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INTEGRATING THE DEVELOPMENT OF THE OPERATIONAL ABILITIES OF THINKING AND THE TRANSMISSION OF KNOWLEDGE

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BACKGROUND AND FRAMEWORK

As the sciences produce more and more knowledge at an accelerated pace, there is a pressure for schools to include the elements of the new scientific results in their curricula and to teach more and more material. At the same time, there are definite expectations that the schools should develop the thinking abilities of their students more effectively. Whereas periodical revision of the curricula and incorporation of the rudiments of the new scientific information is routine in most educational systems, it is more problematic to devise a systematic way of developing thinking abilities. As there is little chance of including extra developmental activities in already overloaded school programmes, there is a need to find ways to combine and integrate the contradictory requirements of the development of thinking and the transmission of knowledge.

The objective of our present research was to devise methods which systematically develop the operational abilities of thinking within the framework of the school subjects, using the teaching material. We presumed that the teaching material itself offered sufficient possibilities, but that conventional teaching methods paid little attention to the development of basic thinking operations; such development could best be encouraged by reorganizing the contents of the curricula and modifying the process of transmission of knowledge.

The present work forms part of a longer research process. (a) The first phase of this research leads back to Piagetian cognitive theory, but only the general issues of it (e.g., the use of mathematics in the description of the structure of thinking) were used as the conceptual framework for our investigations. The system of operations of thinking was reanalyzed in both psychological and mathematical senses, and a more elaborated system was set up. Three groups of operations were identified: combinative (Csapó, 1985a, 1985b), logical (Csapó, Czachesz, & Vidákovich, 1986) and systematizing (Nagy, 1987) operations. (b) A test-battery was then worked out, containing around 300 tasks based on this system, and investigations were carried out into the structure and development of these operations by using the whole test-battery. We examined 10-, 14- and 17-year-old students, and found that development in this range is very slow. (c) The third stage was that of devising methods and tools for improving operational abilities, and (d) the last phase is the experimental investigation of the effectiveness of these developmental systems.

This paper focuses on the preparation and characteristics of the developing materials. Its main purpose is to describe the way of re-organizing the knowledge transmission process and of creating tasks for predefined structures with the given contents. A wide-ranging experiment to examine the use of these methods in everyday school work is in progress, and only brief data relating to the empirical pilot studies are presented here, to illustrate the practical applications.

There are many traditions that try to include influences aimed at the development of thinking in school curricula. One branch applies the theory of the Geneva school in the course of devising teaching material. The early applications were mostly theory-driven, short-term interventions in well-controlled artificial or even laboratory situations, and were not designed for use in everyday school practice. Even if some of these interventions were very effective, they have a poor chance of becoming part of regular classroom work, because such activities are usually time-consuming and are extra to the curricular material.

The neo-Piagetian applications use modified versions of the theory, and are closer to classroom processes. In some cases, entire early childhood educational programmes were based on Piagetian theory (Kamii & De Vries, 1976; Kamii, 1981). Many applications were realized in mathematics teaching (Brown, 1979; Collis, 1976, 1980) and in science education (Shayer, 1980). Applications of (neo)Piagetian theory can also be found in the teaching of humanities (most of them in history), although the teaching does not always focus directly on the development of operational thought (Hallam, 1970; Jurd, 1978a, 1978b). The Instrumental Enrichment program, designed for improving learning potential, is made up of abstract problem-solving material and the Cognitive Acceleration through Science Education (CASE) project uses modified teaching material for its developmental effect (Feuerstein, 1980; Shayer & Beasley, 1987; Shayer, in press).

The present work is close to these traditions. It uses their results and experience and additionally takes into account the real needs and possibilities of existing school practice. This work resulted in developing systems that have the following features: (a) they use the contents of the standard curricular material; (b) they do not step outside the normal time schedule; (c) parts of the teaching material are formed into tasks and exercises; (d) these tasks and exercises are based on structures that were examined in detail previously; (e) the structures have a variety of numerical features; there are structures that use the minimum possible number of elements, and, with increasing complexity, structures that work with more elements; (f) the tasks have a variety of contents; the same structure is embodied in different task contents.

