.41
Girl	23	19.26	3.53	20.08	3.35
Moderate	34	16.20	3.82	17.29	3.92
Boy	15	16.13	4.17	17.80	4.10
Girl	19	16.26	3.63	16.89	3.82
Low	33	13.81	3.12	14.12	3.77
Boy	29	13.93	3.28	14.20	3.94
Girl	4	13.00	1.63	13.50	2.51
<i>Ordinary</i>	85	16.80	3.32	17.94	3.45
Ability x Gender					
High	30	18.93	2.92	19.70	3.84
Boy	8	17.87	4.61	17.50	5.18
Girl	22	19.31	2.03	20.50	2.98
Moderate	34	16.38	2.57	17.88	2.19
Boy	17	17.23	2.43	18.29	2.36
Girl	17	15.52	2.47	17.47	2.00
Low	21	14.42	3.18	15.52	3.14
Boy	15	15.20	3.12	16.20	3.09
Girl	6	12.50	2.66	13.83	2.78
<i>ALL</i>	181	16.46	3.72	17.38	3.98

TABLE 8 The relationship between the development of Piagetian thinking and the instruction model, school achievement and gender. Based on the 2(instruction model: Ordinary/LEGO/Logo) by 3(school achievement: low/moderate/high) by 2(gender:girl/boy) and by 2(repeated measure effect: pretest/posttest) MANOVA for repeated measures on Piagetian thinking experiment. (MANOVA 1 model, n = 181).

Source of Variation	DF	F	p
Repeated Measure Effect	1,180	15.38	***
Instruction Model x Repeated Measure Effect	1,180	0.33	ns
School Achievement x Repeated Measure Effect	2,180	1.23	ns
Gender x Repeated Measure Effect	1,180	0.60	ns

(continues)

TABLE 8 (continues)

Source of Variation	DF	F	p
Instruction Model x School Achievement x Repeated Measure Effect	2,180	0.46	ns
Instruction Model x Gender x Repeated Measure Effect	1,180	1.57	ns
School Achievement x Gender x repeated Measure Effect	2,180	0.43	ns
Instruction Model x School Achievement x Gender x Repeated Measure Effect	2,180	0.33	ns

Note. \*\*\*  $p < .001$ ; ns = not significant.

The results of the MANOVA 1 model showed that there was a significant main effect of the Repeated Measure Effect from the pretest to the posttest,  $F(1,180) = 15.38$ ,  $p < 0.001$ , indicating overall improvement in time for all subjects in all groups. No interaction effects were found between time and instruction model,  $F(2, 180) = 0.33$ ,  $p = 0.56$ , between time and school achievement,  $F(2, 180) = 1.23$ ,  $p = 0.29$ , or between time and gender,  $F(2, 180) = 0.60$ ,  $p = 0.43$ . The other interactions without the time effects or higher interaction effects were not statistically significant. This means that all students on average improved their test scores from the pretest to the posttest, but this improvement has no relationship with learning model, gender or school achievement.

### 7.1.2 The effect of the learning model and its relationships to gender and school achievement

While the previous section described the results on the development of Piagetian thinking in the ordinary and LEGO/Logo group, this section concentrates on the development inside the LEGO/Logo groups. Here two different MANOVA models are required because the effect of prior experience of Logo programming was also to be included in the MANOVA model. Thus, gender and prior experience have been differentiated into two different MANOVA models. In this way the frequencies of all cells are sufficient.

To test the development of students' Piagetian thinking during the treatment period in the mediated and discovery LEGO/Logo groups, MANOVA model 2 was implemented. The design was 2(*learning model*: mediated/discovery) by 2(*gender*: boy/girl) by 3(*school achievement*: low/moderate/high) and by 2(*time*: pretest/posttest) MANOVA for repeated measures on Piagetian thinking. In this model 2 the *learning model*, *gender* and *school achievement* serve as between-groups variables and the *Piagetian thinking experiment* (pretest and posttest) as a within-subject factor.

Table 9 shows the mean scores and standard deviations of the mediated LEGO/Logo and discovery LEGO/Logo groups and their subgroups for Piagetian thinking in pre and posttests. In addition, Table 10 shows the results of the MANOVA 2 model.



TABLE 9 Mean scores and standard deviations of the mediated LEGO/Logo and discovery LEGO/Logo groups and their subgroups for Piagetian thinking in pre- and posttest

Learning group	N	Piagetian thinking experiment			
		Pretest		Posttest	
		$\bar{x}$	sd	$\bar{x}$	sd
<i>Mediated</i>	47	15.78	3.77	16.80	4.03
Ability x Gender					
High	11	18.81	2.82	19.36	2.65
Boy	2	18.50	0.70	19.50	0.70
Girl	9	18.88	3.14	19.33	2.95
Moderate	18	15.88	3.47	17.77	3.31
Boy	8	16.12	3.52	18.87	2.74
Girl	10	15.70	3.62	16.90	3.60
Low	18	13.83	3.41	14.27	4.11
Boy	17	13.88	3.51	14.35	4.22
Girl	1	13.00	0.00	13.00	0.00
<i>Discovery</i>	49	16.53	4.29	16.98	4.68
Ability x Gender					
High	18	18.77	4.16	19.72	4.21
Boy	4	16.25	4.78	16.75	5.37
Girl	14	19.50	3.85	20.57	3.61
Moderate	16	16.56	4.25	16.75	4.55
Boy	7	16.14	5.11	16.57	5.22
Girl	9	16.88	3.75	16.88	4.28
Low	15	13.80	2.85	13.93	3.45
Boy	12	14.00	3.07	14.00	3.66
Girl	3	13.00	2.00	13.66	3.05
<b>ALL</b>	<b>96</b>	<b>16.16</b>	<b>4.04</b>	<b>16.89</b>	<b>4.35</b>

TABLE 10 The relationship between the development of Piagetian thinking, and the learning model, school achievement and gender. Based on the 2(*learning model: mediated/discovery*) by 3(*school achievement: low/moderate/ high*) by 2(*gender:girl/boy*) and by 2(*repeated measure effect: pretest/posttest*) MANOVA for repeated measures on Piagetian thinking experiment. (MANOVA 2 model, n = 96).

Source of Variation	DF	F	p
Repeated measure effect	1, 95	4.04	*
Learning Model x Repeated Measure Effect	1, 95	0.57	ns
School Achievement x Repeated Measure Effect	2, 95	0.45	ns
Gender x Repeated Measure Effect	1, 95	0.17	ns
Learning Model x School Achievement x Repeated Measure Effect	2, 95	1.03	ns

(continues)

TABLE 10 (continues)

Source of Variation	DF	F	p
Learning Model x Gender x Repeated Measure Effect	1, 95	0.64	ns
School Achievement x Gender x Repeated Measure Effect	2, 95	0.33	ns
Learning Model x School Achievement x Gender x Repeated Measure Effect	2, 95	0.00	ns

Note. \* $p < .05$ ; ns = not significant.

The result of the MANOVA 2 model showed that there was a significant main effect of the Repeated Measured Effect from the pretest to the posttest,  $F(1, 95) = 4.04$ ,  $p < 0.05$ , indicating overall improvement in time for all subjects in all groups. No interaction effects were found for the repeated measure effect by learning model,  $F(1,95) = 0.57$ ,  $p = 0.45$ , for the repeated measured effect by gender,  $F(1, 95) = 0.17$ ,  $p = 0.67$ , or for time by school achievement,  $F(2, 95) = 0.45$ ,  $p = 0.63$ . The other higher interaction effects were found to be not statistically significant. This means that on average all students improved their testscores from the pretest to the posttest, but this improvement has no relationship with learning model, gender or school achievement.

### 7.1.3 The effect of prior Logo programming experience and its relationships to the learning model and school achievement

To test the effect of prior Logo programming experience on the development of students' Piagetian thinking during the treatment period in the mediated and the discovery LEGO/Logo groups the MANOVA 3 model was implemented. Its design was 2(*learning model*: mediated/discovery) by 2(*prior experience*:yes/no) by 3(*school achievement*: low/moderate/high) and by 2(*time*: pretest/posttest) design for repeated measures on Piagetian thinking experiment. In this model the *learning model*, *prior experience* and *school achievement* serve as between-group variables and the *Piagetian thinking experiment* (pretest and posttest) as a within-subject factor.

Table 11 shows the mean scores and standard deviations of the mediated and discovery LEGO/Logo groups and their subgroups for Piagetian thinking in pre- and posttest. Table 12 shows the results of the MANOVA 3 model.

TABLE 11 Mean scores and standard deviations of the mediated LEGO/Logo and discovery LEGO/Logo groups and their subgroups for Piagetian thinking in pre- and posttest

Learning group	N	Piagetian thinking experiment			
		Pretest		Posttest	
		$\bar{x}$	sd	$\bar{x}$	sd
<i>Mediated</i>	47	15.78	3.77	16.80	4.03
Ability x Gender					
High	11	18.81	2.82	19.36	2.65
Yes	3	18.33	1.15	17.33	2.08
No	8	19.00	3.29	20.12	2.53
Moderate	18	15.88	3.47	17.77	3.31
Yes	7	14.57	4.15	16.71	4.53
No	11	16.72	2.86	18.45	2.25
Low	18	13.83	3.41	14.27	4.11
Yes	8	13.25	3.32	13.37	4.03
No	10	14.30	3.59	15.00	4.24
<i>Discovery</i>	49	16.53	4.29	16.98	4.68
Ability x Gender					
High	18	18.77	4.16	19.72	4.21
Yes	8	16.50	4.84	16.87	4.67
No	10	20.60	2.50	22.00	1.88
Moderate	16	16.56	4.25	16.75	4.55
Yes	4	16.00	4.54	18.25	4.19
No	12	16.75	4.35	16.25	4.73
Low	15	13.80	2.85	13.93	3.45
Yes	4	12.00	2.00	13.25	1.70
No	11	14.45	2.91	14.18	3.94
<b>ALL</b>	<b>96</b>	<b>16.16</b>	<b>4.04</b>	<b>16.89</b>	<b>4.35</b>

TABLE 12 The relationship between the development of Piagetian thinking, and the learning model, school achievement and prior logo programming experience. Based on the 2(*learning model*: mediated/discovery) by 3(*school achievement*: low/moderate/high) by 2(*prior logo experience*: yes/no) and by 2(*repeated measure effect*: pretest/posttest) MANOVA for repeated measures on Piagetian thinking experiment. (MANOVA 3 model, n = 96).

Source of Variation	DF	F	p
Repeated Measure Effect	1, 95	8.17	*
Learning Model x Repeated Measure Effect	1, 95	0.01	ns
School Achievement x Repeated Measure Effect	2, 95	1.39	ns
Prior Logo programming experience x Repeated Measure Effect	1, 95	0.09	ns

(continues)

TABLE 12 (continues)

Source of Variation	DF	F	p
Learning Model x School Achievement x Repeated Measure Effect	2, 95	1.00	ns
Learning Model x Prior Logo programming experience x Repeated Measure Effect	1, 95	2.88	ns
School Achievement x Prior Logo programming experience x Repeated Measure Effect	2, 95	2.76	ns
Learning Model x School Achievement x Prior Logo programming experience x Repeated Measure Effect	2, 95	0.11	ns

Note. \* $p < .05$ ; ns = not significant.

The result of the MANOVA 3 model showed that there was a significant main effect of the Repeated Measured Effect from the pretest to the posttest,  $F(1, 95) = 8.17, p < 0.05$ , indicating overall improvement in time for all subjects in all groups.

No interaction effects were found for the repeated measure effect by learning model,  $F(1,95) = 0.01, p = 0.92$ , for the repeated measure effect by prior Logo programming experience,  $F(1, 95) = 0.09, p = 0.76$ , or for the repeated measure effect by school achievement,  $F(2, 95) = 1.39, p = 0.25$ . The higher interaction effects were found to be not statistically significant. This means that all students improved the overall average of their test scores from the pretest to the posttest, but this improvement has no relationship with the learning model, prior Logo experience or school achievement.

#### 7.1.4 Summary of the results concerning the development of Piagetian thinking during the treatment period

The learning of Logo programming in the LEGO/Logo learning environment had no effects on the development of students' Piagetian thinking. The development of Piagetian thinking was independent of the instruction model (ordinary/LEGO/Logo), the learning model (mediated/ discovery), gender, school achievement and prior Logo experience.

In general, the results are consistent with the negative results of previous studies on the transferability of context-independent problem solving skills from general teaching intervention ( DeCorte 1990; Frederiksen 1984; Neisser 1983; Palumbo 1990; Wagner & Sternberg 1984) as well as from computer programming experience (Pea & Kurland 1984; Klahr & Carver 1988). In addition, this same result has been found in some Logo intervention experiments (Geva & Cohen 1987; Hawkins 1987; Nielsen 1986; Pea & Kurland 1984; Pea et al. 1987; Siann & MacLeod 1986). Furthermore, the results can also be regarded as consistent with Papert's general methodological argument, according to which significant changes in individuals were actualized outside of the pre- and posttest measurements (Papert 1980).

However, this result contradicts the study of Enkenberg (1989), which showed that the learning of Logo programming influences especially girls' Piagetian thinking development. The probable reason for the difference between the results of this study and of Enkenberg's study could be that in Enkenberg's study students used screen Logo and in this study students used LEGO/Logo. In the LEGO/Logo learning environment students dealt with more concrete material than in the screen Logo learning environment. Thus, working with LEGO/Logo is more time-consuming and students can use part of their learning time on developing their LEGO-machine, whereas in the case of screen Logo environment, all activity is dedicated to programming.

The reason for the lack of transferability of high-level problem solving skills in previous research as well as in this study may be that the learning phase was not arranged according to the demands of transfer. Klahr and Carver (1988) have analysed the criteria for transfer from computer programming skills to other problems. They argue that there are two prerequisites for transfer. First, that component skills are precisely specified and taught directly during the learning phase, and, second, the learned component skills have to be evoked and applied in other domains that share relevant features (Klahr & Carver 1988). In the same vein, Palumbo (1990) argued that generalized problem-solving transfer is difficult to achieve in any context, and thus there is not reason to claim that programming language instruction will provide contrary evidence (Palumbo 1990). This is the problem especially with regard to a short-term course in programming (Palumbo 1990).

