STUDY OF COMPLEX PROBLEM-SOLVING IN REAL LIFE PROBLEMS

Thesis of a PhD dissertation

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Introduction

The most important aim of education would be to prepare pupils for future life, for the unknown, for work, and for real-life problems. The prerequisite of this is, that school-related knowledge of pupils should not be fragmented into subjects and restricted to school context, but should be a uniform, systematised knowledge, applicable and transferable to novel situations, where not only the quality matters, but the quantity too. There are however, several national and international surveys indicating that a considerable number of pupils are not effective enough in independent knowledge acquisition and in the application of this acquired knowledge to new, everyday situations (*Csapó* and *Korom*, 1998). The mental representation of acquired knowledge is not sufficient, new knowledge is not connected to the existing system of knowledge. So the transfer and application of acquired knowledge is problematic. Research results have shown that knowledge transfer is generally not automatic and only proper education can ensure its broader applicability (*Csapó*, 1999a).

The demand for transmitting high-quality knowledge became central to researches related to transfer and problem-solving. In the backgrounds of researches there are several questions regarding teaching methods, instructional practice, and the curriculum. From the above problems the present dissertation emphasizes the role of content in problem solving and the ability to apply knowledge in real-life, complex situations. The dissertation consists of five sections. In the first two chapters we summarize and synthesize some of the key findings from international literature on transfer and problem solving. The third, fourth and fifth chapter introduces our empirical researches.

The first two chapters are introductory chapters that provide definitions and describe the various theoretical frameworks that have been offered about knowledge application so far. The first chapter offers a rather general, theoretical framework about transfer, types of transfer, highlighting the schema-based analogical transfer. The second chapter discusses the different traditions about problem solving that have been developed in Europe and North America. That is followed by their synthesis in real-life complex problem solving. This is a relatively new research field that opens new ways in transfer researches too. We try to describe the revival of this theme in literature that, following the international studies, emerges slowly in Hungary as well. After a historical overview the focus of the dissertation shifts to our empirical researches (chap. 3-5), namely on the ability to apply knowledge in novel, real-life situations. We would like to know how students can apply school-related knowledge in real-life situations that are full with disturbing and redundant information.

The dissertation presents the results of four empirical studies. The first study examines the role of content in problem-solving processes using problems with similar deep-structure but different content. Among the tasks there are several problems adapted from international literature that makes the comparison of our results possible. The second study examines the transferability of pupils' previous experiences and the applicability of their mathematical knowledge acquired at school, in practical, real-life situations by using problems with identical deep-structure, but different surface structure. The design of the third study is similar to the second one, but it examines problem solving in a context more realistic to students: family travels. Apart from mathematical problems our test contains other natural sciences

questions also. In addition to the complex problem solving test-series, there is a mathematics and a natural sciences test-series too, deprived of the life-related context of complex problem solving, placed into a school context. The fourth, large-scale study is built entirely on the third assessment, but it contains a reading test too. In the followings we summarise the main results.

The theoretical framework of knowledge transfer and knowledge application

The concept of continuity of knowledge is not new. The roots of modern researches are at the beginning of the 20th Century when efforts towards expanding and reforming American public education made learning transfer a central issue. Major figures in American education and psychology – *Edward L. Thorndike, Charles Hubard Judd* and *John Dewey* – considered the facilitation of learning transfer as central to the future success of American education, although their opinions strongly differed in what transfer was.

On the basis of influence by cognitive psychology in the 1970s the concept of learning transfer and its role in pedagogical research has gained new perspectives. Most of the cognitive psychologists accepted the "traditional" view of transfer (Transfer occurs if the new learning situation has common elements with the original one, or when the guiding principles learnt in one task are applied in another learning situation.), but they also studied those thinking procedures, cognitive structures (schemas) and metacognitive strategies, which demonstrate the ability of learning to transfer. The number of transfer researches has increased again in the 1990s, which were indicated by several publications in international literature too (*Detterman* and *Sternberg*, 1993; *De Corte*, 1998; *Bransford* and *Schwartz*, 1999; *Beach*, 1999; *Dyson*, 1999; *Haskell*, 2001). Apart from the classical types of transfer (negative – positive transfer, near – far transfer, surface structure – deep-structure transfer) novel, more complex groupings, such as the high and low road transfer, also received research attention.

Researches in the field of real-life problem solving have opened new alternatives leading to researches in learning transfer and knowledge application in new contexts. Another group of researchers has found the opportunity of supporting knowledge application in the development of problem solving skills and related research. To get a more precise notion of today's problem-solving researches, first we give a brief historical overview of the most important milestones in research.