The pupils' activity in the construction of knowledge also plays a basic role, but this activity is not necessarily a manipulative or physical one. In the following sections, examples of these features will be presented.

ANALYSIS OF THE LEARNING MATERIAL

The structures of the three groups of operations that had been studied in the previous phase of the research formed the basis of the present analysis. The *combinative operations* form complex compositions from certain elements, for example, forming Cartesian products of sets, forming variations, permutations, combinations (with or without repetitions) of given elements, forming all subsets of a set, for example. The group of *logical operations* involves the most important binary operations of propositional logic and the operations of inference. The binary relations form the mathematical background of the *systematizing operations*; most of these operations are also known from Piagetian research (e.g., seriation, class inclusion, multiple classification, etc.).

Four school subjects were selected for the purpose of the analysis and experiment: grammar and environmental science in the fourth grade, and physics and chemistry in the seventh grade of the primary school. In the first step of the analysis, the texts and the problem-tasks of the school-books were examined and the operational structures were looked for. The exact functions of the operational thinking in the learning process were then identified.

We found that in most cases the operational structures of the learning material remain hidden: most of the texts are linear sequences of more or less independent facts, and they present only a fraction of the possible relationships between concepts and facts. Or, when the texts involve operational structures (seriations, classifications, systematic combinations, etc.), the pupils are not forced to activate their own operational abilities. In the books, in the usual mode of presentation, the operational side of the problems is already solved: the books present ready-made systems, and enumerate the possible combinations, providing full lines of logical reasoning, without asking the pupils to create the systems, the combinations or the inferences.

We therefore modified the modes of presentation and restructured the teaching material, the content remaining unchanged. First the concepts and propositions of the texts were identified. Then these elements of the teaching material and the operational structures to be developed were matched: the concepts and facts served as elements with which to operate. Finally, tasks were constructed that highlighted a number of further possible relationships between the concepts and propositions.

As we defined three operational abilities and analysed four school subjects, twelve separate task-systems were devised, one for each combination of the abilities and subjects (developing the combinative ability in grammar, the logical ability in grammar, and the systematizing ability in physics).

For each of the 12 task-systems a working group was set up; among the members were school teachers and experts on research in cognitive development. As a result of this work, there are more than 50 tasks, specifically devised for their developing effects, for each ability per subject per year. Thus, the task-systems include more than 600 specific tasks in all.

CHARACTERISTICS OF THE TASKS

The most important feature of the tasks is that they integrate developmental influences into the teaching-learning processes. For example, the *logical tasks* help a better understanding of the complex propositions.

Let us look at an example from physics. Newton's first law of motion states:

A body remains at rest or in uniform motion in a straight line unless acted upon by a force.

We can explain the exact meaning of this proposition to the pupils by asking them to express the same statement in other forms. Or we can ask them to evaluate other expressions, for example, by asking them if the following statements are true:

1. If a body is not acted upon by a force, then it remains at rest or in uniform motion in a straight line.

2. A body remains at rest or in uniform motion in a straight line if and only if is not acted upon by a force.

We can also systematically evaluate the truth-table of the complex proposition by asking which combinations of the three simple propositions (a body 'is acted upon by a force', 'remains at rest', 'remains in uniform motion in a straight line') can be true at the same time according to Newton's first law.

1. Is acted upon by a force. Remains at rest. Remains in uniform motion in a straight line.

All pairs of the three statements are mutually contradictory.

2. Is acted upon by a force. Remains at rest. Does not remain in uniform motion in a straight line.

The first and second statements are contradictory.

3. Is acted upon by a force. Does not remain at rest. Remains in uniform motion in a straight line.

The first and third statements are contradictory.