The goal of the learning phase in this study was not to increase the scores on the Piagetian test, but the goal was for students to cope with the open LEGO/Logo experiment phase. In the following sections I shall describe students' actual problem solving processes in the LEGO/Logo learning environment.

## **7.2 Students' problem solving processes in the LEGO/Logo learning environment**

This chapter studies student pairs' problem solving processes in a real programming situation. The central problem concerns the suitable learning model to be adopted in a problem solving environment. To what extent should the teacher give ready-made solutions, and to what extent should the students discover solutions by themselves?

88 students' problem solving processes in the open LEGO/Logo learning environment were studied. 42 of them learned programming through the mediated model of learning, and 46 followed the discovery model of learning. The students' problem solving processes were videotaped in the open problem solving situation arranged after the teaching period, in which one pair of students at a time programmed the Lego robot to go through a certain route.

The factor matrix of the three factor solution is presented in appendix 4. Based on the unrotated loading matrix, the factor solution explained 55,4 % of the total variance. The first factor explained 25,8 %, the second 15,6% and the third

14,0 % of the total variance. The factor solution with oblimin rotation is presented in Table 13.

TABLE 13 Three Factor solution with Oblimin rotation concerning Problem solving measurement, n = 88

Variables		Factors			Communi- nality
		I Loading <sup>1</sup>	II Loading <sup>1</sup>	III Loading <sup>1</sup>	
Attempt to Resolve					
Cognitive Conflicts	(S) <sup>2</sup>	.84	-.24	-.20	.85
Cognitive Conflict	(S)	.83	-.10	-.02	.96
Failure to Resolve					
Cognitive Conflict	(S)	.77	-.06	-.11	.75
Persistence	(E) <sup>3</sup>	.66	.03	-.08	.77
Performance Components	(I) <sup>4</sup>	-.49	.01	-.26	.99
Monitoring Solution Process	(I)	.47	.27	.25	.99
Success in Resolving					
Cognitive Conflict	(S)	.47	-.13	-.08	.79
Cooperation with the Teacher	(S)	-.20	.94	-.22	.99
Cooperation with another Child	(S)	-.21	-.94	.24	.99
Assistance Seeking	(E)	-.10	.50	.12	.51
Selecting Performance					
Components	(I)	.16	-.34	-.13	.99
Rule Determination	(E)	.05	.01	.79	.51
Self Directed Work	(E)	-.00	-.01	.57	.38
Deciding on the Nature					
of the Problem	(I)	-.06	.26	.57	.90
Combining Performance					
Components	(I)	.00	-.11	.42	.67
Expressing Pleasure	(E)	-.21	-.18	.25	.27

I = Cognitive Conflict Solving  
 II = Cooperation with Teacher  
 III = Explicit Planning

<sup>1</sup> Loadings are from the pattern matrix

<sup>2</sup> S in parentheses means that the variable belongs to social problem solving in the initial measurement, see Table 2 on page 60.

<sup>3</sup> E in parentheses means that the variable belongs to effectance motivation in the initial measurement, see Table 3 on page 64.

<sup>4</sup> I in parentheses means that the variable belongs to information processing in the initial measurement, see Table 4 on page 67.

Three interpretable and reliable factors were composed. Factor I was named as *Cognitive Conflict Solving*, factor II was named as *Cooperation with Teacher* and Factor III *Explicit Planning*.

Factor I, (*Cognitive Conflict Solving*) included *Attempt to resolve cognitive conflict*, *Cognitive conflict*, *Failure to resolve cognitive conflict*, *Success in resolving of cognitive conflicts*, *Persistence*, *Performance components* and *Monitoring solution processes*. All previously enumerated variables had a clear loading for the first

factor. The highest loadings on the factor were *Attempt to resolve cognitive conflict* (loading 0.84), *Cognitive conflict* (loading 0.83) and *Failure in resolving of cognitive conflict* (loading 0.77). The variables *Persistence* (loading 0.66), *Success in resolving of cognitive conflicts* (loading 0.47) and *Monitoring solution processes* (loading 0.47) also had a substantial loading. Only *Performance components* had a negative loading (-0.49) on this factor.

The first factor was formed from the areas of social problem solving, and effectance motivation, as well as from the information-processing of the initial problem solving measurement. First, social problem solving in the initial measurement (See Table 2 in page 60) includes the variables *Attempt to resolve cognitive conflict*, *Cognitive conflict*, *Failure in resolving of cognitive conflict* and *Success in resolving of cognitive conflicts*. Second, effectance motivation in the initial measurement (See Table 3 in page 64) includes the variable *Persistence*. And finally, information-processing in the initial measurement (see Table 4 in page 67) includes variables *Performance components* and *Monitoring solution processes*.

It is to be noticed that the variables *Failure in resolving of cognitive conflicts* and *Success in resolving cognitive conflicts* both have a positive loading on the cognitive conflict solving factor. Thus, the occurrence of cognitive conflicts during problem solving can lead to both success and failure. Variables from social problem solving in this factor all describe behaviour in which cognitive conflict and its resolution process are transparent. Persistence also describes behavior in which the learner has difficulties, but in spite of these difficulties s/he tries to continue working. *The monitoring of the solution process* is the only metacognitive variable in this factor. Thus, it looks as if the use of metacognition was closely related to the occurrence of cognitive conflicts, as Papert has supposed in his theory (Papert 1980). *Performance components* have a negative loading on the cognitive conflict solving factor.

To sum up the high score of the cognitive conflict solving factor (Factor I) means that students have many cognitive conflicts and that they make many attempts to solve those conflicts during the problem solving processes. This process may lead to either failure or success. Cognitive monitoring is also related to this process.

Factor II (*Cooperation with teacher*) included *Cooperation with the teacher*, *Cooperation with another child*, *Assistance seeking* and *Selecting performance components*. All previously enumerated variables had a clear loading for the second factor. The highest loadings on the factor were *Cooperation with the teacher* (loading 0.94) and *Cooperation with another child* (loading -0.94). In addition, the variable *Assistance seeking* (loading 0.50) also had a substantial loading. Although the variable *Selecting performance components* (loading -0.34) did not have such a substantial loading for factor II, it clearly belongs to this factor because the loadings for factor I (loading 0.16) and for factor III (loading -0.13) were much lower. The variables *Cooperation with another child* and *Selecting performance components* has a negative loading on this factor.

The second factor was formed from the area of social problem solving, effectance motivation, as well as from the information-processing of the initial problem solving measurement. First, social problem solving in the initial measurement (see Table 2) includes the variables *Cooperation with the teacher* and

*Cooperation with another child*. Second, effectance motivation in the initial measurement (see Table 3) is included in the variable *Assistance seeking*, and finally, information-processing in the initial measurement (see Table 4) includes the variable *Selecting performance components*. This factor is clearly bipolar, with a high positive loading on *Cooperation with the teacher* and a high negative loading on *Cooperation with another child*. These two kinds of interaction during problem solving appear to be polar dimensions. Also the variable *Selecting performance components* has a negative loading on this factor, but the meaning of this variable in the explanation of variance in this factor is not so important because the loading is relatively low. The variable *Assistance seeking* had a positive loading on the factor and this means that the preference for working together with the teacher is also related to asking questions to the teacher. A high score on *Cooperation with teacher* factor means that students prefer to work with the teacher during problem solving. In contrast, a low score on this factor means that students prefer to cooperate with another student.

Factor III (*Explicit planning*) included *Rule determination*, *Self directed work*, *Expressing pleasure*, *Deciding on the nature of the problem* and *Combining performance components*. The highest loadings on the factor were *Rule determination* (Loading 0.79), *Self directed work* (loading 0.57) and *Deciding on the nature of the problem* (loading 0.57). Also the variable *Combining performance components* (loading 0.42) had a substantial loading and the variable *Expressing pleasure* (loading 0.25) had a relatively low loading. All variables with the highest loadings for factor III had positive loadings on this factor. The high score of *Explicit planning* means that students plan in an explicit way about the final goal of the task and about how this goal could be achieved during the problem solving process. Also much self directiveness occurs if students have a high score on this factor. *Explicit planning* describes a planning strategy in which a high score on this factor describes a formal programming style like behavior, whereas a low degree of occurrence describes concrete programming style like behavior.

The connections between the different problem solving processes and students' thinking level, prior experiences of Logo programming and gender were studied. To determine whether there were overall differences between the groups in the problem-solving process, described by the variables *Cognitive conflict solving*, *Cooperation with teacher* and *Explicit planning*, two three-way analyses of variance (ANOVA) were used.

Two separate ANOVA models were necessary because the four way ANOVA model reduced the number of subjects in cells to such an extent that an ANOVA was not possible.

### **7.2.1 The effect of the learning model and its interaction with Piagetian thinking and prior experience on the occurrence of cognitive conflicts in the students' problem solving process**

In the ANOVA 1 model the variables *learning model* (Mediated/Discovery), *Piagetian thinking level* (Low/High) and *prior experience of Logo programming* (Yes/No) were used as grouping variables and *Cognitive conflict solving*, *Cooperation with teacher* and *Explicit planning* were used as dependent variables.



Table 14 presents the means and standard deviations of the occurrence of *Cognitive Conflict Solving*, *Cooperation with Teacher* and *Explicit Planning* during problem solving in the LEGO/Logo learning environment, when *learning model*, *Piagetian thinking level* and *prior experience* are used as grouping variables.

TABLE 14 Mean scores of the mediated and discovery LEGO/Logo groups and their subgroups for cognitive conflicts, cooperation of teacher and explicit planning of the problem solving process (factor scores).

		The area of the problem solving process					
		Cognitive conflict solving		Cooperation with teacher		Explicit planning	
Learning group	N	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
<i>Mediated</i>	42	0.52	0.94	-0.26	0.94	-0.19	0.89
Ability x Gender							
High	24	0.63	0.93	-0.37	0.84	-0.09	0.94
Yes	8	0.85	0.69	-0.61	0.85	-0.06	0.97
No	16	0.52	1.03	-0.26	0.84	-0.11	0.94
Low	18	0.36	0.97	-0.11	1.06	-0.33	0.84
Yes	9	-0.06	0.62	-0.28	1.26	-0.39	0.67
No	9	0.78	1.12	0.07	0.86	-0.26	1.02
<i>Discovery</i>	46	-0.47	0.86	0.24	1.03	0.18	0.87
Ability x Gender							
High	21	-0.59	0.88	0.31	1.09	0.49	0.83
Yes	6	-0.04	0.89	0.36	0.42	0.06	0.38
No	15	-0.82	0.79	0.29	1.27	0.67	0.90
Low	25	-0.36	0.85	0.17	0.99	-0.09	0.83
Yes	10	0.01	0.73	0.04	1.06	-0.18	0.60
No	15	-0.61	0.85	0.25	0.97	-0.03	0.97
Learning model x prior experience							
Med/Yes	17	0.37	0.79	-0.23	0.82	-0.23	0.82
Med/No	25	0.62	1.05	-0.16	0.96	-0.16	0.96
Dis/Yes	16	-0.02	0.77	-0.09	0.53	-0.09	0.53
Dis/No	30	-0.71	0.82	0.32	0.99	0.32	0.99

Table 15 presents the results of the ANOVA 1 model when the variable cognitive conflict solving is used as a dependent variable.

TABLE 15 The relationship between the occurrence of cognitive conflict solving (the factor score) during in the problem-solving process and the learning model, Piagetian thinking level in pretest and prior experience. Based on the 2(*learning model: mediated/discovery*) by 2(*Piagetian thinking level in the pretest: low / high*) and by 2(*prior experience: yes/no*) three-way ANOVA (ANOVA 2 model,  $n = 88$ ).

Source of Variation	DF	F	p
Learning Model	1,87	26.94	***
Prior experience	1,87	1.52	ns
Piagetian thinking	1, 87	0.04	ns
Learning model x Prior experience	1, 87	6.14	*
Learning model x Piagetian thinking	1 87	0.75	ns
Prior experience x Piagetian thinking	1,87	3.01	ns
Learning model x Piagetian thinking x Prior experience	1,87	1.60	ns

Note. \*\*\*  $p < .001$ ; \*  $p < .05$ ; ns = not significant.

The analysis revealed significant main effect of the learning model for cognitive conflict solving,  $F(1, 87) = 26.94, p < 0.001$ . The main effect of the learning model indicates that the mediated group ( $x = 0.52$ ) have more cognitive conflict solving than the discovery group ( $x = -0.47$ ) in the open problem solving situation.

Table 15 shows that there was also a significant Learning model x Prior experience interaction effect,  $F(1,87) = 6.14, p < 0.05$ . Figure 4 presents the mean rates of occurrence of cognitive conflict solving in every subgroup on the basis of this interaction. Least-significant difference (LSD) post hoc pairwise tests were used with the ANOVA when verified in order to determine the sources of the effect in the cases of significant interaction effects.

On the basis of the interaction four subgroups have been formed. The subgroups were students in the mediated group who had no prior logo programming experience (MED/NO) and who had prior logo programming experience (MED/YES); students in the discovery group who had no prior logo programming experience (DIS/NO) and who had prior logo programming experiences (DIS/YES).

Based on the LSD pairwise test, the groups differ as follows: DIS/NO group ( $x = -0.71$ ) differ significantly from MED/NO group ( $x = 0.62$ ), [ $t(53) = 5.29, p < 0.001$ ] and from MED/YES group ( $x = 0.37$ ), [ $t(45) = 4.43, p < 0.001$ ], and from DIS/YES group ( $x = -0.02$ ), [ $t(45) = 2.81, p < 0.01$ ]. In addition, MED/NO group ( $x = 0.62$ ) differs significantly from DIS/YES group ( $x = -0.02$ ), [ $t(39) = 2.08, p < 0.05$ ].