The classical view considers problem solving to be a stepwise process, which is passive, reproductive and domain-general, based on trial and error. As a contrary, the Gestalt psychologists describe problem solving as an active and productive process, where insight, reorganisation and functional fixedness play an important role. The development of computers and the information-processing approach and problem-space theory of *Newell* and *Simon* has provided new alternative ways and directions in research. Researchers have realised that empirical findings and theoretical concepts derived from single laboratory tasks were not generalisable to more complex, real-life problems. These realisations have led to the appearance of rather different directions in North America and in Europe. North American research on problem solving has typically concentrated on examining the development of expertise in separate, natural knowledge domains and on the task – problem solver interaction, while most of the European researches are task specific, and has focused on the solving processes of complex, unknown problems, and on the characteristic features of problems to be solved. These researches were performed with the help of computerised scenarios. The approach on complex problem solving in real-life situations is an integrated whole of researches on transfer, and of the European and American models on problem solving. This

model contains tasks, which must be novel, unknown, complex, semantically rich, dynamically changing over time, ill-structured, knowledge intensive, intransparent and similar to real-life problems (*Frensch* and *Funke*, 1995a, 1995b; *Krems*, 1995).

In the next part of the dissertation we are focusing on the results of empirical studies related to knowledge application in new contexts. The assessment of cross-curricular problem solving contains tasks (in such formulation) pupils have never met at school before, but that are similar to real-life problems. This type of problem formulation is suitable for measuring, how pupils transfer knowledge application to new contexts, how they use their problem solving strategies in unusual situations.

The role of content in the effectiveness of problem solving

In connection with studies on problem-solving and thinking, the problem of context-boundless or independence of knowledge often arises. In this section we present the results of our two empirical studies. The objectives of the researches were to observe, how pupils can apply their experiences with solving problems to problems of the same deep structure, but different surface structure, and how pupils can transfer their mathematical knowledge, learnt at school, to novel, everyday situations.

The first study – methods and results

In the first study 151 11^{th} grade pupils participated, from secondary grammar school Lovassy László, Veszprém. 50% of the sample was girls, and 50% was boys. Data collection took place in the spring of 2000. Each pupil filled the same test in. The test contained 8 tasks, which were in fact only four different problems. The other four tasks were different only in their content dimension (surface structure). Problems with the same structure were placed to the same page, to make transfer between tasks easier.

The results of the first study are more or less in accordance with phenomena known from the literature. Experiences show, that not even this geometrical proximity has supported transfer of problem solutions to the analogous problem to be found under or above. Context and the content the tasks are embedded in play a crucial role in problem-solving. Pupils find less sense in school-related tasks formulated with the help of abstract symbols and signs. They try to solve these tasks automatically with the help of acquired algorithms, based on the surface structure, instead of looking for their meaning, their deep structure and search for an easier way of problem solving, on the basis of their experiences. Because of the defining role of surface structure, the transfer of solution method applied in one problem to the next problem differing in surface structure, is low.

The second study ("Problems of building a family house") – methods and results

The second study goes further than the mere examination of the role content plays in solving isolated problems. To study the role of context in problem-solving it uses a more compound, more complex test simulating real-life situations. The study is based on the test called „Problems of building a family house". In this phase of the study the use of a representative sample was not required, as the aim was only to compare two groups with different developmental levels. The survey was carried out in the winter of 2000. The subjects were 14- (grade 8) and 17- (grade 11) year-old pupils (n=215 and 160, respectively) from Hungarian primary and secondary schools of Csongrád and Szeged, Hungary. The results of these two age-groups are appropriate for presenting pupils' performance at the end of primary school and for demonstrating the developmental trends in secondary school.

The instrument used is a paper and pencil test with two task types. First, pupils responded to multiple choice items, and then they had to justify their decisions in open, constructed responses. All tasks were embedded in one single realistic situation, i.e. building a family house. There are many problems presented in the test with the same deep structure, but different surface structure, the solution method of which are the same despite of the different presentation. The presentation of the tasks is to a more or less extent different from those used at school. The context used for presenting the problems concerns various situations– work, personal life, family and entertainment – of everyday life. If pupils try to solve problems formulated in everyday language with the help of knowledge acquired at school, first they have to convert these into the specific sign system of mathematics. The specific symbols have to be interpreted, and the tasks should be solved according to rules familiar in the given context. The pages of the test booklet were divided into two columns. The left column presented information in realistic formats (e.g. map, newspaper article, advertisement, picture, drawing, letter, contract, etc.), while the right column described the story of building a house and prompted pupils to solve problems (using the information provided and knowledge learnt at school) as they appear during the building process. Each of the problems contained some well-identifiable mathematical operations.

The tasks of the test were categorised according to the mathematical nature of reasoning (e.g. proportional, combinatorial, numeric), complexity (number of solution types) context (familiar, unfamiliar), and form of representation (table, test, figure, etc.). Trend indicators show how results change over time. The analysis has revealed that the choice of mathematical methods and the presentations of results are often dependent upon the setting in which the problems appear. The mean performance on tasks formulated similar to the ones used at school is higher (above 80 percent), than the mean performance on those with an analogous structure, but unknown context (about 20-30 percent). The essence of problem-solving and transfer based on familiarity of context is underlined by the fact, that pupils have not found any relationships between tasks with similar deep-structure (requiring the same problem solution), but they have solved tasks with similar presentation but different surface structure (requiring different problem solution) with similar methods. No significant gender differences were found. The results show that regarding the developmental level of pupils' problem solving ability we can't draw conclusions from the parents' level of education, or from pupils' attitudes towards school. At the same time, there are enormous differences among pupils' achievement in the different school types. The results of the first two studies provided the basis for the design of the third one, directed at the measure of the development of complex problem-solving ability.

