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Problem-Solving in Teaching/Learning Packages for Technology

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ABSTRACT: In the project "Technology in Secondary Education: Problem-solving in Teaching/learning Packages", two experiments regarding a construction problem and an explanation problem were conducted, in which two variants of a teaching/learning package (strongly structured *vs.* weakly structured) were compared. Only with the strongly structured instructional variant of the package for the explanation problem did the pupils come to a quick solution of the problem. In both experiments, the factors that influenced the problem-solving processes of the pupils were investigated. The results are of importance for curriculum developers and the authors of teaching/learning packages for Technology but further research into the factors influencing the problem solving process of pupils is necessary.

Keywords: problem-solving, technology, secondary education, teaching/learning package, curriculum, evaluation

1. INTRODUCTION

In the Netherlands, the subject Technology was introduced into schools in 1985 as the successor of the subject General Techniques and it is now a component of basic education. During the period from 1985 up to the introduction of basic education in August 1993, the subject was elaborated further.

The attainment targets for the subject Technology were used by the National Institute for Curriculum Development (abbreviated in Dutch to SLO) to develop a curriculum which was published in 1993 (Huijs & Hermans, 1993). The SLO developed exemplary teaching/learning packages in which technological problem-solving activities were a prominent feature.

With the introduction of basic education in the first stage of secondary education, pupils from 12 to 14 years of age, following junior vocational, secondary general or pre-university education will be taught Technology as a subject. In the development of the teaching/learning packages too little attention has as yet been paid to attuning the instruction to the various achievement levels. This caused the SLO to identify the need to evaluate the teaching/learning packages, with a particular interest in the question of what the design of the packages should be for the various achievement levels.

It was this action of the SLO which gave rise to the project *Technology in Secondary Education: Problem-solving in Teaching/learning Packages* (abbreviated as the PSIT-project). The project, undertaken by the Centre for Applied Research in Education (abbreviated in Dutch to OCTO) of the University of Twente, started on December 1, 1992 and ended on December 31, 1993. The research focused on a construction problem in the teaching/learning package *Technology in Water Purification* and an explanation problem in the teaching/learning package *Process Technology* (Doornekamp & Streumer, 1992). The final report was published in 1994 (Doornekamp & Streumer, 1994a).

2. PROBLEM STATEMENT

From the start of the development of the subject known as General Techniques, problem-solving activities have played an important role in the publications of the SLO. In the further development of the subject Technology, this role was continued. Problem-solving activities are discussed in the curriculum for Technology with the attainment targets related to the domains 'Using products of technology' and 'Producing functional pieces of work'. Problem-solving activities are regarded as a technical skill (De Jong, 1989) and they offer a structured method of solving technical problems, with a step-wise approach by means of questions, followed by a practical execution of the solution of the problem (Huijs & Hermans, 1993). In this definition, the pupils' procedural knowledge is stressed. To solve a technical problem the procedural knowledge of the pupils presupposes the presence of conceptual knowledge (McCormick *et al.*, 1994).

There are various typologies with which to classify problems. For this research, the distinction between open and closed problems is the most important. In a closed problem, the problem features (initial situation, objective situation and operations) are clearly specified. There is only one possible solution. In an open problem, the problem features are not well-defined. This makes various solutions to the problem possible (Mettes & Pilot, 1980).

Another classification, one that is mentioned in the curriculum for Technology, distinguishes design, construction, malfunctioning and maintenance, service and explanation problems. In this classification, the structure of the subject is an important criterion (Huijs & Hermans, 1993). In the problem-solving process, a number of stages can be distinguished. The various models show a great deal of similarity. The differences are mainly related to the concepts used and to the number of stages that are distinguished. The description of identical concepts is also different, with regard to both content and extent.

The model developed by De Jong (1989) consists of five stages: (1) orientation (2) planning and transformation (3) checking (4) deciding on a solution: routine actions and evaluation, and (5) reflection. The model drawn up by van der Sanden (1986) to carry out practical assignments shows many similarities. He distinguishes: (1) conceptualization (2) analysis (3) planning (4) execution and (5) evaluation. Both models point at procedural knowledge.

In general, three methods for solving problems can be identified: the *algorithmic method*, the *heuristic method* and the *blind search method* (De Jong, 1989).

Pupils tackle a problem in various ways. Chi *et al.* (1982) distinguish the experienced problem-solver who uses problem-solving schemes he has developed while solving various problems, as a result of which he has procedural knowledge, from the novice problem-solver who pays more attention to superficial characteristics of the problem, in which factual and declarative knowledge are used.

Van Eck-Schouten (1983) distinguishes pupils who achieve well from those who achieve poorly. The first group of pupils is marked by a purposeful approach, whereas the other group spends much of the time on orientating activities.

In order to be able to execute independently practical assignments in which problem-solving plays a major part, the role of the teacher or his/her substitute, for example self-instructing material, is initially important. Later, the influence of the teacher will diminish. The pupils then have to possess metacognitive skills in order to be able to work independently on their own. (De Klerk *et al.*, 1989).

The concept of 'metacognition' is defined as the knowledge someone has of, and the control he/she has over, his/her own cognitive processes (Flavell, 1976). This means among other things that one checks one's results and wonders whether one has sufficient knowledge. A beginner has little or no metacognitive skills; as pupils become more experienced, they display active and conscious self-regulation.