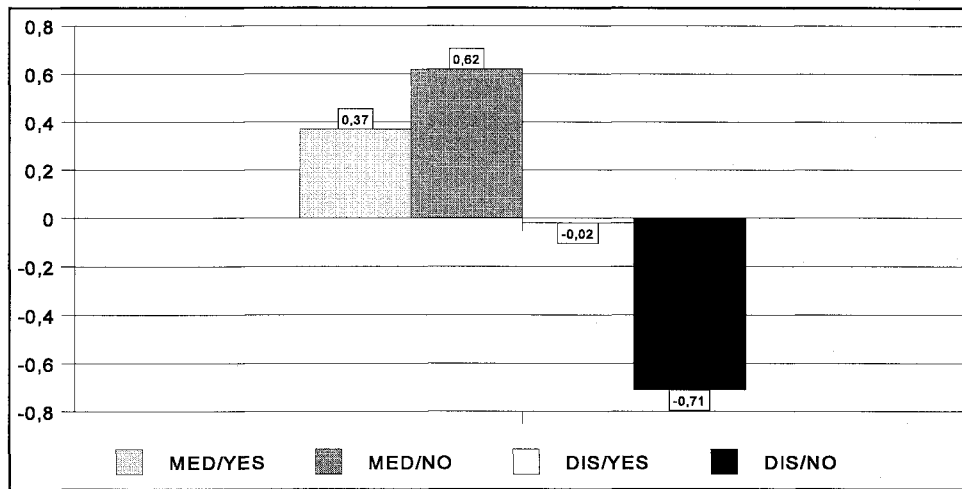


FIGURE 4 The mean occurrences of cognitive conflict solving (C.Conflict) during problem solving processes among students in the MED/YES, MED/NO, DIS/YES and DIS/NO groups (factor scores).

### 7.2.2 The effect of the learning model and its interaction with Piagetian thinking and prior experience on the occurrence of cooperation with the teacher in students' problem-solving processes

Table 16 presents the results of the ANOVA 1 model when the variable of cooperation with teacher is used as a dependent variable. This analysis revealed only one significant main effect concerning the learning model,  $F(1, 87) = 4.97, p < 0.05$ . This indicates that the mediated group ( $x = -0.26$ ) has less cooperation with the teacher than the discovery group ( $x = 0.24$ ) during the problem solving processes (see Figure 5).

TABLE 16 The relationship between the occurrence of Cooperation with teacher (the factor score) during the problem solving process and the learning model, Piagetian thinking level in pretest and prior experience. Based on the 2(learning model: mediated/discovery) by 2(Piagetian thinking level in the pretest: low/ high) and by 2(prior experience: yes/no) three-way ANOVA (ANOVA 1 model,  $n = 88$ ).

Source of Variation	DF	F	p
Learning Model	1,87	4.76	*
Prior experience	1,87	0.92	ns
Piagetian thinking	1,87	0.13	ns
Learning model x Prior experience	1,87	0.37	ns
Learning model x Piagetian thinking	1,87	1.16	ns
Prior experience x Piagetian thinking	1,87	0.01	ns
Learning model x Piagetian thinking x Prior experience	2,87	0.09	ns

Note. \*  $p < .05$ ; ns=not significant.

### 7.2.3 The effect of the learning model and its interaction with Piagetian thinking and prior experience on the occurrence of explicit planning in students' problem solving processes

Table 17 presents the results of the ANOVA 1 model when the variable of *explicit planning* is used as a dependent variable. This analysis revealed two significant main effects concerning the *learning model*,  $F(1, 87) = 4.68, p < 0.05$ , and *Piagetian thinking level*,  $F(1, 87) = 4.39, p < 0.05$ . This indicates that the mediated group ( $x = -0.19$ ) shows less explicit planning during the problem solving than the discovery group ( $x = 0.18$ ). In addition, *low achievers* in the Piagetian thinking pretest ( $x = -0.19$ ) show less *explicit planning* than high achievers ( $x = 0.18$ ) in the same test. There were no significant interaction effects.

TABLE 17 The relationship between the occurrence of *Explicit planning* (the factor score) in the problem solving process and the *learning model*, *Piagetian thinking level* in pretest and *prior experience*. Based on the 2(*learning model*: mediated/discovery) by 2(*Piagetian thinking level in the pretest*: low/high) and by 2(*prior experience*: yes/no) three-way ANOVA (ANOVA model,  $n = 88$ ).

Source of Variation	DF	F	p
Learning Model	1,87	4.68	*
Prior experience	1,87	0.92	ns
Piagetian thinking	1,87	4.39	*
Learning model x Prior experience	1,87	0.69	ns
Learning model x Piagetian thinking	1,87	0.66	ns
Prior experience x Piagetian thinking	1,87	0.13	ns
Learning model x Piagetian thinking x Prior experience	1,87	0.69	ns

Note. \*  $p < .05$ ; ns=not significant.

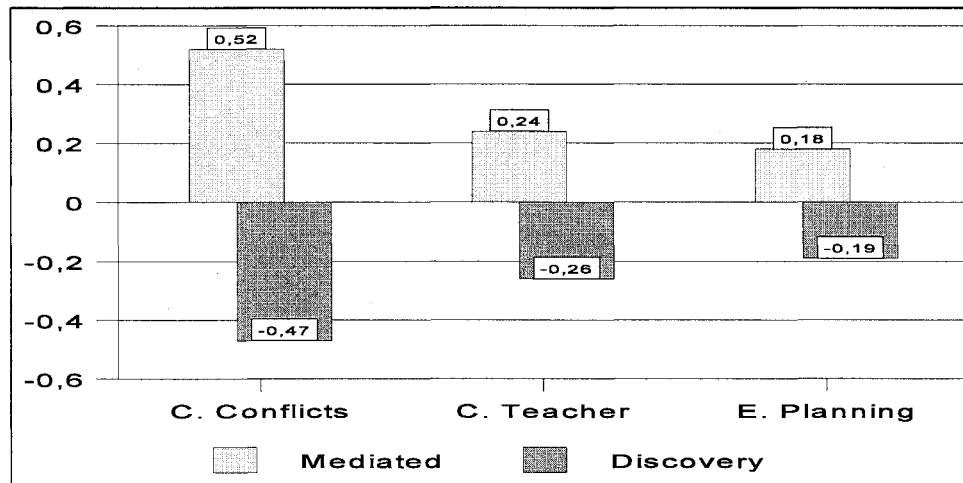


FIGURE 5 Factor scores of cognitive conflict solving (C. Conflicts), cooperation with teacher (C. Teacher) and explicit planning (E. Planning) during problem solving in the mediated ( $n = 42$ ) and discovery groups ( $n = 46$ ) (Factor score).

To sum up, Figure 5 presents the differences between the mediated and discovery group with regard to the problem solving process.

#### 7.2.4 The effect of gender on problem solving processes

In order to examine the effect of gender and its interaction with other independent variables on cognitive conflict solving, cooperation with teacher and explicit planning, the ANOVA 2 model was implemented. In the ANOVA 2 model the variables *learning model* (Mediated/ discovery), *Piagetian thinking level* (Low/ high) and *gender* (Boy/girl) were used as grouping variables and *Cognitive conflict solving*, *Cooperation with teacher* and *Explicit planning* were used as dependent variables. As in the ANOVA 1 model, Least-significant difference (LSD) post hoc pairwise tests were used with the ANOVA when warranted, to determine the sources of the effect in the cases of significant interaction effects.

Table 18 displays the means and standard deviations of these data; Table 19 presents the results of the ANOVA model when *cognitive conflict solving* is a dependent variable; Table 20 the results when *cooperation with teacher* is a dependent variable; and Table 21 the results when *explicit planning* is a dependent variable.

Following the result Tables, statistically significant effects are described in Figure 6. Table 18 presents the means and standard deviations of occurrences of cognitive conflicts, cooperation with teacher and explicit planning during the problem solving in the LEGO/Logo learning environment. The significant main effect of the learning model for cognitive conflict solving has been reported previously (See Table 16 and Figure 5).

TABLE 18 Mean scores of girls (n = 40) and boys (n = 48) and their subgroups for cognitive conflicts, cooperation with teacher and explicit planning of the problem solving process (factor scores).

The area of the problem solving process							
Gender	N	Cognitive conflict solving		Cooperation with teacher		Explicit planning	
		$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
<i>Boy</i>	48	-0.28	0.97	-0.20	1.01	-0.28	0.65
Model x Ability							
Mediated	24	0.25	0.80	-0.38	1.10	-0.44	0.62
High	11	0.46	0.79	-0.56	0.99	-0.52	0.68
Low	13	0.07	0.80	-0.23	1.21	-0.38	0.59
Discovery	24	-0.75	0.87	-0.02	0.88	-0.11	0.64
High	10	-0.93	0.92	-0.05	0.77	0.03	0.58
Low	14	-0.61	0.84	-0.01	0.98	-0.21	0.67
<i>Girl</i>	40	0.30	1.02	0.24	0.98	0.33	1.04
Model x Ability							
Mediated	18	0.87	1.03	-0.10	0.65	0.14	1.09
High	13	0.77	1.04	-0.22	0.69	0.27	0.99
Low	5	1.13	1.07	0.21	0.47	-0.19	1.39
Discovery	22	-0.17	0.76	0.52	1.12	0.49	0.99
High	11	-0.29	0.76	0.65	1.26	0.92	0.81
Low	11	-0.05	0.78	0.39	1.00	0.05	0.99

Table 19 presents the results of the ANOVA 2 model, with the variable cognitive conflict solving as a dependent variable. This analyses revealed a significant main effect of gender,  $F(1, 87) = 10.63, p < 0.001$ . This indicates that boys ( $x = -0.28$ ) have less cognitive conflict solving than girls ( $x = 0.30$ ) during the problem solving process.

TABLE 19 The relationship between the occurrence of cognitive conflicts (the factor score) during the problem solving process and the learning model, Piagetian thinking level in pretest and gender. Based on the 2(*learning model*: mediated/discovery) by 2(*Piagetian thinking level in the pretest*: low/moderate/ high) and by 2(*gender*: boy/girl) three-way ANOVA (ANOVA 2 model,  $n = 88$ ).

Source of Variation	DF	F	p
Learning Model	1,87	30.46	***
Gender	1,87	10.63	**
Piagetian thinking	1, 87	0.27	ns
Learning model x Gender	1,87	0.01	ns
Learning model x Piagetian thinking	1,87	0.90	ns
Gender x Piagetian thinking	1,87	0.56	ns
<u>Learning model x Piagetian thinking x Gender</u>	<u>1,87</u>	<u>1.11</u>	<u>ns</u>

Note. \*\*\*  $p < .001$ . \*\* $p < .01$  \* $p < .05$ . ns=not significant.

TABLE 20 The relationship between the factor score of cooperation with teacher during the problem solving process and the learning model, Piagetian thinking level in pretest and gender. Based on the 2(*learning model*: mediated/discovery) by 2(*Piagetian thinking level in the pretest*: low/ high) and 2 by (*gender*: boy/girl) three-way ANOVA (ANOVA 2 model,  $n = 88$ ).

Source of Variation	DF	F	p
Learning Model	1,87	4.67	*
Gender	1,87	4.14	*
Piagetian thinking	1,87	0.33	ns
Learning model x Gender	1,87	0.17	ns
Learning model x Piagetian thinking	1,87	1.08	ns
Gender x Piagetian thinking	1,87	0.09	ns
<u>Learning model x Piagetian thinking x Gender</u>	<u>1,87</u>	<u>1.65</u>	<u>ns</u>

Note. \*  $p < .05$ ; ns=not significant.

Table 20 displays the results of the ANOVA 2 model, with the variable cooperation with teacher as the dependent variable. This analysis revealed the significant main effect of gender,  $F(1, 87) = 4.14, p < 0.05$ . This indicates that boys ( $x = -0.20$ ) have less cooperation with the teacher than girls ( $x = 0.24$ ) during the problem solving process (see Figure 6). The main effect of the learning model has been reported previously (See Table 17 and Figure 5).

TABLE 21 The relationship between the factor score of explicit planning (factor score) and the learning model, Piagetian thinking level in pretest and gender. Based on the 2(learning model: mediated/discovery) by 2(Piagetian thinking level in the pretest: (low/moderate/ high) and by 2(gender: boy/girl) three-way ANOVA (ANOVA 2 model, n = 88).

Source of Variation	DF	F	p
Learning Model	1,87	4.66	ns
Gender	1,87	8.96	**
Piagetian thinking	1,87	3.41	ns
Learning model x Gender	1,87	0.06	ns
Learning model x Piagetian thinking	1,87	1.16	ns
Gender x Piagetian thinking	1,87	2.85	ns
Learning model x Piagetian thinking x Gender	1,87	0.003	ns

Note. \*\* p < .01; ns=not significant.

Table 21 presents the results of the ANOVA 2 model with the variable explicit planning as the dependent variable. This analysis revealed significant main effects of gender,  $F(1, 87) = 8.96, p < 0.01$ . The main effect of gender indicates that boys ( $x = -0.28$ ) perform less explicit planning than girls do ( $x = 0.33$ ) during the problem solving process. To sum up, Figure 5 shows the differences in the quality of boys' and girls' problem solving.

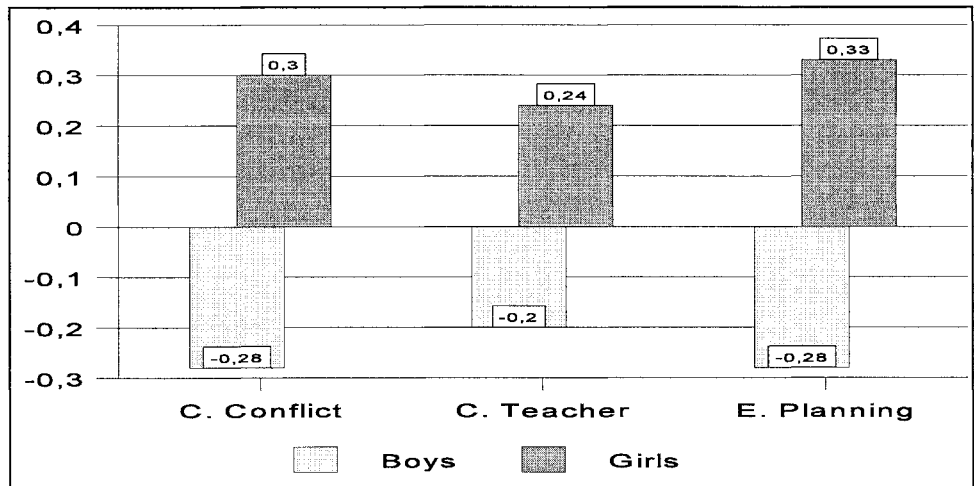


FIGURE 6 Factor scores of cognitive conflict solving (C.Conflict), cooperation with teacher (C.Teacher) and explicit planning (E.Planning) during the problem-solving process in the groups of boys' (n = 48) and girls' (n = 40) (Factor scores).