4. Is acted upon by a force. Does not remain at rest. Does not remain in uniform motion in a straight line.

True according to the law.

Etc.

We can also ask questions like the following. Would this law be true if we found experimentally that:

1. the body is acted upon by a force, but it remains at rest?

2. the body is acted upon by a force and it does not remain at rest?

Etc.

This kind of practice, which can sometimes be presented in a playful way, may not only help towards a better understanding of the actual learning material of physics, but can develop the operations of propositional logic as well.

The learning material also offers numerous possibilities for the development of the *systematizing ability*. There are many opportunities to practise the operations of class inclusion, seriation, classification and multiple classification. For example, we can practise the transitive characteristics of a relationship by means of the following task in chemistry:

> Hydrogen reacts more strongly with bromine than with iodine. Chlorine reacts less strongly than fluorine with hydrogen. Hydrogen reacts less strongly with bromine than with chlorine. Fluorine is more electro-negative than iodine. What is the sequence of electro-negativities of the four halogen elements?

The *combinative operations* play an important role in creative thinking. Despite the many functions they can have in thinking, little attention has been paid to their development.

The following example from our tasks for fourth-grade science shows how we can help to distinguish between the really existing, the possible, and the impossible (but conceivable) combinations of things. In a particular context, let us enumerate the words Sun, Earth and Moon in all possible sequences. Which sequences are possible in reality? If the three celestial bodies are in one straight line, in which cases can there be an eclipse of the Moon, and in which cases an eclipse of the Sun?

Sun	Earth	Moon	lunar eclipse
Sun	Moon	Earth	solar eclipse
Earth	Sun	Moon	not possible
Earth	Moon	Sun	solar eclipse
Moon	Sun	Earth	not possible
Moon	Earth	Sun	lunar eclipse

The solution of this task not only requires a comprehension of the structure of the solar system, but also helps the development of a scheme to enumerate all permutations of given elements.

The following task from seventh-grade chemistry helps to produce unusual relationships between given concepts and develops the ability to deal with remote associations. The book enumerates the possible grouping of materials, for example: sources of energy, inflammable materials, nutritive materials, metals and minerals. Let us combine these aspects and discuss the connections between the various concepts in pairs. What can we say about these relationships?

source of energy	inflammable material
source of energy	nutritive material
source of energy	metal
source of energy	mineral
inflammable material	nutritive material
inflammable material	metal
inflammable material	mineral
nutritive material	metal
nutritive material	mineral
metal	mineral

In this way we can collect together many known facts, for example: numerous sources of energy are inflammable; certain nutritive materials are sources of energy for living organisms; salts of certain metals are vital, whereas others are poisonous for living organisms; most metals can be found in the form of natural minerals, and so forth. Practice with these operations makes it possible to increase the consistency of knowledge, as they highlight relationships which might otherwise never appear in the teaching-learning processes.

At the present stage of our research, the tasks have been edited into booklets and offered to teachers for use as supplementary or alternative learning material. At the same time, we have begun the experimental examination of the effectiveness of these task-systems.

FEASIBILITY STUDIES AND SOME EARLY RESULTS

In 1984/85 a pilot study was carried out in mathematics in the fourth grade, and in 1985/86 in the mother tongue in the fifth grade, in order to develop the combinative operations. These experiments took place in specially chosen school classes, and were controlled by experienced researchers. As the main aim of these studies was to test how the task-systems worked in the classroom, there were no control groups, but the results of the earlier representative assessments can be used for comparison.

In the mathematics study (with the assistance of S. Fülöp), 67 tasks of the standard curricula were modified and used in the teaching-learning process. The results of the 10-month intervention can be found in Table 1. Shortened versions of former tests were used as pre- and posttests, and the Table contains the results of corresponding tasks from the representative surveys. *As these results are suitable only for a tentative estimation of the effectiveness* of the experimental intervention, with the aim of a better comparison the initial level in both cases (the pretest one in the experiment and the fourth-grade sample in the representative surveys) was taken as 100%. The results suggest that the development during the 10-month experiment was as much as the spontaneous development would otherwise have been during four school years.