General metacognitive skills are: (a) predicting, planning (b) checking (c) monitoring (d) reality testing and (e) coordinating, controlling (Schepens *et al.*, 1981). The concept of 'self-regulation' is closely related to that of 'metacognition'. In self-regulation, the pupil thinks of a suitable sequence, asks himself questions and runs his own internal checks on the course of the learning process.

Education can influence this self-regulation by taking over the pupils' processing and controlling activities, by encouraging these activities, by helping the pupils to develop skills in self-guided learning and by influencing pupils' conceptions and orientation (Vermunt, 1989).

Various studies have been executed in which measures were taken to facilitate the development of metacognitive skills. These studies do not concern Technology in particular, but relate mainly to language teaching (the studying of texts), arithmetic and science education (Van Daalen-Kapteijns & Elshout-Mohr, 1989; Van Hout-Wolters, 1986; Veenman & Elshout, 1992).

The measures taken are: the addition, or not, of metaphors to study-texts, the use of advanced organizers, the making of a set of notes or study questions, the addition of study tasks, intermediate test questions, the marking of parts of the text by teachers and pupils, the indicating of steps to be taken on a planning list, and the giving of supplementary instructions before, during and after the learning of concepts.

The additional measures in this PSIT-project relate to the task structure of the practical assignments in the teaching/learning packages of the SLO. A strongly structured task has many externally imposed strategies, whereas a weakly structured task needs many self-initiated strategies (van der Sanden, 1986). It is expected that low-ability pupils will have the best results with strongly structured assignments, but that high-ability pupils will benefit more from weakly structured assignments (see also section 4).

3. RESEARCH QUESTIONS

The PSIT-project concentrates on the formative evaluation of variants of a teaching/learning package concerning a construction problem (construction of a rotating filter) and an explanation problem (assembling a model of a time-switch). For each of these two types of problems, two instructional variants, varying in the structure of the instruction (i.e. strongly structured and weakly structured) were developed. With these instructional variants, the following two research questions are addressed.

1. In what respect does variation of instructional procedures (strongly structured *vs.* weakly structured) influence the pupils' technical problem-solving processes?
2. In what respect do pupil characteristics (e.g. gender, spatial and technical orientation, field (in)dependence, type of secondary education (i.e. low- and high-ability)) influence their technical problem-solving processes when a particular instructional variant is applied?

It is hypothesised that the pupils who use the strongly structured variant will achieve better, i.e. they will need less time and their final product will be valued more highly. Additionally, it is expected that some pupil characteristics will affect achievement in positive ways.

4. DESIGN OF THE RESEARCH

The research was preceded by a feasibility study (Doornekamp & Streumer, 1993) to establish whether sufficient schools for junior vocational education, and schools for secondary general and pre-university education in particular, were willing to take part in the research and whether these schools had the necessary facilities for carrying out practical assignments. Because of a change in the conduct of the research, this last question is no longer relevant (the required material is supplied by the PSIT-project).

Members of the Association for Technology Teachers (abbreviated in

Dutch to VeDoTech) were approached by means of a questionnaire to ascertain their willingness to participate in the research. The result of this feasibility study was that 21 schools with sufficient pupils were willing to take part in the study.

The research started with a preliminary investigation in which the two instructional variants for each of the chosen problems had to be developed. From the teaching/learning package, *Technology in Water Purification*, the lesson chosen concerned the construction of a rotating filter. From the teaching/learning package *Process Technology*, the lesson selected was about a mechanical device used in a time-switch. To solve the problems the pupils used FischerTechnik construction material.

A prototype of an instructional variant was presented to a number of pupils from junior vocational education in order to find out how they solved the problem and how they used the developed instructional variant and the construction material while doing so. By asking the pupil questions, while she/he was solving the problem, information was gathered about the problem-solving processes used and the part that the developed instructional variant played in these processes.

On the basis of the literature on metacognition, and particularly that relating to the measures that can be taken in written material to stimulate metacognitive skills with pupils, it was decided that the strongly structured variant (instructional variant A) would be supplied with additional information and instructions which the pupils could use to solve the problem concerned. In the construction problem, these instructions consist of photographs and accompanying information about the use of the parts of FischerTechnik in order to be able to build the drive and the transmission of a rotating filter. This information was not included in the instructional variant B of the construction problem. The following four practical assignments have to be carried out in the construction problem (in both variants): (1) mounting a rotating filter (2) designing the drive and the transmission (3) mounting the drive and the transmission, and (4) testing the solution. In the explanation of the problem, a series of step-by-step drawings was included in the strongly structured variant (instructional variant A) on the basis of which the pupil can build the model of a time switch. In the weakly structured variant (instructional variant B), only a photograph (black and white) of the final result was shown. Four practical assignments have to be carried out in this problem in both variants: (1) assembling a model of a time switch (2) connecting the electric motor to the transformer (3) testing the solution, and (4) improving the model by adding parts to the wheel and testing. For both problems, each of the instructional variants contained a parts list (black and white photograph and text per part) of the contents of the box of FischerTechnik.