### 7.3 The differences in the final Logo program

In order to examine the quality of the final Logo programs, the general properties of programs are described in this section. In addition, the comparison among students will be presented according to the learning model, thinking level, prior experience and gender. A comparison will be also made among subgroups on the basis of the interaction between learning model and prior experience.

During the open problem solving test situation, all pairs created a Logo program that worked. Thus, every pair used at least moving commands (FORWARD, BACK, RIGHT and LEFT) in their final Logo program. The mean number of all Logo commands was 21.77 commands (range 7 to 88). The three most general types of command were moving commands (mean 10.87), music commands (mean 4.2) and light commands (mean 2.66). Only 2 pairs used REPEAT commands, and only 4 pairs used subprocedures. In addition, 11 pairs used WAITUNTIL commands.

Table 22 shows the diversity of the final programs. The examples of different Logo programs are presented in Appendix 5. Only 3 pairs used a program that included only MOVING commands and 10 pairs had two components (MOVING commands and one of the following: LIGHT or MUSIC or REPEAT or SUBPROCEDURES or WAITUNTIL); 18 pairs had three components; 12 pairs had four components; and, finally, only one pair had five components. However, there was no statistically significant difference between the mediated and discovery group - nor between any other groups - with regard to the degree of diversity of the program. The number of MUSIC commands was the only area of commands which differentiated groups in a statistically significant way.

TABLE 22 The Frequency of student pairs classified by the level of diversity of the final Logo program (n = 44)

The level of the program's diversity	The number of pairs
MOVING COMMANDS	3
2 components	10
3 components	18
4 components	12
5 components	1

*The length of program* in the mediated and discovery groups was 18.90 and 24.39 respectively [ $t(69.64) = 1.99, p < .05$ ]. The mediated group had an average of 3.71 and the discovery group 7.15 music commands in their final Logo program. This difference was statistically significant [ $t(82.38) = 2.43, p < .05$ ]. Students who belonged to the high-level Piagetian thinkers did not differ from low-level thinkers in their Logo program.

Boys' had an average of 25.83 and girl's 16.90 Logo commands in their final Logo program. This difference was statistically significant [ $t(73.38) = 3.45, p < .01$ ]. In addition, the boys had an average of 6.79 and the girls 3.98 music commands in their final Logo program, and this difference was statistically significant [ $t(84.23) = 2.00, p < .05$ ].

In terms of the properties of their final Logo program, students who had previous experience of Logo programming (20-hour-long learning phase) did not



differ from students without previous experience. However, students in the subgroups formed from the interaction of prior experience by learning model differed from each other in the following way. First, the mean number of all Logo commands in the MED/YES group was 22.82, and this differed statistically significantly from the mean in the med/no group ( $x=16.24$ ), [ $t(40.00) = 2.59, p < .05$ ]. Second, the same group (MED/NO) differed statistically significantly from the mean of the DIS/NO group (26.80), [ $t(39.06) = 2.78, p < .001$ ]. Finally, the mean number of TONE commands in the final Logo program was 4.00 in the dis/yes group and 8.83 in the dis/no group. Thus, those groups differed in a statistically significant way, [ $t(35.59) = 2.82, p < .001$ ].

The mean time students spent on problem solving in the experimental phase was 38.77 minutes. There was no difference between the groups concerning the time, the students spent on their problem solving.

#### **7.4 Summary of the results concerning the students' problem solving processes and the final Logo program in the open problem solving experiment**

The problem solving processes of the students in the mediated group differed from those of the students in the discovery group in the following ways: The mediated group showed more cognitive conflict solving during programming than the discovery group. In contrast, the discovery group had more cooperation with the teacher than the mediated group. The discovery group used more explicit planning during problem solving processes than the mediated group. Furthermore, a difference between the mediated group and the discovery group was found in the characteristics of the final Logo programs. The programs of the discovery group were longer than those of the mediated group because the discovery group's programs included on average more music. Even if research on the development of programming skills (Fay & Mayer 1994) regards a longer program as a manifestation of undeveloped programming skills compared with a shorter program, but this is not the case in LEGO/Logo programming. Because the mean programming time in the experimental phase did not differ between the learning groups, the discovery group was more capable than the mediated group of producing more music in their Logo programs.

*Prior experience* of Logo programming as such did not differentiate students in this study. However, the learning model had an interaction effect with the prior experience for the occurrence of cognitive conflict solving. The subgroups were students in the mediated group who had no prior logo programming experience (MED/NO) and who had prior logo programming experience (MED/YES); students in the discovery group who had no prior logo programming experience (DIS/NO) and who had prior logo programming experiences (DIS/YES). The occurrence of cognitive conflict solving was the highest in the MED/NO group, second highest in the MED/YES group, second lowest in the DIS/YES group and the lowest in the DIS/NO group. A statistically significant difference was found between the DIS/NO and all the other groups.

In addition, a difference was found between the DIS/YES and the MED/NO group. Thus, in this study a general tendency appears in this interaction: Both students who possessed prior logo experience and students who possessed no prior logo experience in the discovery groups had fewer cognitive conflict solving than students in the mediated group. But the interesting result is that students who had no prior experiences represent the extremities of their learning groups. Students with prior experience within the discovery group had the lowest amount of cognitive conflict solving during problem solving, whereas students with prior experience within the mediated group had the highest amount. Thus, the learning model has a more noticeable influence on students who had no prior experience of Logo programming. While previous research has shown that the programming process depends less on previous programming experience than on teaching method (Volet & Lund 1994), this study shows that the computing processes was depended on the teaching method, if students had no prior experience, but the effect of the teaching method was not so essential if students had prior experience.

The problem solving processes of boys and girls differ in the following respects: Girls had more cognitive conflict solving, more cooperation with the teacher and more explicit planning during programming than boys. In addition, a difference between boys and girls was found in the characteristics of the final Logo programs. The programs of boys were longer than those of girls, because boys' programs included more music.

Boys and girls differed in the quality of the problem solving process. Papert and Turkle have assumed that, in general, girls prefer to program with a concrete style whereas boys want to use a formal style (Turkle & Papert 1990; 1992). In addition, they point out that girls are less articulate than boys (Turkle & Papert 1992). Since in this study girls had statistically significantly more explicit planning than boys, the results give a picture of boys' and girls' programming processes which is in contrast with that given by Papert. In this study, girls were more articulate and they planned their programming process in a more explicit way. On the other hand, the result of this study is consistent with Edwards et al. (1997) study, in which girls talked about what they would do or should do before acting (Edwards & al. 1997).

It seems that an authentic and technology-rich learning environment may be motivating also for girls, if social interaction is possible during problem solving. On a verbal level girls are more able to discuss and make more holistic plans than boys. Such kind of action is not possible if the problem solver has not engaged him/herself with the task.

The problem solving processes of the high and low achieving students differed only in the explicit planning during the problem solving experiment. The high achievers had more explicit planning than the low achievers during problem solving. However, this difference had no effect on the characteristics of the final Logo program among the high and low achieving students. In addition, no difference was found between the high and low achievers in the occurrence of cognitive conflict solving and cooperation with the teacher during problem solving.

While previous research has suggested that low ability learners need more the teacher guidance than high-ability learners (Bradley 1985; German 1989;

Mayer 1987; Snow 1994; Snow & Lohman 1984; Suomala 1996), in this study the general ability to learn had no interaction effects with the learning model on the quality of students problem solving processes. It is possible that the LEGO/Logo learning environment equalized student learning, because also the low achievers may felt this learning environment as meaningful. It is possible, that high achievers had more ideas for different kinds of solutions, but this explicit planning did not translate itself into a more diverse program.

Table 22 shows how students' problem solving processes and the final Logo program differed from each other among the subgroups. We can see that the number of conflict solutions during problem solving has an inverse relationship with the length of the final Logo program as well as with the number of music commands. Every subgroup which had statistically significantly more cognitive conflict solving (mediated group and girls) than comparison group (discovery group and boys ) had shorter final programs. (i.e. their programs did not include as much music as their comparison group's programs). Probably the reason for this is that the former groups spend their time on cognitive conflict solving while their comparison groups spend their time on creating more music for the Logo programs. Thus a high number of cognitive conflicts is not necessarily a manifestation of higher-order thinking, as Clements and Nastasi have argued (1988). On the contrary, it may be a manifestation of undeveloped cognitive skills. Students who have created more longer programs have probably learnt basic Logo commands better than their counter group, and thus they have had cognitive energy to create more playful Logo programs. However, explicit planning and cooperation with teacher did not have a similar relationship with the quality of the final Logo program as cognitive conflict solving had.

TABLE 22 Statistically significant differences between the subgroups in cognitive conflict solving, cooperation with teacher, explicit planning, length of program, and diversity of the program.

Subgroups	The features of problem solving			The features of final Logo program	
	Cognitive conflict solving	Cooperation with teacher	Explicit Planning	The length of the final Logo program	The number of TONE commands in the final Logo program
Learning model	MED*** DIS	MED DIS*	MED DIS*	MED DIS*	MED DIS*
Gender	Girls*** Boys	Girls* Boys	Girls*** Boys	Girls Boys**	Girls Boys*
Level of achievement	HIGH ns LOW	HIGH ns LOW	HIGH* LOW	HIGH ns LOW	HIGH ns LOW

1 The length refers to the number of all Logo commands the students have constructed during problem solving.

<sup>2</sup> MED means the mediated group in the experiment phase.

<sup>3</sup> DIS means the discovery group in the experimental phase.

\* The mean of the group was higher ( $p < 0.05$ ) than the mean of the other group.

\*\* The mean of the group was higher ( $p < 0.01$ ) than the mean of the other group.

\*\*\* The mean of the group was higher ( $p < 0.001$ ) than the mean of the other group.

## 8 DISCUSSION

In this discussion chapter, I first describe the essential results of this study. Then I draw conclusions based on the results. After that, I discuss and evaluate the methodological solutions and, finally, I discuss the educational and scientific importance of this study.

### 8.1 Results

This study had two goals. First, it tried to clarify the effect of learning in the LEGO/Logo environment on the students' Piagetian thinking. For this purpose, Piaget's classroom test was arranged before and after the teaching phase, both for the LEGO/Logo group and for the original group. The second goal of this study was to describe students' problem solving processes and to analyze their final Logo programs in the open LEGO/Logo environment. For this second purpose, the open problem solving situation was arranged after the teaching phase for the 88 members of the LEGO/Logo group. 42 of the students were taught by the mediated method and 46 by the discovery method. The learning of Logo programming in the LEGO/Logo learning environment had no effects on the development of students' Piagetian thinking. The development of Piagetian thinking was independent of the instructional model, gender and school achievement. The probable reason for the lack of transferability of problem solving skills may be that the learning phase in this study did not meet the requirements of transfer. The main goal was that students would learn to program LEGO machines in as versatile a way as possible. Previous research has shown that transfer does not occur without explicit teaching which focuses on the transfer skills (Klahr & Carver 1988). In addition, the results can also be regarded

as consistent with Papert's general methodological argument. According to this argument, significant changes in the individuals were actualized outside of the pre- and posttest measurements (Papert 1980).

In this study, students' problem solving processes were examined as a discovery process, in which the important elements are cognitive conflict solving, cooperation with teacher, and explicit planning. The occurrence of these elements was investigated in the experimental phase, which was carried out within the open LEGO/ Logo learning environment. The results of the study indicated that the learning model, gender, and thinking level as well as the interaction between the learning model and prior experience accounted for group differences in the problem solving processes among students. In addition, a difference between groups was found in the characteristics of the final Logo programs.

### **8.1.1 Students' problem solving processes in the mediated and in the discovery group**

The problem solving processes of the students in the mediated group differ from those of students in the discovery group in the following ways: The mediated group had more cognitive conflict solving during programming than the discovery group. By contrast, the discovery group had more cooperation with the teacher than the mediated group. In addition, the discovery group showed more explicit planning during problem solving processes. Furthermore, the final Logo programs of the discovery group were longer than the mediated group's programs, because the discovery group's programs included more music. In addition, the interaction between the learning model and prior experience accounted for group differences in the occurrence of cognitive conflict solving during problem solving in the experimental situation.

Thus, the mediated group spent more time engaged in cognitive conflict solving and they did not cooperate as much with the teacher as the discovery group. In addition, they used less explicit planning during programming than the discovery group. This means that students in the mediated group had many cognitive conflicts and that they frequently made attempts to solve those conflicts during their problem solving processes. Their solving processes included both failure and success. When they solved cognitive conflicts during programming they also used cognitive monitoring and showed a lot of persistence.

Students in the mediated group preferred to cooperate with their partners more than with the teacher. Thus, if they did not participate in the solving of conflicts, they cooperated with their partner without transparent cognitive conflicts, but not with their teacher. This cooperation included silent working, too. It is possible that during cooperation intraindividual conflicts may have been engendered within one or both of the partners via the exchange of ideas. In these cases, the resolution of the discrepancy may occur internally, within the individuals, rather than externally, between the individuals.

Finally, the problem solving processes of the mediated group did not include as much explicit planning as the discovery group's. This means that the discovery group talked in an explicit way more about the final goal of the task and they considered more how the final goal could be achieved during problem

solving. The behaviour of the discovery group showed more rule determination and self-directed work than that of the mediated group.

Furthermore, the final Logo programs of the discovery group were longer than the mediated group's programs, because programs included more music. It has to be borne in mind that both groups spent on the average the same amount of time on problem solving processes in the open LEGO/Logo experiment.