In fifth-grade classes learning grammar, 54 developing tasks were used, some of them supplementary to the standard curricular material (with the assistance of L. Wiegand). The results and the comparative data are displayed in Table 2. (The tests of these measurements were more complex than in the mathematics study, and therefore the data cannot be compared with those in Table 1.) The results here likewise demonstrate that the enriched material accelerated development.

Table 1: Development of the combinative ability using the enriched fourth-grade mathematics

Group	n	mean score
Experimental pretest	160	100
Experimental posttest	160	118
Control fourth grade	150	100
Control eighth grade	550	117
Control 17-year-olds	150	132

Table 2: Development of the combinative ability using the enriched fifth-grade grammar

Group	n	mean score
Experimental pretest	163	100
Experimental posttest	163	119
Control fourth grade	150	100
Control 17-year-olds	150	117

The results of the pilot studies suggested that development in the experimental situation was much faster than spontaneous development, and therefore further investigations were carried out to measure the effect of the experimental intervention more exactly. In the next phase, in 1986/87, we examined how these systems work in average schools. Seven experimental groups were organized to develop: the *combinative ability* (a) in the mother tongue and (b) in science in the fourth grade, and (c) in chemistry and (d) in physics in the seventh grade; and also to develop the *logical ability* (e) in chemistry and (f) in physics; and the *systematizing ability* (g) in chemistry. (Each group contained three classes, and thus altogether 21 experimental classes took part. Six classes in the fourth grade and six classes in the seventh grade formed the control groups.)

The main aim of this phase of the research was *to find the best ways of working with the developmental task-systems* in everyday school practice. Teachers were asked to use the tasks, but they retained the right to choose their methods of working. They wrote reports on their experiences. We found that there were no preferred ways of using the tasks: they were used equally in individual, in group or in whole-class work, or as homework. About 30-50 tasks were presented to the pupils during the year. This number of tasks can easily be worked with in the usual time schedule without disturbing the other objectives of instruction. A precise quantitative evaluation was not the aim of these experiments, and only some brief data will be presented to indicate the effectiveness of these developing systems. The effect of the enriched fourth-grade grammar on the combinative ability is displayed in Table 3. For comparison the Table includes the results of both the fourth- and the seventh-grade control groups. In the experimental classes 50 developmental tasks were used, while the pupils in the control classes were instructed in the usual way. Pre- and posttests were administered to each group. Development in the experimental group was about three times faster than in the control group, and by the end of the school year the children in the fourth-grade experimental groups had reached about the same level as that usually attained by the beginning of the seventh grade in the nonexperimental situation.

Table 3: Development of the combinative ability using the enriched fourth-grade grammar

Group	n	pre-test	post-test	mean difference
Experimental	99	90.6	108.9	18.3
Control (4th)	247	94.1	99.8	5.7
Control (7th)	191	110.2	119.1	8.9

The results for the other groups also showed that the children in the fourth-grade experimental classes had reached approximately the same developmental level in operational abilities as that of the control groups in the seventh grade. The developmental influence of the experimental instruction was less in the seventh grade than in the fourth grade.

Although these studies demonstrate the possibilities of improving operational abilities in the school by using the teaching material, further investigations are necessary to prove their effectiveness. The task-systems will be revised on the basis of the experiences, and the teachers' reports will be used to improve classroom work with the task systems. In 1987/88, a full, well-controlled experiment is being carried out for each of the combinations of the three operational abilities and school subjects. In order to measure the changes, a test battery was administered at the beginning, and will be repeated at the end of the school year. These tests examine the developmental levels of the three operational abilities, the mental background (intelligence), motivation, and the affective domain (self concept and test anxiety).

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