After the preliminary investigation, two studies (one per problem) were conducted in parallel. In design and execution, these two studies were identical.

In research into the use of metacognitive skills, as in this study, interviews and thinking aloud procedures are common research methods (Garner, 1988). In spite of the fact that these methods are often used, there are some objections to their use. Thus it is often the case that it is extremely difficult to understand fully what has actually been done. This requires a reasonable language skill on the part of the pupils. In addition, pupils are often inclined to tell what they should have done, and asking them questions may lead to socially desirable rather than accurate answers. Also, a check of the reports after a given period of time is often lacking and it is possible that thinking aloud might affect the execution of the assignments (Veenman *et al.*, 1993).

Garner (1988) has offered some suggestions to overcome these objections. These are: (1) gather the information as quickly as possible (2) ask what pupils are doing, not what they are thinking (3) disturb the (problem-solving) process as little as possible (4) take into consideration those pupils who have language difficulties (5) verify the reliability, and (6) combine a variety of research instruments. Alternative research methods are: stimulated recall on the basis of video recordings, peer tutoring and the making of optimal and non-optimal products.

With these labour-intensive research methods, it is only possible to study a limited number of pupils. This often results in laboratory-like situations in which pupils take part in the research under controlled conditions.

The PSIT-project opted for a more large-scale research programme in which the research context is as similar as possible to the situation in which Technology is taught. Research methods such as interviews and thinking aloud procedures can then no longer be used. It becomes necessary to check by observation how pupils solve problems and in what way the instructions that appeal to metacognitive skills are used in this process.

The 'construction problem' study and the 'explanation problem' study were designed as an experiment according to the 'independent group design' (Willems, 1989). In each school the participating cohort of pupils is divided into two groups. One group is given instructional variant 'A' and the other, instructional variant 'B'. There is no control group in this design.

On the basis of an evaluative research by the SLO (Huijs, 1991) the research distinguishes pupils in junior vocational and junior secondary general education on the one hand from pupils in senior secondary general and pre-university education on the other. This distinction is related to the approach to Technology education at these schools. At schools for junior vocational and junior secondary general education, the approach is more practical, whereas at schools for senior secondary general and pre-university education a more theoretical approach is the norm.

It was the aim to have 80 pupils in the first form of secondary education per study per category taking part in the research (i.e. a total of 320 pupils). This applied to both the construction and the explanation problem.

In the research, a variety of instruments was used. A brief explanation of the instruments is given below. The pupils fill out a *Pupils' Questionnaire* (gender, age, ethnic background, experience with FischerTechnik etc.), and complete the *Subtest Mechanical Reasoning* and the *Subtest Space Relations* (subtests of the Differential Aptitude Testseries, the DAT '83 (Evers & Lucassen, 1983), the *Group Embedded Figures Test* (Witkin *et al.*, 1971) and an *Evaluation Form* (seeking opinion about the teaching/learning package).

While the practical assignments are being carried out, an *Observation Outline* is used. The activities executed by the pupils recorded on this form are recorded at one-minute intervals. For each practical assignment, a separate outline was developed.

After the last practical assignment of the construction problem had been completed, a *colour photograph was taken of the final result.* Afterwards, the end result is judged for its degree of complexity based on the number of transmissions and the use of full speed or reduced speed. Prior to the execution of the practical assignments, the Technology teacher also gave an estimation for each group of pupils of the extent to which problems could be expected. He used the *Teachers' Questionnaire* for this purpose. The questionnaire includes two questions on problem-solving activities in Technology.

Each teaching/learning package consists of two volumes. The practical assignments are put together in volume 2. The written assignments in the package for the construction problem are all in volume 1. The package for the explanation problem has written assignments in both volumes (Doornekamp & Streumer, 1994b).

The research at school level is led by an experimenter. He takes care of the presentation of the problem, the introduction to the various instruments, including the psychological tests, and the execution of the practical assignments. For the execution of the practical assignments, each pupil has a box with FischerTechnik parts at his/her disposal. For the construction problem, there is also a synthetic aquarium with tubes and a filter. During the execution of the problem, pupils are observed by trained observers using the observation outline. The observers were instructed beforehand on the use of this outline by means of video-recordings of pupils engaged in problem solving. The research starts in the first lesson and ends after the sixth lesson.

5. RESULTS OF THE CONSTRUCTION PROBLEM STUDY

The study was carried out at 15 schools for secondary education with a total number of 305 pupils. Slightly less than half of the pupils were girls. Half of the pupils were categorised as 'junior vocational/junior secondary general education', while the other half were involved with 'senior secondary general/pre-university education'. About half of the pupils used the strongly structured variant of the instructional material.

Over 60% of the pupils were 13 years old. On average, pupils of the category 'junior vocational/junior secondary general education' were a little older (mean = 13.1) than pupils of the category 'senior secondary general/pre-university education' (mean = 12.7). This is due to the fact that more pupils of the category 'junior vocational/junior secondary general education' have repeated a year more often. The difference is significant ($t = 5.03$, $\alpha \leq 0.05$).

Few pupils have direct prior experience with FischerTechnik (boys 29%, girls 8%). More pupils have experience with Lego (Technic) and/or Meccano (almost 90%). On the whole, three quarters of the pupils had been taught Technology at school. In the category 'senior secondary general/pre-university education,' this percentage was smaller (68%).