The learning processes in the mediated group were arranged first by organizing the students' programming task during the teaching phase and, second, by using scaffolding discussion between the students and the teacher during the planning processes. The goal of the scaffolding discussion was that the students learnt to deal with new situations by explicit planning using a formal programming style. The presupposition was that in this way the students will develop into skillful planners, who can take into account all important programming elements and build a mental representation in which those elements are in structural order. The second presupposition was that after the teaching period the students would be able to concentrate on the whole problem before the actual problem solving and in this way the problem would become familiar to the problem solver before s/he begins to program. The assumption was that when students are capable of planning, this leads to a situation in which the actual programming process does not include cognitive conflicts.

Thus, the teacher's role in the mediated group was twofold. First, in the planning process, he provided scaffolding for every pair to find a suitable solution to the programming task. Second, in the programming process, students were instructed to consult with their partner or other peers as well as the teacher. During programming, students could then work together if they did not like to ask the teacher. In the mediated group, students' learning was arranged according to the problem solving style called *formal programming* by Turkle and Papert (1990) and *breadth first programming* by Vessey (1985).

By contrast, the learning process of the discovery group during the teaching period was arranged in such a way that the students would learn to deal with new situations by solving cognitive conflicts during programming processes. In the discovery group, students' programming tasks were more open than in the mediated group. A conscious planning process before programming was not necessary, but it was possible. This means that pupils could begin writing the Logo program without planning it. In the discovery group, students became familiar with the problem during the actual programming process. In the discovery group, students' learning during the teaching phase was arranged in such way that students tried to find solutions to the given task during the actual programming process. The idea was that interindividual cognitive conflicts as well as cognitive conflicts between the pair and the computer during the programming process may help students learn through self-discovery. Thus, with regard to learning in the discovery group the presupposition was that the self-discovery process engenders social interaction which requires coordination of actions or thoughts and facilitates cognitive development (Perret-Clermont 1980). The other presupposition was that the metacognitive skills will develop especially during solving cognitive conflicts (Clements & Nastasi 1988, Markman 1977). The teacher's role was thus different in the discovery group than in the

mediated group. The teacher did not check pupils' work during programming if the students themselves did not ask for advice. In the discovery group, students' learning was arranged according to the problem solving style called *concrete programming* by Turkle and Papert (1990) and *depth first programming* by Vessey (1985). The presupposition was that the students in the discovery group will learn to concentrate on only one part of the problem at time and that they will learn to cope with conflicts without the teacher's advice. Although in cognitive science in general this kind of programming style is not considered to be a high quality style, in Papert's theory it is as good as the formal style.

When learning was organized according to the mediated model, the students subsequently preferred to work without the advice of the teacher and they had more cognitive conflicts in the experimental phase. On the other hand, the students who learnt through the discovery model preferred to work with the teacher and they did not have so many cognitive conflicts. In addition, the discovery group used more explicit planning during the experiment than the mediated group.

However, the final Logo program of the discovery group was longer and included more music than the mediated group's final program. Thus, the discovery group had learnt the Logo programming language better than the mediated group because they were able to produce more music in their programs in the same time.

Even if the research on the development of programming skills (Fay & Mayer 1994) regards longer programs as the a manifestation of undeveloped programming skills compared with shorter programs, this is not the case in LEGO/Logo programming. The increase in the diversity of the program have a direct linear relationship with the length of the Logo program.

This study shows that different types of educational interventions engender different types of problem solving processes. This result as such supports Papert's argument that a LEGO/Logo learning environment provides opportunities for different kinds of learning processes (Papert 1980; 1993; Turkle & Papert 1993). But, while Papert assumes that the different kinds of learning processes reflect different kinds of inherited personality (formal or concrete programming style), the results of this study show that the differences in the processes are the result of different instructional interventions<sup>15</sup>. These different interventions develop students' cognitive capabilities in different ways.

In this study, the learning processes of the students in the mediated group emphasized the negative features of the mediated method, whereas in the discovery group students' learning processes might emphasize the positive features of the discovery method. This means that in the mediated group students may comply with the teacher's authority and this compliance may hinder students' own cognitive restructuring processes (Granott & Gardner 1994). Ready made tasks during the teaching period in the mediated group could hinder students' own cognitive restructuring processes, too. Although the explicit

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<sup>15</sup> In this study, students' personality was not studied. But the same problem appears in Papert's study, in which he (with Turkle) assumed that the formal and concrete style as such are manifestations of personality.



planning process was supported by scaffolding discussions between the students and the teacher, one can conclude that this discussion could not be symmetric in nature (Elbers, Maier, Hoekstra & Hoogsteder 1992; Perret-Clermont 1980). Since the starting point of the problem solving processes was a ready made task with ready made subquestions, this educational solution could lead to a situation, in which the scaffolding discussion is based on the teacher's own goal (to mediate expert-like thinking to the students). Students' own intentions may not have a meaning in this scaffolding discussion. In Bruner's original study (Bruner 1975), mothers try to interpret their childrens' own striving, and then to help the child achieve his/her own goal; or to constrain the child's own goal into a more suitable form. Thus, the original idea of scaffolding in Bruner's sense is that more capable persons try to interpret the learner's own intention and, in this way, it is possible to scaffold the learner to achieve his/her own goal. By contrast, in this study, the starting point of the scaffolding discussion was the given task and the subquestions concerning the task. In such a situation, students have to interpret the goal of the teacher, and maybe this is too demanding a task for students who are only beginning to learn programming. This arrangement could also lead to a learning process which students feel to be boring and irrelevant (Papert 1980; Linn 1986). This asymmetric scaffolding may lead to learning processes in which learners do not take personal responsibility for the task (Granott & Gardner 1994). This kind of situation does not give students as much chance to become excited by the learning activity as compared to situations in which they themselves take the responsibility for the tasks (Martin & Resnick 1990, A. Brown et al. 1993).

It can be concluded, on the basis of the analysis of students' final Logo program, that the mediated group concentrated on the more limited possibilities of programming during their problem solving processes because their programs include an average of two different parts, moving commands and lights, whereas in the discovery group, students' programs include on average three different parts (moving commands, lights and music). When, in addition, the mediated group does not use explicit planning as much as the discovery group, the following conclusion could be made: With the explicit planning method students did not learn the basic Logo commands as well as the discovery group did. Thus, the students' cognitive energy during the experiment phase was used up on move and light commands, and they did not have cognitive energy for effective planning.

In respect of the learning of the mediated group, one can conclude that too early mediation of expert-like thinking can slow down the development of both a suitable cognitive structure and a suitable motivational orientation toward complex tasks compared to the discovery method. Even if the occurrence of cognitive conflicts was greater in the mediated group during the open LEGO/Logo experiment, the solutions of these conflicts are more a message about the lack of the skill in applying basic Logo commands than a message about higher order thinking. Thus, the occurrence of the cognitive conflicts in problem solving does not necessarily lead to better results in programming. As previous research has shown, cognitive conflicts do not necessarily lead to the reorganization of an individual's mental models (Chinn & Brewer 1993). Chinn and Brewer (1993) argue:

Instead of abandoning or modifying their preinstructional belief in the face of new conflicting data and ideas, students often staunchly maintain the old ideas and reject or distort the new ideas. (pp. 1-2).

In the discovery groups, students' learning processes emphasized the positive features of the discovery method. It can be assumed that especially the nature of the problem solving task during a teaching period influences the effective learning of the students in the discovery group. Even though the tasks during the teaching period were not so open as in Papert's teaching experiments (Papert 1980, 1993; Turkle & Papert 1993; see also Martin & Resnick 1990), the tasks offered the students several different opportunities. Students could discover within the given frame. This freedom caused the better results in the open LEGO/Logo problem solving experiment. Even if students did not have as much cognitive conflict solving during problem solving, their final program included more music.

It can be supposed that students in the discovery group have learnt more and thus they had more cognitive energy for effective planning than the students in the mediated group. Thus, the discovery group could concentrate on making more versatile programs because they had learnt moving commands during the teaching period better than the mediated group. Because they can use moving commands more automatically, their memory capacity was released for the planning of more versatile Logo programs. This interpretation of the result is consistent with the previous researches (Case 1978, Sweller 1994, Marcus et al. 1996). As Case has argued, automaticity concerning learning elements is a prerequisite for transition to using these learning elements with other elements (Case 1978). The skill of using words as a genuine tool enables action in which planning is used in goal determination, in the analysis of one's own action and in error elimination. The conscious control of phenomena that is characteristic of scientific concepts presupposes that the phenomena are related to each other as parts of a general and hierarchical conceptual system (Vygotsky 1978). If the problem solver has a limited amount of processing capacity, it is easily overloaded by the memory requirements of an unfamiliar problem (Kotovsky et al. 1985). This overload of memory prevents the use of memory capacity for planning. Humans can overcome the problems of limited capacity of STM by chunking information and by automatizing the processing of information.

In computer programming the familiarity of the problem releases memory capacity for effective planning because the use of lower-level knowledge (syntactic and semantic knowledge) can be applied in an automatic way (Sweller 1994, Marcus et al. 1996). Thus, the automation of the use of knowledge is a necessary condition for effective planning in a problem solving situation (Kotovsky et al. 1985). It looks as if the automatizing of syntactic processing reduces the cognitive load, and the cognitive capacity is sufficient for focusing attention on the meaning and structure of the program.

While previous research has shown that the mediation of domain knowledge decreases the cognitive load and releases cognitive resources for effective planning and the acquisition of new knowledge (Linn 1986), in this study it seems as if the mediation of the expert way of thinking (explicit planning

method) slows down students' acquisition of new knowledge and prevents effective planning.

However, on the basis of the data of this study, it is difficult to say whether the more complicated goal, or more automatic cognitive skills produced the better results of the discovery group. There is also reason to remember that students in the discovery group cooperate more with the teacher during the experiment. Thus, it is also possible that the discovery learning model encourages students to discuss with the teacher during problem solving. Thus, the better results may be caused by cooperation skills, and not by better cognitive skills compared to the mediated group. In any case, students in the discovery group had more intrinsic motivation and they had more responsibility for the tasks than the mediated group.

Students in the discovery group had more freedom in their problem solving processes during the teaching phase. This freedom may lead to better responsibility for their own learning processes. Thus, the learning processes in the discovery group lead to a situation where students feel their learning to be meaningful, as Papert (1980, 1993), and others in Papert's research group (Martin & Resnick 1990) have described.

### **8.1.2 Girls' and boys' problem solving processes**

Some previous research has found differences between females and males in the problem solving processes, whereas other research has found no differences. Even though no difference has been found on how females and males perform in computer courses (Webb 1985, Lai 1993), females' attitudes towards the computer are nevertheless more negative than those of males and this is reflected in females' unwillingness to participate in computer courses (Webb 1985, Edwards et al. 1997). In the previous research, the following differences were found: First, boys called for help more frequently than girls, and girls tended to work more autonomously than boys. Second, girls showed greater persistence than boys when conflict occurred during programming. Third, girls talked about what they would do or should do before acting, whereas boys tended to act before discussing (Edwards et al. 1997). And finally, Papert (with Turkle) has found that females solve problems with a concrete programming style, whereas boys use a formal problem solving style (Papert 1980, 1993; Turkle & Papert 1990, 1992, 1993). Papert's main argument concerning gender differences in problem solving, as well as in scientific reasoning in general, is that females' concrete problem solving style is as effective as males' formal problem solving style, but that our culture values only the formal style. Thus, Papert considers girls as skillful as boys in the Logo learning environments, if both genders can program the computer using Logo in their own way. In this study, the content of the teaching period was organized so that the projects would be interesting for both genders.

Boys and girls differed in the quality of their problem solving processes in the open LEGO/Logo learning environment. As such, this result is consistent with Papert's ideas concerning Logo. Logo offers everyone opportunities to program in a personal way. The result that girls show more explicit planning than boys, in this study, gives a picture of boys' and girls' programming processes

which is in contrast with the one Papert has given. In this study, girls were more articulate and they planned their programming process more explicitly than boys. Thus, the results of this study are consistent with Edwards and her colleagues' study, in which girls talked about what they would do or should do before acting (Edwards et al. 1997). However, it is worth noting that the boys' final Logo programs were longer and included more music than the girls' final program.

It seems that a technology-rich learning environment can also be motivating for girls if social interaction is possible during problem solving. On a verbal level girls can discuss and plan in a more holistic way than boys. The action of this kind is not possible if the problem solver does not engage him/herself in the task. However, the boys had learnt the basic Logo commands better because they produced more music in their Logo programs in the same time.

### **8.1.3 High and low achievers' problem solving processes**

The problem solving processes of the high and low achieving students was different only in the amount of explicit planning during the problem solving experiment. The high achievers had more explicit planning during programming than the low achievers. This difference had no effect on the differences in the final Logo program among the high and low achieving students. In addition, no difference was found between the high achievers and low achievers in the occurrence of cognitive conflict solving and cooperation with the teacher during problem solving.

While previous research has suggested that low ability learners need more teacher guidance than high ability learners (Bradley 1985, German 1989, Mayer 1987, Snow 1994, Snow & Lohman 1984, Suomala 1996), in this study, the general ability to learn had no interaction effects with the learning model for the problem solving processes. It is possible that the LEGO/Logo learning environment equalized the students' learning because the low achievers may also have experienced this learning environment as meaningful. It is possible that the high achievers had more ideas for different kinds of solutions, but this explicit planning did not manifest itself as a more versatile program.

## **8.2 Evaluation of the methodology**

Two methods were used in the study: the group test of Piagetian thinking (Pre- and posttest) and the observation procedure. The test was built on the four Piagetian schemata, i.e., conservation of displaced volume, propositional reasoning, probabilistic reasoning, and mastering of permutations. These schemata have been regarded as an essential part of formal thinking in Piaget's theory (Enkenberg 1989; Inhelder & Piaget 1958; Karplus et al. 1978). A starting point of this study was that this group test could be used to evaluate the level of students' thinking development in general (Enkenberg 1989). The main constraint a test of this sort is that it can test childrens' thinking only in a structured test

situation and it does not give information about how children can solve problems in self-selected test situations. We can, however, assume that the construct validity of the Piagetian group test is good in the area of context independent thinking.

The reliability of the group test of Piagetian thinking was evaluated on its internal consistency (Cronbach's alpha). The reliabilities of the pretest ( $\alpha = 0.67$ ) and the posttest ( $\alpha = 0.74$ ) were satisfactory, and they were mostly at the same level as in the original study ( $\alpha$  was 0.78 in the pretest and 0.82 in the posttest in Enkenberg's 1989 study). The reason for a somewhat lower reliability in this study than in Enkenberg's study could be that the test in this study included two subtests fewer than in Enkenberg's study. In this study, the intercorrelation between the pretest and the posttest was 0.78, thus the constancy of the Piagetian test measurement was satisfactory. To improve the external reliability of the thinking test, the same person (the researcher) conducted the tests. In assigning the scores to the students' answers, the tasks were assessed one at a time. The answer sheets of the LEGO/Logo group and the ordinary group were randomly mixed (Enkenberg 1989). The interpretation of the answers was based on Enkenberg's study (1989).

The second goal of the present study was to study the different routes of the students' problem solving processes in the open LEGO/Logo learning environment. An observational procedure was used because "traditional" tests exclude contextual factors of thinking. In addition, the shortcoming of previous studies has been that they do not explain students' differences in the open learning environment. In this study, video technology was available for collecting the on-line data from the students' problem solving processes in the open problem solving situation.

While previous research has concentrated on comparing students' learning outcomes as well as processes between different kinds of learning environments (Clements & Nastasi 1988; Nastasi et al. 1990; Nastasi & Clements 1991; Nastasi & Clements 1993), this study concentrated on the differences in the problem solving processes of the students who took part in the same open LEGO/Logo learning environment.

In order to construct an open problem solving situation, an effort was made to develop a research method that takes into account both internal and external factors of problem solving. The main assumption in this study is that the construct validity of the study will be better if students are studied as they solve self-selected problems. The content of the observational procedure derives from the social, motivational and information-processing part of problem solving.

Thus we can assume that the observational procedure used in this study gives a multifaceted picture of children's problem solving in an open problem situation. In a measurement of this sort, the picture of problem solving skills based on crystallized thinking is amplified through the addition of problem solving skills based on fluid thinking. Thus, we can judge that the construct validity of observational measurement was good in this study.

### 8.3 Implications for the future research

During its brief history Logo has produced a diverse range of research on students' learning with this "evocative tool". During this twenty-year period, many new technological tools for education have been developed. Multimedia, the Internet and multiple other network applications have been adopted for education. A good example of this development is Logo itself. The latest product of the Logo-Family is LEGO Mindstorm, which is supported by abundant material available on the Internet. We can, however, ask whether it makes sense to continue to use the combination of LEGO blocks and a Logo-like programming language in future research? My answer is yes.

New technological tools give students many opportunities for collaborative learning and problem solving in a dynamic learning environment. Because LEGO/Logo is a combination of simplicity and complexity, it can serve as research environment for obtaining more precise knowledge of the nature of collaborative learning and problem solving. This kind of technology-rich learning environment can serve as an educational research tool in the same way as chess has served research in cognitive psychology (Saariluoma 1995). Knowledge of students' thinking processes in LEGO/Logo can also enhance our general understanding of collaborative learning, problem solving and the role of teachers, both in the context of education in general, and in the computerized environment in particular.

In my view there will be two essential research themes. First, how the teacher can support students' discovery processes during problem solving, and, second, how students' dynamic learning can be organized in the whole class context (see, Hatsch & Gardner 1993). Consistent with the common view in the current literature, this study shows that student's role as an active learner during progressive problem solving should be respected by the teacher (Häkkinen 1994, Järvelä 1996d, Marttunen 1997). Especially in situations where learners encounter cognitive conflicts or when they show that they have novel ideas, the teacher's role as a sensitive "coach" is important. In the whole class context, the essential questions will be how to maintain students' long-term problem-solving projects and how to assist them to overcome obstacles during such projects.

## YHTEENVETO

### Johdanto

Tietokoneiden koulukäyttöä on perusteltu sekä yhteiskunnan muutoksen että oppilaiden yksilöllisen kehittymisen näkökulmista. Yleisesti on nähty, että toimiminen tietoyhteiskunnassa edellyttää kansalaisilta kykyä selviytyä usein muuttuvissa tilanteissa. Kerran opittuja tietoja ja taitoja ei välttämättä voida soveltaa koko ihmisen elinajan, vaan kansalaisten tulee pystyä oppimaan uusia asioita ja kohtaamaan uusia tilanteita. Uusien asioiden omaksumisessa on keskeistä taito valita oleellinen tieto suuresta informaatiomäärästä. Yksilön kasvun ja oppimisen näkökulmasta tietotekniikan käyttöä on perusteltu sillä, että tietotekniikan hallinnan avulla oppimisen laatu paranee, kun oppilaat voivat oppia yksilöllisesti mielekkäällä ja tehokkaalla tavalla. Yksilöllistä kehittymistä korostettaessa on todettu, että kouluopetus ei yleensä tarjoa oppilaille mielekkäitä kokemuksia ja että nimenomaan tietotekniikan avulla koulujen oppimistilanne saattaa muuttua myönteiseen suuntaan.

Yhdysvaltalainen Seymour Papert kehitti 1970-luvulla Logo-ohjelmointikielen lasten oppimisen välineeksi. Logoon liittyvässä oppimisen taustateoriassa yhdistyy sekä yhteiskunnallinen että yksilöllinen näkökulma. Tulevaisuuden yhteiskunnassa menestyvät ne, jotka oppivat ongelmanratkaisutaitoja. Toisaalta koulun tulee muuttua, jotta oppiminen olisi laadukasta. Papertin ajatukset liittyvät yhdysvaltalaiseen progressiivisen pedagogiikan perinteeseen. Nyt vain uudistuksen välineenä toimivat tietokone ja sen yksilön ajattelua kehittävä ohjelmisto.

Tässä tutkimuksessa keskitytään erityisesti kahteen Papertin esittämään ajatukseen. Papert väittää, että Logon avulla on mahdollista oppia luonnollisen oppimisen periaatteen mukaisesti. Hän väittää myös, että oppilaiden ongelmanratkaisutaidot kehittyvät, kun he ohjelmoivat Logolla. Luonnollisen oppimisen periaatteen mukaan lapsi oppii parhaiten, jos hänelle annetaan mahdollisimman paljon vapautta toimia aktiivisesti oppimistilanteessa. Tämä edellyttää sitä, että oppilaat voivat valita oppimisen kohteen itse ja että oppimisprosessiin liittyy oleellisena osana keskustelu toisten oppilaiden ja opettajan kanssa. Ongelmanratkaisutaitojen kehittyminen taas perustuu oletukseen virheiden merkityksestä oppimisessa. Ohjelmoidessaan Logolla lapset tekevät virheitä, ja kun he miettivät, mikä virheen on aiheuttanut, he samalla joutuvat pohtimaan oman ajattelunsa perusteita. Tällainen pohtiva ajattelu on hyvin keskeistä ongelmanratkaisussa, ja tällaisten ajattelutaitojen avulla on mahdollista selviytyä myös täysin uusista ongelmista. Tämä tutkimus rakentuu paljolti näiden kahden Papertin oppimista koskevan väitteen tarkasteluun.

Logoa on tutkittu melko paljon ja tulokset ovat ristiriitaisia. Erityisesti luonnollisen oppimisen periaatetta on kritisoitu. Tutkimusten ongelmana on ollut se, että niissä on annettu oppilaille hyvin valmiita tehtäviä, jolloin idea luonnollisesta oppimisesta ei ole päässyt toteutumaan. Sama problematiikka sisältyy myös muihin ajattelua koskeviin tutkimuksiin. Niistä suurin osa on toteutettu tilanteissa, joissa oppiminen ei voi toteutua luonnollisen oppimisen periaatteen mukaan.

Tällöin myös oppilaiden vapaa vuorovaikutus ja virheiden korjaamismahdollisuus on usein eliminoitu. Papertin omien tutkimusten ongelmana puolestaan on se, että hän perustaa havaintonsa sellaisiin ideaalisiin esimerkkitapauksiin, jotka toimivat hänen ajatustensa mukaisesti. Kaikki oppilaat eivät nimittäin kykene hyödyntämään avointa oppimisympäristöä ilman opettajan tukea. Tässä työssä Logo-tutkimuksiin liittyvä problematiikka on pyritty ratkaisemaan niin, että opettaja on tarvittaessa tukenut oppilaiden ongelmanratkaisua avoimessa ongelmanratkaisutilanteessa. Tutkimuksen kohteena ovat oppilaiden toiminta ja keskustelut.

### **Tutkimuksen toteuttaminen**

Ensimmäisessä Logo-versiossa lapset tekivät Logo-ohjelmia, joiden avulla he liikkuvat kilpikonnarobottia lattialla. Tämän jälkeen ohjelmoinnin kohteeksi kehitettiin tietokoneen kuvaruudulla liikuteltava kilpikonna. Tässä tutkimuksessa käytettiin LEGO/Logoa. LEGO/Logossa tekniikkalegot sähkömoottoreineen ja tunnistimineen korvaavat alkuperäisen kilpikonnarobottin. LEGO/Logossa oppilaille tutut legopalikat yhdistyvät vaativaa ajattelua edellyttävään ohjelmointiin.

Tutkimus käsittelee viidesluokkalaisten oppilaiden (N = 198) ongelmanratkaisua LEGO/Logo - oppimisympäristössä. Papertin ajatuksia on testattu niin, että osalle oppilaista opetettiin Logo-ohjelmointia ohjatun opetuksen periaatteen mukaan ja osalle keksivän opetuksen periaatteen mukaan. Opetusjakson jälkeen järjestettiin avoin ongelmanratkaisutilanne, jossa tutkittiin näiden kahden opetusmenetelmän vaikuttavuutta. Tutkimuksen koehenkilöinä olivat kolmen ala-asteen viidennen luokan oppilaat. Tutkimukseen sisältyy kaksi osaa. Ensimmäisessä osassa tutkittiin LEGO/Logo- oppimisympäristössä tapahtuneen oppimisen vaikutusta oppilaiden kykyyn selviytyä formaalia ajattelua edellyttävistä tehtävistä (syrjäytetty tilavuus, verrannollisuus, todennäköisyys ja permutaatio). Tehtävät esitettiin oppilaille luokkakokeena, jonka on kehittänyt Enkenberg Piaget'n teoriaan pohjautuen. LEGO/Logo-ryhmä (n = 103) opiskeli kevätlukukauden aikana 20 tunnin ajan legopalikoiden ohjelmointia Logolla ja kontrolliryhmä (n = 95) sai opetusta ilman tietokoneita. Oppilaat testattiin ennen opetusjaksoa ja opetusjakson jälkeen. Näin saatiin selville, mikä oli LEGO/Logon vaikutus oppilaiden sisällöstä riippumattomaan ajatteluun.

Tutkimuksen toinen osa käsitteli ohjatun ja keksivän LEGO/Logo-oppimisen vaikutusta oppilaiden ongelmanratkaisuun avoimessa tehtäväympäristössä. Tämän osan oppilaat muodostuivat tutkimuksen ensimmäisen osan LEGO/Logo-ryhmästä. Ohjatulle LEGO/Logo-ryhmälle (n = 48) annettiin opetusta ohjatun opetuksen periaatteen mukaan. Tämä merkitsi sitä, että opettaja antoi opetusjakson aikana oppilaille valmiita tehtäviä. Oppilaita ohjattiin analysoimaan tehtäviä ennen kuin he ryhtyivät ohjelmoimaan. Tällä pyrittiin siihen, että oppilaat olisivat oppineet suunnittelemaan omaa ohjelmointiprosessiaan tietoisesti. Keksivän LEGO/Logo - ryhmän (n = 56) opetusjakso toteutettiin niin, että oppilaat saivat itse mahdollisimman vapaasti keksiä sopivia ohjelmointitehtäviä. He saivat myös aloittaa ohjelmoinnin milloin halusivat, eikä ennakkosuunnittelua



vaadittu. Molemmissa ryhmissä oppilaat toimivat pareittain, ja 20 tuntia kestäneen opetusjakson aikana toteutettiin sekä karuselliprojekti että robottiprojekti. Karuselliprojektissa kukin oppilaspari rakensi legoista karusellin, joka toimi sähkömoottorilla. Karusellissa oli myös valoja ja oppilaat saattoivat ohjelmoida musiikkia samanaikaisesti, kun valot vilkkuivat ja karuselli pyöri. Robottiprojektissa oppilaat rakensivat kaksimoottorisen robotin, jossa oli valoja. Robotin toimintaan saattoi ohjelmoida myös musiikkia.

Opetusjakson jälkeen osa ohjatusta LEGO/Logo-ryhmästä (n = 42) ja osa keksivästä LEGO/Logo-ryhmästä (n = 46) osallistui pareittain koejaksoon. Heidän tehtävänä oli suunnitella legorobotille reitti ja tehdä Logolla ohjelma, joka liikutti robotin oppilaiden suunnittelemaa reittiä pitkin maaliaalueelle. Oppilaiden oli mahdollista käyttää valoja ja musiikkia, kun robotti kulki. Robotin liikkeen, valojen toiminnan ja musiikin tuottamisen ohjelmointi edellyttivät oppilailta suunnitelmallista ongelmanratkaisua, jota tässä tutkimuksessa haluttiin tutkia. Kaikkien koetilanteeseen osallistuneiden oppilaiden ongelmanratkaisuprosessi videoitiin. Aineisto analysoitiin jälkepäin kehittämällä Clementsin ja Nastasin (1988) observointimittaria tähän tarkoitukseen sopivaksi. Analyysi kohdistui ongelmanratkaisun kannalta keskeisiin käyttäytymispiirteisiin, joita olivat kognitiivisen konfliktin ratkaiseminen, yhteistyö opettajan kanssa ja tietoinen suunnittelu.

Opetusmenetelmien vaikutuksen lisäksi tutkittiin, miten aikaisempi ohjelmointikokemus, sukupuoli ja formaalin ajattelun taso olivat yhteydessä ongelmanratkaisuun. Oppilaiden tekemien Logo-ohjelmien rakenne analysoitiin myös.