Three psychological tests were administered. 95% of the pupils completed all of these tests. The reliability coefficients varied between 0.86 and 0.93. The mean scores were 34.05 (sub-test Mechanical Reasoning), 28.59 (subtest Space Relations) and 10.02 (Group Embedded figures Test).

In general, girls scored lower than boys on these three tests. The differences were statistically significant. The pupils from 'senior secondary general/pre-university schools' have higher mean scores on these texts than the pupils from 'junior vocational/junior secondary general education'. Here too, the differences were significant (see Table I).

There was no (significant) difference between the pupils who used the strongly structured and those who used the weakly structured instructional variant (see Table I).

The teaching/learning package contains seven written assignments. The pupils' mean total score was 6.2 (the maximum score is 7). The girls had a higher mean score than the boys. In addition, the pupils from 'senior secondary general/pre-university education' had a higher score than pupils from 'junior vocational/junior secondary general education'. The differences are statistically significant (see Table II).

The construction problem consists of five practical assignments (e.g. the application of FischerTechnik).

Over 62% of the pupils, 191 pupils in total, completed all the practical assignments. The following results relate to these pupils only. They produced effective, working solutions. More boys, more pupils who used the weakly structured variant and more pupils from 'senior secondary general/pre-university education' completed all the practical assignments.

The time needed to complete all practical assignments indicates the degree of efficiency. For each practical assignment, there were major differences in the amount of time spent on it. The mean time spent on all practical assignments was 58.2 minutes. This mean was calculated for the 191 pupils who completed all the practical assignments. The girls, the pupils who used the strongly structured variant and the pupils from 'senior secondary general/pre-university education' spent more than the mean time on these assignments. The differences were statistically significant (see Table II).

There was no relation between one or more pupil's characteristics (technical orientation, spatial orientation and field(in)dependence) and the

TABLE I.
Results of psychological tests: mean scores on mechanical reasoning, space relations and embedded figures and t-values per gender, instructional variant and category of secondary education.

	Gender			Instructional variant			Category of sec. education		
	Girl	Boy	t-value	Strongly structured	Weakly structured	t-value	j. voc./ j. sec. general	s. sec. gen./ pre-univ	t-value
Mechan. Reas.	29.5	38.2	7.94*	34.3	33.8	0.41	29.7	38.4	7.97*
Space Relat.	26.5	30.4	2.80*	29.2	28.2	0.87	22.5	34.7	9.95*
Embedded Fig.	9.3	10.6	1.36*	10.2	9.9	0.60	7.9	12.1	8.61*

* $\alpha \leq 0.05$.

TABLE II.
Results construction problem: mean total score written assignments, practical assignments (total time in minutes) and score on appreciation of the final product and t-values per gender, instructional variant and category of secondary education.

	Gender			Instructional variant			Category of sec. education		
	Girl	Boy	t-value	Strongly structured	Weakly structured	t-value	j. voc./ j. sec. general	s. sec. gen./ pre-univ.	t-value
Written ass. 1	6.3	6.0	2.77*	6.3	6.1	1.78	5.9	6.4	5.09*
Practical ass.	62.3	55.2	3.10*	60.8	56.0	2.11*	55.4	60.5	2.24*
Final product	11.9	13.3	3.73*	12.9	12.5	0.95	12.9	12.6	0.79

* $\alpha \leq 0.05$.

amount of time spent on the practical assignments of the construction problem.

In one of the practical assignments, the pupils were required to make a drawing. It appeared that almost half of the pupils made this drawing afterwards rather than beforehand. About 60% of the pupils drew both views (front view and side view). Almost all pupils drew both the drive and the transmission. Almost 60% did give no explanation of the drawing.

On the basis of the photograph of the final working product, it was determined that over 40% of the pupils had made a very simple solution (one transmission and full speed). Only 7% had built a more complex solution. This 7% mainly consisted of boys.

Pupils who used the strongly structured variant, spent more time on the construction problem (see Table III).

TABLE III.

Mean time (in minutes) spent on the construction problem, split up according to instructional variant and category of secondary education and according to instructional variant and gender.

Construction problem n = 191 58.22			
Strongly structured n = 88 60.81		Weakly structured n = 103 56.01	
Junior vocational/ junior secondary general n = 39 59.51	Senior secondary general/ pre-university n = 49 61.84	Junior vocational/ junior secondary general n = 46 51.89	Senior secondary general/ pre-university n = 57 59.33
Girl n = 36 66.50	Boy n = 52 56.87	Girl n = 45 58.89	Boy n = 58 53.78

For the weakly structured variant the difference between 'junior vocational/junior secondary general education' and 'senior secondary general/ per-university education' regarding the total amount of time spent was larger than for the strongly structured variant. In both cases, pupils from 'senior secondary general/pre-university education' needed more time than pupils from 'junior vocational/junior secondary general education' (see Table III).

The difference between girls and boys in the mean time spent was larger for the strongly structured variant than for the weakly structured variant. For both variants, girls needed more time than boys (see Table III).