### **Tutkimuksen tulokset ja johtopäätökset**

Tutkimuksen mukaan oppilaiden käsitys syrjäytetystä tilavuudesta, verrannollisuudesta, todennäköisyydestä ja permutaatiosta kehittyi tutkimusjakson aikana. Tämä kehittyminen oli kuitenkin opetusmenetelmästä, sukupuolesta, aikaisemmasta ohjelmointikokemuksesta ja koulumenestyksestä riippumatonta. Sen sijaan oppilaiden ongelmanratkaisussa oli useita laadullisia eroja.

Keksivän ryhmän ongelmanratkaisu sisälsi enemmän tietoista suunnittelua ja yhteistyötä opettajan kanssa kuin ohjatun ryhmän ongelmanratkaisu. Ohjatulla ryhmällä sitä vastoin oli ongelmanratkaisussa enemmän kognitiivisia ristiriitoja kuin keksivällä ryhmällä. Molemmat ryhmät käyttivät keskimäärin saman verran aikaa ongelmanratkaisuun, mutta keksivän ryhmän oppilaat laittoivat enemmän musiikki-komentoja ohjelmiinsa. He siis saivat robotin toimimaan monipuolisemmin kuin ohjatun ryhmän oppilaat. Lisäksi havaittiin, että kognitiivisten ristiriitojen esiintyminen ongelmanratkaisun aikana ei ollut merkki korkeatasoisesta ongelmanratkaisusta vaan paremminkin kognitiivisten taitojen puutteesta.

Tutkimuksen johtopäätöksenä on, että liian valmiiden ongelmanratkaisumallien (ohjattu ryhmä) opettaminen oppilaille voi hidastaa ongelmanratkaisutaitojen omaksumista. Ongelmanratkaisutaitojen oppimisen kannalta on tärkeää sellaisten oppimisympäristöjen kehittäminen, jotka mahdollistavat oppilaiden omien ideoiden tuottamisen. Opettajan tehtävänä tällaisessa tilanteessa on tukea oppilaita heidän kohdatessaan vaikeuksia ideoitensa toteuttamisessa.

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## APPENDIX 1

## List of variables

Variables	M	SD	The p-value <sup>16</sup>
<b>A. The variables of Piaget's pretest (n = 192)</b>			
1. The displaced volume	3.06	1.10	0.00
2. Proportionality A	1.96	0.45	0.00
3. Proportionality B	1.90	0.49	0.00
4. Probability A	3.05	1.08	0.00
5. Probability B	2.22	1.06	0.00
6. Permutation A	2.22	1.07	0.00
7. Permutation B	2.05	0.98	0.00
8. Sumvariable of the pretest	16.47	3.78	0.37
<b>B. The variables of Piaget's posttest (n = 189)</b>			
9. Displaced volume	3.23	1.04	0.00
10. Proportionality A	2.02	0.57	0.00
11. Proportionality B	1.94	0.59	0.00
12. Probability A	3.23	1.00	0.00
13. Probability B	2.33	0.99	0.00
14. Permutation A	2.28	1.09	0.00
15. Permutation B	2.18	1.03	0.00
16. Sumvariable of the posttest	17.24	4.03	0.15
<b>C. The observational measurement of the problem solving process (n = 88)</b>			
<b>C.1. Variables of the social problem solving</b>			
17. Cooperation	76.83	7.07	0.83
18. Cooperation with a teacher	15.04	7.39	0.53
19. No cooperation	0.18	0.61	0.00
20. Cognitive conflict	8.48	3.55	0.40
21. The attempt to resolve cognitive conflict	15.11	9.40	0.34
22. Success in resolving of cognitive conflict	3.11	1.68	0.42
23. Failure in resolving of cognitive conflict	2.88	2.37	0.01
<b>C.2. Variables of the effectance motivation</b>			
24. Self directed work	1.10	0.91	0.20
25. Rule determination	3.48	2.71	0.35
26. Persistence	22.18	9.60	0.28
27. Assistance seeking	2.17	2.85	0.00
28. Expressing pleasure	9.28	7.22	0.28
<b>C.3. Variables of the information-processing</b>			
29. Deciding on the nature of the problem	4.40	2.70	0.60
30. Selecting performance components	30.94	9.31	0.42
31. Combining performance components	1.15	1.27	0.00
32. Allocating resources	0.25	0.67	0.00

(continues)

<sup>16</sup> If  $p > 0.05$ , then the distribution does not differ statistically significantly from the normal distribution. p-value is on the basis of Kolmogorov - Smirnov test.

## APPENDIX 1 (continues)

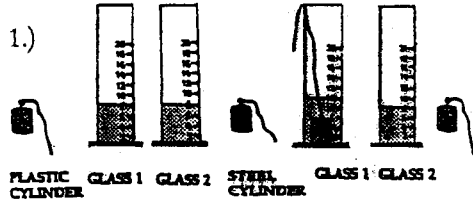
Variables	M	SD	The p-value <sup>17</sup>
33. Monitoring solution processes	25.10	8.62	0.90
34. Being sensitive to external feedback	1.12	1.16	0.02
35. Performance components	35.36	10.38	0.83
36. Other	1.72	2.35	0.00
<b>D. The properties of final Logo program (n = 88)</b>			
37. The programming time	38.77	10.71	0.59
38. The number of the commands	21.77	13.45	0.01
39. The number of the tone commands	5.51	6.89	0.00
<b>E. The school achievement (n = 196)</b>			
40. Mathematic	7.78	1.02	0.00
41. Finnish	8.08	0.88	0.00
42. English	7.84	1.20	0.00
43. Sumvariable (Math+ Finnish+English)	23.70	2.69	0.01

<sup>17</sup> If  $p > 0.05$ , then the distribution does not differ statistically significantly from the normal distribution. p-value is on the basis of Kolmogorov - Smirnov test.



APPENDIX 2: The Piagetian thinking experiment

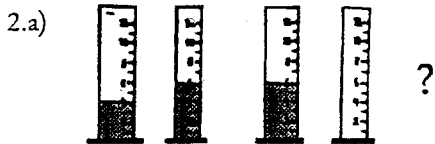
NAME \_\_\_\_\_  
 SCHOOL \_\_\_\_\_  
 CLASS \_\_\_\_\_  
 DATE OF BIRTH \_\_\_\_\_



What happens to the water surface of glass 2 when the steel cylinder is sunk into the water?

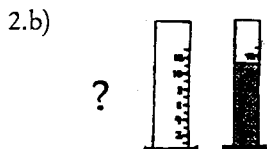
If the water surface rises or sinks, at which height does it stop?

How did you reach this conclusion?



How high does the water surface rise in the narrow glass when the same amount of water is poured into it as into the broad glass?

How did you reach this conclusion?



How high does the water surface rise in the broad glass when the same amount of water is poured into it as into the broad glass?

How did you reach this conclusion?



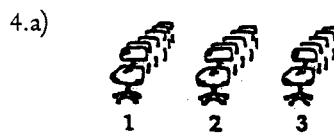
From which bag are you more likely to pick up a white ball?

How did you reach this conclusion?



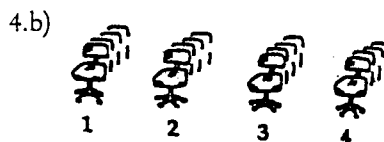
What is the likelihood of picking up a red object out of this bag?

How did you reach this conclusion?



In how many different combinations can the persons sitting on these chairs be placed?

How did you reach this conclusion?



In how many different combinations can the persons sitting on these chairs be placed?

How did you reach this conclusion?

## APPENDIX 2 (continues)

Every student had his/her own answer sheet with four pages (See page 136). The researcher demonstrated each subtest to the class. The researcher read the problem aloud and it was also written on the answer sheet. After that students wrote their solution on their own paper, which includes also the picture of the situation

### 1. The test of displaced volume.

#### 1.1 Instruction for carrying out.

Apparatus: Two identical measuring glasses, with the same scale. Two cylinders of the same size; one made of plastic, the other of steel. The researcher presented test one in the following way:

Here are two glasses, both have the the same scale (researcher shows). The glasses are the same size and the same shape. In both, the water reaches up to 6 on the scale (Researcher shows). Here are two cylinders of the same size made of plastic and steel. The steel cylinder is heavier than the plastic cylinder. Both sink when they are placed on the water. When the plastic cylinder is placed in one of the glasses (researcher places the plastic cylinder in glass 1), the water surface rises to the 10 mark on the glass. After this the steel cylinder is placed in glass 2.

After this demonstration, the researcher read the problem for the students. The same problem is written on the answer sheet. Students had 5-10 minutes to answer the question.

#### 1.2 Scoring criteria

Score	Description of the answer
4	The answer is correct. The explanation is correct; Because the plastic- and the steel cylinders are same size, the water surface rises to the same mark (10) as on class 1.
3	The answer is correct, but the explanation is not sufficient or it includes incorrect concepts.
2	The answer is incorrect. The weight and the volume have not been kept apart. The student has not realized that weight has no effect on the displaced volume.
1	The answer is incorrect. The explanation is illogical and it does not refer to the concepts of weight and volume. The task has not been understood right. Either answer or explanation is missing.

### The tests of proportionality

#### 2.1 Instruction for carrying out.

Apparatus: Two containers with circular bottoms and scales with scales; one narrow glass and one broad glass. In addition, two glasses with similar scales and water. The researcher presented the test 2A in the following way:

(continues)

## APPENDIX 2 (continues)

Here are two different containers with circular bottoms (researcher shows). First there is a narrow glass and second a wide glass. When the same amount of water is poured into them (researcher pours from glasses with scales), the water surface in the wide glass rises to the 4 mark, and to the 6 mark in the wide glass. Now we shall make an other observation, but I won't make it here. You may predict the result of the observation. In this second observation, the water surface rises to the 6 mark in the wide glass.

After this demonstration, the researcher reads out the problem to the students, written on the answer sheet 2a. The students had 5 to 10 minutes to answer.

After time for answering problem 2a had run out, researcher presented problem 2B in the following way:

Now we shall make third observation. However, I won't demonstrate it here. You may predict its results. The containers are the same as in previous observation. Now, the water surface rises to the 11mark.

After this demonstration, the researcher read out the problem to the students, written on the answer sheet 2b. Answering time was 5 to 10 minutes.

## 2.2 Scoring criteria

The same scoring criteria are used both for answer 2a and 2b.

Score	Description of the answer
5	The answer is correct. The explanation is based on proportionality.
4	The answer is correct. The explanation is based on comparison of the quantities of the water.
3	The answer is correct or incorrect. An attempt to use relation. The calculations are incorrect. The results were iterated.
2	The answer is incorrect. The differences of the scalenumbers were used. The result was obtained by addition and subtraction.
1	The answer is incorrect. It has been conjectured or the students has paid attention to other things than scalenumbers. The explanation is not rational. Either answer or the explanation is missing.

## 3 The tests of probability

### 3.1 Instruction for carrying out 3a

Apparatus: Two opaque plastic bags, 8 white balls and 10 black balls. The balls are on the table and students can see them. The researcher presents problem 3a in the following way:

(continues)

## APPENDIX 2 (continues)

3 white balls and 3 black balls are placed in bag A (Researcher places the balls). 5 white balls and 7 black balls are placed in bag B (Researcher places the balls). (Researcher writes on the blackboard: Bag A: 3 white balls and 3 black balls. Bag B: 5 white balls and 7 black balls). Without looking inside the bags, the researcher takes one ball from each bag.

After this demonstration, the researcher read out the problem to the students, written on the answer sheet 3a. Answering time was 5 to 10 minutes.

### 3.2 Scoring criteria

Score	Description of the answer
4	The answer is correct. In the explanations the relation of the white and black balls in both bags is compared.
3	The answer is correct or incorrect. In the explanation the relation of the white and black balls in one bag is compared..
2	The answer is correct or incorrect. In the explanation the total number of of white and black balls in the two bags is compared.
1	The answer is conjectured and it is not rational. The explanation is illogical or the problem is understood in the wrong way. Either answer or the explanation is missing.

### 3.3 Instruction for carrying out 3b

Apparatus: One opaque bag; 3 red, 4 yellow and 5 blue balls; 4 red, 2 yellow and 3 blue cubes. The balls and cubes are on the table and students can see them. The researcher presents problem 3b in the following way:

3 red, 4 yellow and 5 blue balls are placed in a bag (researcher places balls) together with 4 red, 2 yellow and 3 blue cubes (researcher places cubes). (The researcher writes on the blackboard: 3 red, 4 yellow and 5 blue balls ; 4 red, 2 yellow and 3 blue cubes). The researcher then takes objects out of the bag without looking at them.

After this demonstration, the researcher read out the problem to the students, written on the answer sheet 3b. Answering time was 5 to 10 minute

### 3.4 Scoring criteria

Score	Description of the answer
5	The answer is correct. In the explanations the number of red objects is compared with the number of all objects in the relation: the beneficial cases/all elementary cases.
4	The answer is correct. In the explanations the number of red objects is compared to all other objects. Seeking to use the relation. A small calculation error is possible.

(continues)

## APPENDIX 2 (continues)

- |   |   |
|---|---|
| 3 | The answer is correct qualitatively. In the explanations different coloured objects together are compared. This comparison is based on the relative amounts of the objects. |
| 2 | The answer is given as an approximation. The answer refers to the absolute amounts of the objects qualitatively.  |
| 1 | The answer is conjuctered or the explanation is illogical. The problem has been understood wrong. Either answer or the explanation is missing.                              |

**4. Test of permutations****4.1 Instruction for carrying out 4a**

Apparatus: A picture showing characteristic features of an auditorium, in the front row, there are three seats, numbered 1,2 and 3. The researcher presents problem 4a in the following way:

Three seats, numbered 1,2 and 3 have been reserved for three VIPs in the auditorium of the theatre (Researcher shows the picture). The VIPs arrive and sit in their reserved seats.

After this demonstration, researcher read out problem for the students, written on the answer sheet 4a. Answering time was about 5 to 10 minute

**4.2 Instruction for carrying out 4b**

Apparatus: A picture showing characteristic features of an auditorium, in the front row, there are five seats, numbered 1,2,3,4 and 5. The researcher presents problem 4a in the following way:

Five seats, numbered 1,2,3,4 and 5 have been reserved for fiveVIPs in the auditorium of the theatre (Researcher shows the picture). TheVIPs arrive and sit in their reserved seats.