For the strongly structured variant, pupils with a high technical orientation, a high spatial orientation or high field (in)dependence generally needed less time than other pupils. In an analysis of variance there is a significant interaction-effect for the pupil's characteristic 'field(in)depen-

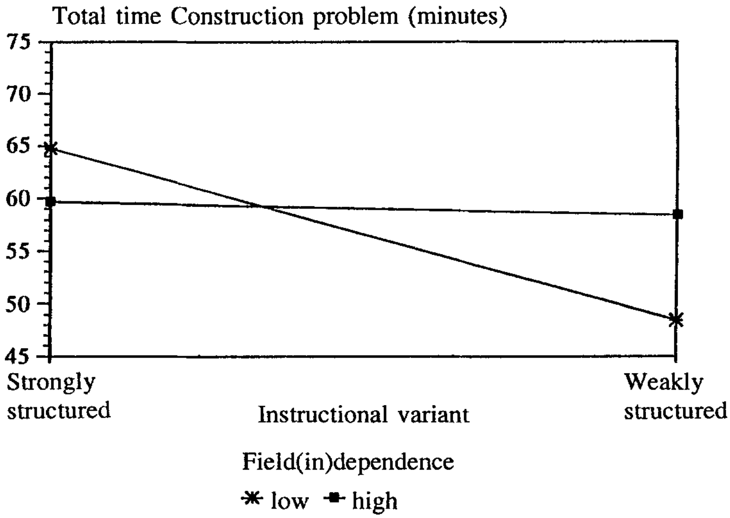

Fig. 1. Mean time spent on construction problem of pupils with low and high field(in)dependence per instructional variant.

dence' (F(1.135) = 6.88). Figure 1 is a graphic representation of this interaction.

Pupils who did have prior experience of FischerTechnik generally needed less time than pupils who did not have this experience. For the strongly structured variant pupils with experience needed on the whole less time than with the weakly structured variant. Here, too, the interaction-effect was significant F = (1.178) = 4.41.

On the basis of a combination of various results (among others, scores based on the process e.g. the execution of the third and fourth practical assignment and the drawing of the design, and scores based on the product like the complexity) a score measuring appreciation of the final product was calculated. The mean score of the 191 pupils was 12.7.

The mean score on appreciation of the boys' final product was significantly higher than that of the girls' score. The difference between the pupils from 'junior vocational/junior secondary general education' and the pupils from 'senior secondary general/pre-university education' was small as far as the score an appreciation of the final product is concerned (see Table II).

For pupils who used the strongly structured variant, the mean score on appreciation of the final product was somewhat higher than for pupils who used the weakly structured variant. The difference however, is not significant.

The teachers expected girls to have more difficulties than boys. They did not expect large differences between the two variants. Teachers of schools in the category 'senior secondary general/pre-university education' anticipated that their pupils would encounter few difficulties. They were more positive about their pupils than their colleagues from the category 'junior vocational/junior secondary general education'.

The teachers pointed out several problems related to problem-solving activities, in particular, the analysis and solution of problems by pupils themselves. In addition, teachers of schools in the category 'junior vocational/junior secondary general education' mentioned reading problems, fear of failure and concentration difficulties.

By means of multiple regression analysis, it was possible to examine how pupil characteristics affected both the total time spent on the construction problem and the score on appreciation of the final product. The multiple regression analysis was based on the following independent variables: the pupil's gender, type of secondary school attended, technical and spatial orientation, the field (in)dependence, and the experience with FischerTechnik and with other construction toys. The instructional variant was also included in the analysis.

For both the total amount of time spent and the score on appreciation of the final product the (pupil's) characteristics accounted for only a small part of the variance. Tables IVa and IVb present the results of the two multiple regression analyses.

With the total amount of time spent as the dependent variable, the (pupils) 'experience with FischerTechnik', 'the used instructional variant', 'the pupil's gender', 'experience with construction toys' and 'the category of secondary education' accounted for 16% of the variance.

The score on appreciation of the final product of the construction problem

TABLE IVa.
Results of the stepwise multiple regression analysis with the total time spent on the construction problem as the dependent variable (n = 179)

Step	Variable	R	R^2	R^2 change	F change	Sign.
1	FischerTechnik	0.25	0.06	0.06	12.16	0.00
2	Instructional variant	0.30	0.09	0.03	5.58	0.02
3	Pupil's gender	0.35	0.12	0.03	5.20	0.02
4	Construction toys	0.37	0.14	0.02	3.29	0.07
5	Categ. of second. educ.	0.40	0.16	0.02	4.54	0.03

TABLE IVb.
Results of the stepwise multiple regression analysis with the score on appreciation as the dependent variable (n = 179)

Step	Variable	R	R^2	R^2 change	F change	Sign.
1	Space Relations	0.31	0.09	0.09	18.45	0.00
2	Categ. of second. educ.	0.38	0.15	0.06	10.57	0.00
3	Pupil's gender	0.42	0.18	0.03	6.57	0.01

was affected by the (pupils') characteristics 'spatial orientation', 'category of secondary education' and gender. These (pupil's) characteristics account for 18% of the variance.

6. RESULTS OF THE EXPLANATION PROBLEM STUDY

The study was carried out at 14 secondary schools with a total number of 295 pupils. Half of the pupils were girls. Over 55% of the pupils were receiving a 'junior vocational/junior secondary general education', the other pupils belong to the category 'senior secondary general/pre-university education'. About half of the pupils used the strongly structured instructional variant.

Almost 60% of the pupils were 13 years old. In general, pupils from the category 'junior vocation/junior secondary general education' were a little older (mean = 13.3) than pupils from the category 'senior secondary general/pre-university education' (mean = 12.7). This is because more pupils receiving a 'junior vocational/junior secondary general education' have repeated a year. The difference is significant ($t = 8.15$, $\alpha \leq 0.05$).

Few pupils have any experience with FischerTechnik (boys 28%, girls 18%). More pupils have experience with Lego(Technic) or Meccano (over 85%). In general, three quarters of the pupils were taught Technology at school. In the category 'junior vocational/junior secondary general education' this figure was slightly higher (80%).

The three psychological tests were administered to 95% of the pupils. The reliability coefficients varied from 0.85 and 0.92. The mean scores were 34.70 (subtest Mechanical Reasoning), 28.42 (subtest Space Relations) and 10.43 (Group Embedded Figures Test).

On these three tests, girls had a lower mean score than boys. The differences were significant, with the exception of the Group Embedded Figures Test. The pupils receiving a 'senior secondary general/pre-university education' had higher mean scores on these tests than those pupils from 'junior vocational/junior secondary general education'. Here too the differences were significant (see Table V).

Once again, there was no (significant) difference between the pupils who used the strongly structured instructional variant and those who used the weakly structured variant.

The teaching/learning package includes ten written assignments in volume 1 and eight written assignments in volume 2. The mean total score of the pupils for volume 1 was 8.5 (maximum score is 10) and for volume 2, 5.5 (maximum score is 13). Although the eighth written assignment of volume 2 consists of several parts, not all pupils answered these written assignments.

For volume 1, the pupils from 'senior secondary general/pre-university education' had a higher mean score than pupils from 'junior vocational/

TABLE V.
Results of psychological tests: mean scores mechanical reasoning, space relations and embedded figures and t-values per gender, instructional variant and category of secondary education.

	Gender			Instructional variant			Category of sec. education		
	Girl	Boy	t-value	Strongly structured	Weakly structured	t-value	j. voc./ j. sec. general	s. sec. gen./ pre-univ.	t-value
Mechan. Reas.	30.3	39.2	9.01*	34.6	34.8	0.14	32.1	37.9	5.44*
Space Relat.	26.4	30.5	3.12*	27.9	28.9	0.78	23.9	34.0	8.48*
Embedded Fig.	10.4	10.5	0.26	10.5	10.4	0.16	9.2	12.0	5.34*

* $\alpha \leq 0.05$.

TABLE VI.
Results explanation problem: mean total score written assignments, practical assignments (total time in minutes) and score on appreciation of the final product and t-values per gender, instructional variant and category of secondary education.

	Gender			Instructional variant			Category of sec. education		
	Girl	Boy	t-value	Strongly structured	Weakly structured	t-value	j. voc./ j. sec. general	s. sec. gen./ pre-univ.	t-value
Written ass. 1	8.5	8.6	0.63	8.4	8.6	1.09	7.9	9.5	8.72*
Written ass. 2	4.8	6.1	3.91*	5.8	5.1	2.01*	4.5	6.7	6.94*
Practical ass.	58.7	50.3	5.11*	53.2	54.5	0.79	53.3	54.4	0.67
Final product	7.3	8.3	2.71*	8.5	7.1	3.92*	7.8	8.0	0.53

* $\alpha \leq 0.05$.

junior secondary general education'. The difference was significant. For volume 2, the boys, the pupils who used the strongly structured variant and the pupils from 'senior secondary general/pre-university education' had a higher mean score. The differences are significant (see Table VI).

The explanation problem consists of four practical assignments. A total of 192 pupils (65% of all pupils) completed all of these assignments. The following results refer to these pupils only. They produced effective, working solutions. More boys, more pupils who used the strongly structured variant and more pupils from 'senior secondary general/pre-university education' completed all the practical assignments.

The time needed to complete all the practical assignments indicates the degree of efficiency. For each practical assignment there were major differences in the amount of time spent on it. The mean time spent on all practical assignments was 53.8 minutes. This mean was based on the 192 pupils who executed all practical assignments. The girls, the pupils who used the weakly structured variant and the pupils from 'senior secondary general/pre-university education' spent more time on these practical assignments. Only the difference between the girls' and the boys' means was significant (see Table VI).

There is a small negative relation between pupils' 'technical orientation' and the amount of time spent on the explanation problem. The relation between the other two pupils characteristics of 'spatial orientation' and field(in)dependence' and the amount of time spent on the practical assignments of the explanation problem is negligible.

During the observation of one of the practical assignments, the construction sequence of the major parts was recorded. For this purpose, the task was divided into six major parts. On the basis of the step-by-step drawings, there is an 'ideal' sequence.

It appears that pupils who used the strongly structured variant mostly stuck to this ideal sequence. For the weakly structured variant, this sequence was less in evidence. Girls and boys differed on one point in this construction sequence. The girls start with the switch, whereas the boys begin with the engine and the gearbox.

Pupils who used the strongly structured variant spent less time on the explanation problem (see Table VII).