After this demonstration, researcher read out problem for the students, written on the answer sheet 4b. Answering time was about 5 to 10 minute

**4.3 The criteria for scoring permutation tests 4a and 4b**

Score	Description of the answer
5	The answer is correct. In the explanations the student has described the number of permutations in such a way that it is clear that s/he has understood the idea.
4	The answer is correct or incorrect. The explanation is rather qualitative than quantitative. The enumeration does not make sense or is incomplete. Signs of understanding the idea.

(continues)

## APPENDIX 2 (continues)

- 3 The answer is incorrect. In the explanation the number of persons and the number of chairs has been applied.
- 2 The explanation of the solutions is based on the number of chairs and persons. Enumeration of the number of places and persons stops at 3 and 5.
- 1 The answer is conjectured. The explanation has focused on other things than the amount of chairs and persons. The explanation is illogical. The problem has been understood in the wrong way. Either the answer or the explanation is missing.

## APPENDIX 3

## The intercorrelations of the variables in the observation measurement ( r x 100)

Variable	CO	CO	NO	AL	AT	SU	FA	SE	RU	PE	AS	PL	DE	SE	CO	AL	MO	BE	PE	OT
Cooperat	1.00																			
Coteach	-89 <sup>b</sup>	1.00																		
Nocooper	-30 <sup>a</sup>	26 <sup>a</sup>	1.00																	
Allconfl	-11	-35 <sup>b</sup>	-10	1.00																
Attempt	07	-40 <sup>b</sup>	-04	71 <sup>b</sup>	1.00															
Success	00	-34 <sup>b</sup>	03	73 <sup>b</sup>	51 <sup>b</sup>	1.00														
Failure	-09	-26 <sup>a</sup>	-16	73 <sup>b</sup>	74 <sup>b</sup>	36 <sup>b</sup>	1.00													
Selfdirw	10	-06	09	-07	-14	-04	-08	1.00												
Rulemake	12	-11	-01	-03	-21	-12	-13	51 <sup>b</sup>	1.00											
Persist	-16	-06	-09	50 <sup>b</sup>	72 <sup>b</sup>	07	61 <sup>b</sup>	-10	-13	1.00										
Asseekin	-46 <sup>b</sup>	46 <sup>b</sup>	07	-08	-29 <sup>a</sup>	05	-13	18	13	-25 <sup>a</sup>	1.00									
Pleasure	25	-17	-04	-11	-24	-14	-20	25 <sup>a</sup>	16	-11	-01	1.00								
Deciding	-05	16	-16	-19	-33 <sup>b</sup>	-17	-18	34 <sup>b</sup>	42 <sup>b</sup>	-17	38 <sup>b</sup>	06	1.00							
Selectin	22	-29 <sup>a</sup>	-14	17	29 <sup>a</sup>	10	21	-06	-17	12	-26 <sup>a</sup>	-09	-20	1.00						
Combinin	13	-12	-07	-02	-12	-12	-13	24	36 <sup>b</sup>	02	-10	15	20	-01	1.00					
Allocres	-21	22	45 <sup>b</sup>	-10	-01	-01	-13	-07	-13	-07	01	03	-04	-02	-16	1.00				
Monitori	-21	09	09	25	22	10	23	-02	17	33 <sup>b</sup>	-02	-10	14	-36 <sup>b</sup>	-02	13	1.00			
Besenfed	-20	20	01	-01	-15	-18	-03	03	07	06	-03	09	-04	-13	19	-02	12	1.00		
Performc	03	10	-04	-26 <sup>a</sup>	-31 <sup>a</sup>	-11	-25 <sup>a</sup>	-05	-12	-31 <sup>a</sup>	18	11	-16	-50 <sup>b</sup>	-17	-21	-56 <sup>b</sup>	-10	1.00	
Other	-12	10	48 <sup>b</sup>	01	01	15	-15	08	-02	-00	-12	03	-21	-08	04	41 <sup>b</sup>	00	-02	-13	1.00

N of cases: 88 1-tailed Signif: a = .01. b = .001

COOPERAT	Cooperation with another child	PLEASURE	Expressing pleasure
COTEACH	Cooperation with a teacher	DECIDING	Deciding on the nature of the problem
NOCOOPER	No cooperation	SELECTIN	Selecting performance components
PERSIST	Persistence	COMBININ	Combining performance components
COCONFL	Cognitive conflict	ALLOCRES	Allocating resources
ATTEMPT	The attempt to resolve cognitive conflict	MONITORI	Monitoring solution processes
SUCCESS	Success in resolving of cognitive conflict	BESENFED	Being sensitive to external feedback
PERFORMC	Performance components conflict	PERFORMC	Performance components
SELFDIRW	Self directed work	OTHER	Other
RULEMAKE	Rule determination		
ASSEEKIN	Assistance seeking		

## APPENDIX 4

### The three factor solution

The unrotated three Factor solution concerning to Problem solving measurement, n = 88  
(Factor matrix)

Variables		Factors			Comm- unality
		I Loading <sub>1</sub>	II Loading <sub>1</sub>	III Loading <sub>1</sub>	
The Attempt to Resolve					
Cognitive Conflicts	(S) <sub>2</sub>	.94	.08	.02	.84
The Cognitive Conflict	(S)	.80	.15	.21	.95
Failure in Resolving					
Cognitive Conflict	(S)	.77	.19	.12	.75
Persistence	(E) <sub>3</sub>	.62	.23	.13	.76
Success in Resolving					
Cognitive Conflict	(S)	.51	.04	.03	.78
Selecting Performance					
Components	(I) <sub>4</sub>	.34	-.21	-.14	.92
Cooperation with another Child	(S)	-.51	.84	-.05	.99
Cooperation with a Teacher	(S)	.13	-.95	-.06	.99
Assistance Seeking	(E)	-.35	.37	.19	.51
Expressing Pleasure	(E)	-.19	-.29	.11	.26
Rule Determination	(E)	-.23	-.22	.71	.50
Self Directed Work	(E)	-.19	-.19	.50	.37
Deciding on the Nature					
of the Problem	(I)	-.36	.03	.54	.57
Combining Performance					
Components	(I)	-.09	-.22	.35	.41
Performance Components	(I) <sub>4</sub>	-.36	-.04	-.38	.94
Monitoring Solution Process	(I)	.23	.29	.42	.92
Eigenvalue	(%)	4.12	2.49	2.23	8.84
Proportion of total variance	(%)	25.8	15.6	14.0	55.4
Proportion of common variance	(%)	46.6	28.1	25.3	100

I = The Cognitive Conflict Solving

II = The Cooperation Process with Teacher

III = The Explicit Planning

<sub>1</sub> Loadings are from the factor matrix

<sub>2</sub> S in paranthesis means that the variable belongs to social problem solving in the initial measurement, see Table 2 in page 60.

<sub>3</sub> E in paranthesis means that variable belong to the effectance motivation in the initial measurement, see Table 3 in page 64.

<sub>4</sub> I in paranthesis means that variable belong to the information processing in the initial measurement, see Table 4 in page 67.



## APPENDIX 5

### Examples of the final Logo programs

EXAMPLE 1 Logo program which includes only MOVING commands

LINES	COMMANDS	EXPLANATION
Line 1	TO MARIO	Name of the programme
Line 2	FORWARD 40	Robot (R) goes forward for 4 seconds (sec.)
Line 3	RIGHT 10	R turns right for 1 sec.
Line 4	FORWARD 20	R goes forward for 2 sec.
Line 5	LEFT 7	R turns left for 0,7 sec.
Line 6	FORWARD 25	R goes forward for 2,5 sec.
Line 7	LEFT 6	R turns left for 0,6 sec.
Line 8	FORWARD 30	R goes forward for 3 sec.
Line 9	END	End of the programme

EXAMPLE 2 Logo program which includes two components (MOVING and LIGHT commands)

LINES	COMMANDS	EXPLANATION
Line 1	TO BRICK	Name of the programme
Line 2	TALKTO [4 5]	The lines are opened to both lights
Line 3	FLASH 90 70	The lights begin to flash (9 sec. on and 7 sec. off; 9 sec. on and ...)
Line 4	TALKTO [A B]	The lines are opened to both motors
Line 5	LEFT 5	R turns left for 0,5 sec.
Line 6	FORWARD 75	R goes forward for 7,5 sec.
Line 7	RIGHT 10	R turns right for 1 sec.
Line 8	FORWARD 20	R goes forward for 2 sec.
Line 9	LEFT 4	R turns left for 0,4 sec.
Line 10	FORWARD 30	R goes forward for 3 sec.
Line 11	END	End of the programme

EXAMPLE 3 Logo program which includes three components (MOVING, LIGHT and MUSIC commands)

LINES	COMMANDS	EXPLANATION
Line 1	TO T2	Name of the programme
Line 2	TALKTO [4 5]	The lines are opened to both lights
Line 3	FLASH 15 41	The lights begin to flash (1,5 sec. on and 4,1 sec. off; 1,5 sec. on and ...)
Line 4	FORWARD 38	R goes forward for 3,8 sec.
Line 5	LEFT 14	R turns left for 1,4 sec.
Line 6	FORWARD 15	R goes forward for 1,5 sec.
Line 7	RIGHT 11	R turns right for 1,1 sec.
Line 8	FORWARD 40	R goes forward for 4 sec.
Line 9	LEFT 10	R turns left for 1 sec.
Line 10	FORWARD 10	R goes forward for 1 sec.
Line 11	RIGHT 8	R turns right for 0,8 sec.
Line 12	FORWARD 30	R goes forward for 3 sec.

(continues)

## APPENDIX 5 (continues)

Line 13	TONE 440 30	Note is played for 3 sec.
Line 14	TONE 5222 30	Note is played for 3 sec.
Line 15	TONE 440 120	Note is played for 12 sec.
Line 16	TALKTO [4 5]	The lines are opened to both lights
Line 17	OFF	Both lights are turned off
Line 18	END	End of the programme

EXAMPLE 4 Logo program which includes four components (MOVING, LIGHT, MUSIC and WAITUNTIL commands)

LINES	COMMANDS	EXPLANATION
Line 1	TO QWERE	Name of the programme
Line 2	TALKTO [A B]	The lines are opened to both motors
Line 3	FORWARD 40	R goes forward for 4 sec.
Line 4	RIGHT 13	R turns right for 1,3 sec.
Line 5	FORWARD 15	R goes forward for 1,5 sec.
Line 6	LEFT 13	R turns left for 1,3 sec.
Line 7	FORWARD 3	R goes forward for 0,3 sec.
Line 8	ON	R begins to go forward
Line 9	LISTENTO 6	The line is opened to the touch sensor
Line 10	WAITUNTIL [sensor?]	Wait until touch sensor is pressed
Line 11	TALKTO 4	The line is opened to first light
Line 12	FLASH 1 2	First light begin to flash (0,1 sec. on, 0,2 sec. off; 0,1 sec. on ...)
Line 13	TALKTO 5	The line is opened to second light
Line 14	FLASH 2 3	Second light begin to flash (0,2 sec. on; 0,3 sec. off ...)
Line 15	BACK 10	R goes back for 1 sec.
Line 16	TONE 262 4	Note is played for 0,4 sec.
Line 17	TONE 277 4	Note is played for 0,4 sec.
Line 18	TONE 294 6	Note is played for 0,6 sec.
Line 19	TONE 311 8	Note is played for 0,6 sec.
Line 20	LEFT 15	R turns left for 1,5 sec.
Line 21	FORWARD 6	R goes forward for 0,6 sec.
Line 22	RIGHT 10	R turns right for 1 sec.
Line 23	FORWARD 40	R goes forward for 4 sec.
Line 24	TALKTO [4 5]	The lines are opened to both lights
Line 25	OFF	Both lights are turned off (Flashing finish)
Line 26	END	End of the programme

(continues)

## APPENDIX 5 (continues)

EXAMPLE 5 Logo program which includes five components (MOVING, LIGHT, MUSIC, WAITUNTIL and REPEAT commands)

LINES	COMMANDS	EXPLANATION
Line 1	TO DOUBLE	Name of the programme
Line 2	TALKTO [4 5]	The lines are opened to both lights
Line 3	REPEAT 50[FLASH 9 9]	The lights flash 50 times (0,9 sec. on; 0,9 sec. off...)
Line 4	OFF	Both lights are turned off
Line 5	TALKTO [A B]	The lines are opened to both motors
Line 6	FORWARD 42	R goes forward for 4,2 sec.
Line 7	RIGHT 13	R turns right for 1,3 sec.
Line 8	FORWARD 41	R goes forward for 4,1 sec.
Line 9	LEFT 13	R turns left for 1,3 sec.
Line 10	FORWARD 40	R goes forward for 4 sec.
Line 11	LEFT 14	R turns left for 1,4 sec.
Line 12	FORWARD 20	R goes forward for 2 sec.
Line 13	BACK 6	R goes back for 0,6 sec.
Line 14	RIGHT 12	R turns right for 1,2 sec.
Line 15	TALKTO [A B]	The lines are opened to both motors
Line 16	SETEVEN	Both motors goes in same direction
Line 17	LISTENTO 6	The line is opened to the touch sensor
Line 18	ON	Robot begins to go forward
Line 19	WAITUNTIL [SENSOR?]	Wait until touch sensor is pressed
Line 20	BACK 5	Robot goes back for 0,5 sec. (After touch sensor was pressed)
Line 21	RIGHT 12	R turns right for 1,2 sec.
Line 22	FORWARD 8	R goes forward for 0,8 sec.
Line 23	LEFT 12	R turns left for 1,2 sec.
Line 24	FORWARD 40	R goes forward 4 sec.
Line 25	TONE 523 8	Note is played for 0,8 sec.
Line 26	TONE 554 120	Note is played for 12 sec.
Line 27	TALKTO [4 5]	The lines are opened to both lights
Line 28	REPEAT 100[FLASH 3 3]	The lights flash 100 times (0,3 sec. on; 0,3 sec. off...)
Line 29	END	End of the programme



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