For the weakly structured variant the difference between 'junior vocational/junior secondary general education' and 'senior secondary general/pre-university education' is larger than for the strongly structured variant. For both variants pupils from 'senior secondary general/pre-university education' needed more time than pupils in receipt of 'junior vocational/junior secondary general education' (see Table VII).

The differences between girls and boys in the average amount of time spent on the problem is larger for the weakly structured variant than for the strongly structured variant. For both variants, girls generally needed more time than boys.

TABLE VII.
Mean time (in minutes) spent on the explanation problem, split up according to instructional variant and category of secondary education and according to instructional variant and gender.

Explanation problem n = 192 53.81			
Strongly structured n = 102 53.17		Weakly structured n = 90 54.54	
Junior vocational/ junior secondary general n = 50 53.12	Senior secondary general/ pre-university n = 52 53.21	Junior vocational/ junior secondary general n = 53 53.42	Senior secondary general/ pre-university n = 37 56.16
Girl n = 48 56.63	Boy n = 54 50.09	Girl n = 32 61.91	Boy n = 58 50.48

Pupils who used the strongly structured variant but who did not have any prior experience with FischerTechnik generally needed less time than pupils with such experience. However, for the weakly structured variant, pupils who had the relevant experience generally needed less time than pupils without it. From an analysis of variance it becomes evident that the interaction effect is significant (F (1.184) = 12.86). Figure 2 is a graphic representation of the interaction.

On the basis of a combination of various results (e.g. scores based on the construction sequence and the completion of the second, third and fourth practical assignments) a score on appreciation of the final product was calculated. The mean score of the 192 pupils was 7.9.

The mean score on appreciation of the final product of the boys was significantly higher than the score of girls (see Table VI). The difference in score between the pupils from 'junior vocational/junior secondary general education' and those from 'senior secondary general/pre-university education' on the score on appreciation of the final product is small.

Pupils who used the strongly structured variant had a significantly higher mean score on appreciation of their final product than pupils who used the weakly structured variant.

The teachers expected the girls to experience more difficulties than the boys with respect to both variants. Teachers in senior secondary general/ pre-university schools expected their pupils to experience few difficulties. They were more positive about their pupils than their colleagues working in 'junior vocational/junior secondary general schools.'

The teachers pointed out various problems related to problem-solving activities. Pupils have had difficulties in reading the assignments and in

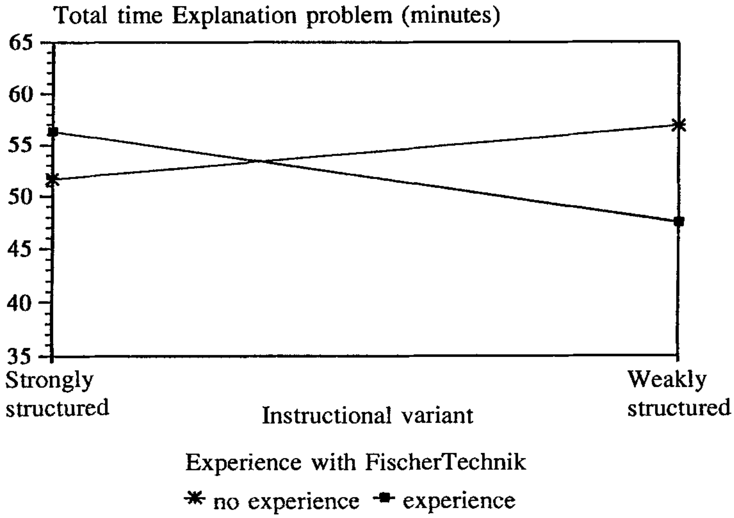

Fig. 2. Mean time spent on explanation problem of pupils who do and do not have experience with FischerTechnik per instructional variant.

turning from the assignment to the task. Also, a fear of failure and concentration problems were identified, particularly by teachers in 'junior vocational/junior secondary general schools.

By means of multiple regression analysis, it was determined which characteristics affected the total amount of time spent on the explanation problem and the score on appreciation of the final product. The multiple regression analysis was based on eight independent variables (see section 5).

For both the total amount of time spent on the problem and for the score on appreciation of the final product the (pupils') characteristics account for only a small part of the variance (see Table VIIIa and Table VIIIb).

With the total amount of time spent as dependent variable the (pupil's) characteristics 'pupil's gender', 'technical orientation' and 'category of secondary education' account for 17% of the variance.

The score on appreciation of the final product of the explanation problem is affected by 'the used instructional variant', 'pupil's gender', 'spatial orientation' and 'field(in)dependence'. These pupil characteristics account for 19% of the overall variance.

7. CONCLUSIONS

On the basis of the two studies, several answers can be offered to the research questions.

As regards the *construction problem* it can be concluded that:

TABLE VIIIa.
Results of the stepwise multiple regression analysis with the total time spent on the explanation problem as the dependent variable (n = 172)

Step	Variable	R	R^2	R^2 change	F change	Sign.
1	Pupil's gender	0.35	0.12	0.12	23.37	0.00
2	Mechan. Reasoning	0.40	0.16	0.04	7.17	0.01
3	Categ. of second. educ.	0.42	0.17	0.01	3.23	0.07

TABLE VIIIb.
Results of the stepwise multiple regression analysis with the score on appreciation as the dependent variable (n = 172)

Step	Variable	R	R^2	R^2 change	F change	Sign.
1	Instructional variant	0.27	0.07	0.07	13.77	0.00
2	Pupil's gender	0.36	0.13	0.06	9.92	0.00
3	Space Relations	0.39	0.15	0.02	5.06	0.03
4	Field(in)dependence	0.44	0.19	0.04	7.78	0.01

1. The strongly structured variant did not lead on average, to a faster completion of the practical assignments. Reading the additional information takes time too. In both variants, low-ability pupils were faster.
2. In general, pupils from senior secondary general and pre-university education do not work faster than pupils from junior vocational and junior secondary general education. This is not affected by the instructional variant.
3. Pupils do not consider making a drawing to be an essential part of the problem-solving process.
4. The strongly structured variant with additional information did not lead to comparatively more complex solutions.
5. Pupils who used the strongly structured variant attained a higher mean score on appreciation of the final product. However, the difference is not significant.
6. Prior experience with FischerTechnik plays a major part in the solving of the problem presented.
7. Girls and boys completed the practical assignments in different ways. This resulted in differences in time, final result and score on appreciation of the final product in favour of the boys.
8. Technical and spatial orientation do not affect the problem-solving process. Field(in)dependence does appear to have an effect, if, for each variant, a distinction is made between pupils with high and pupils with low field(in)dependence.

As far as the *explanation problem* is concerned, the following conclusions can be drawn.

1. The strongly structured variant generally resulted in a quicker solution to the problem. However, the difference is small and not statistically significant. In the weakly structured variant, low-ability pupils were faster than high-ability pupils.
2. The strongly structured variant leads to comparatively more cognitive activities and to fewer motor activities.
3. For both variants, pupils from the category 'senior secondary general/pre-university education' generally needed more time than pupils from the category 'junior vocational/junior secondary general education'. However, the differences are small.
4. The 'ideal' construction sequence is followed more clearly of the strongly structured variant than for the weakly structured variant.
5. The use of the strongly structured variant resulted in a significantly higher score on appreciation of the final product.
6. Boys achieve better than girls on this problem as far as the amount of time needed and the score on appreciation of the final product are concerned. Girls spend less time than by on cognitive and motor activities.
7. As the pupils' technical orientation increases, the amount of time necessary to solve the problem decreases.
8. Pupils with a high field(in)dependence generally needed less time with the strongly structured variant than pupils with low field(in)dependence.
9. In the weakly structured variant, experience with FischerTechnik plays a bigger part than in the strongly structured variant.
10. Experience with construction toys in general is important for solving the problem presented.

8. DISCUSSION

The PSIT project concentrated on the formative evaluation of teaching/learning packages for problem solving in Technology, in terms of the achievement of pupils. It was expected that low-ability pupils, defined as pupils in junior vocational and junior secondary general education, will benefit more from strongly structured assignments in teaching/learning packages, while high-ability pupils, defined as pupils in senior secondary general and pre-university education, will attain the best results with weakly structured assignments in teaching/learning packages.

In addition, it was hypothesised that some pupil characteristics, like gender, would influence achievement.

If this expectation were confirmed, the curriculum developers of the SLO Technology project could take full account of the results of this study in their work and design differentiated teaching/learning packages aimed at the different target populations in secondary education.

However, the conclusions that were drawn in the PSIT-project with reference to the above expectations were ambiguous. As far as the strongly structured variant of the teaching/learning package on the construction problem is concerned, high-ability pupils spent more time on the assignments than low-ability pupils. As far as the weakly structured variant of the teaching/learning package on the construction problem is concerned, high-ability pupils also needed more time to finish their assignments. In both cases, the differences between the two categories of pupils were statistically significant.

The appreciation scores of the final product of the construction problem showed that high-ability students did better on the strongly structured teaching/learning package, while low-ability students obtained better results on the weakly structured teaching/learning package. In both of these cases, the differences were very small and statistically not significant.

The above results therefore do not support the above mentioned hypotheses. The results were contrary to expectations.

As far as the teaching/learning package on the explanation problem are concerned, it was observed that the hypotheses relating the structure of the teaching/learning packages and the ability of pupils were once again rejected, although the differences between the scores were less prominent and accordingly not significant. The appreciation scores of the final product of the explanation problem showed, in all conditions, only slight, non significant differences.

As far as the influence of gender on the achievements of boys and girls, it was concluded that in all circumstances, i.e. all four teaching learning packages, the scores of boys were higher. These results are in line with the expectations and other research findings in the field of Technology (Streumer, 1988).

From this study, it can be concluded that results found in some other research on the interaction between the degree of structure of assignments in teaching/learning packages and the ability level of pupils, as defined in the above mentioned hypotheses (Vvan der Sanden, 1986) are not confirmed. It is evident that the relation between the structure of assignments and the ability of students is far more complex than has been thought. This leads to the conclusion that in-depth research into the expected relations is necessary. The implication is that, at present, no unequivocal recommendations can be given to curriculum developers. Given the extremely complex relations between the variables distinguished in this study, considerable time and research effort will be needed before such recommendations can be made.

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