The study of complex problem solving among 9 to 17-year-old pupils

The third study „Problems of building a family house" (chap. 3) is an empirical research following a new philosophy. Instead of knowledge reproduction, this study examines – on the basis of international assessments – the applicable knowledge of pupils, their ability to orientate in new, unknown, and real-life situations. The aim is not the covering of school curriculum content, but to assess the extent to which young people have acquired knowledge and skills in the given domains, which they will need in adult life. We set the same purpose and basic idea in front of us too. The fourth study covers the three domains favoured by PISA: *reading literacy*, *mathematical literacy* and *scientific literacy* (OECD, 2000).

During the examination of cross-curricular problem solving pupils had to solve tasks they have earlier – in the same form – not met at school. When making decisions corresponding to real-life problems, pupils' background knowledge has played an outstanding role. In the third and fourth study an effort was made also towards extending the scope of

participants and the content dimension of the survey (apart from mathematical problems it contains natural-sciences problems too). We have also tried to include as much background variables (success in solving school-related, explicit tasks; reading skills; inductive reasoning; parents' education; carriers; school marks; subject matter attitudes ...) in the analysis as possible.

The small-scale study ("My diary ...") – methods and results

Data collection took place in the winter of 2001, with the participation of 1371 pupils from four primary, two vocational and two secondary grammar schools from seven Hungarian towns: Derekegyháza, Dombegyháza, Hódmezővásárhely, Kecskemét, Kiskunfélegyháza, Szarvas and Tompa. Apart from the first two grades of primary school, each grade took part in the data collection. Because of reading difficulties we could not use our tests in the first two grades. Participants in secondary schools were 9^{th} -to 11^{th} graders.

Two types of tests were devised parallely: one containing explicit mathematical and science word problems, and another complex one containing structurally equal tasks in real-life context. The three different levels of tests are often referred to as level 1, 2 and 3 respectively. All tasks of level 2 – which is the core test of the survey – are represented half-and-half in test level 1 and level 3. Test level 1 and 3 are independent. 3^{rd}, 4^{th} and 5^{th} grade pupils have solved the first level, 6^{th}, 7^{th} and 8^{th} grade pupils have solved the second level and 9^{th}, 10^{th} and 11^{th} grade pupils have solved the third level instruments.

The basic idea and the design of the survey (The pages of the complex text booklet were divided into two columns. The left column presented information in realistic formats, while the right column described the story and prompted students to solve problems.) remained the same, but the context of the test-serial was much closer to pupils' everyday life. Many questions refer to the explanation of things about pupils' everyday life: do they understand, what they hear, see and experience every day? For example, do they know, what pH 5.5 means, or why is the sunset "red" on summer evenings?

The content aspect of the framework represents the subject matter content of school mathematics and science. Six content dimensions were covered in the mathematical part of the survey (whole numbers, fractions, number sense; measurement; analysis, probability, data representation; geometry; algebra; proportionality) and four content areas in science (life science; earth science; physics; chemistry). The performance expectations aspect of the framework describes, in a non-hierarchical way, the variety of performances or behaviours that might be expected from pupils in real-life and school problems.

The results support the crucial and increasingly important role of context and surface structure in problem solving as well as in transfer of knowledge. The results reveal minimal differences in lower primary grades between achievement in solving complex problems in real-life contexts and in solving explicit given tasks. These differences increase by age in a linear fashion. The reason for this increase could lie in the teaching methods using explicit given tasks, because within these there aren't any opportunities to practise the collecting and combining of information received from different sources, critical evaluation of information and the practice of problem representation. Schema-based mechanical problem solving is in the centre instead. In secondary school there are considerable differences among pupils' achievement in the different school types. Vocational secondary school pupils have shown significantly poorer ($p<0,001$) performance than academic secondary school pupils. The correlation between school achievement and complex problem solving ability are the strongest in grade 7 and 8, and the weakest in grade 9 and 11. When considering school results, pupils' mathematical marks and their grade point averages indicate the developmental level of their problem solving ability the best.

The large-scale study ("My diary ...") – methods and results

The subjects of the study were 9 to 17-year-old primary and secondary school pupils (n=5337) from three Hungarian towns: Miskolc, Pécs and Szeged. Data collection took place in the spring of 2002, in regular lessons, with the help of local teachers. The tests used during the piloting phase and their structure were a little bit modified. Because of the frequent question concerning paper and pencil tests– how important pupils' reading skills are in achievement – there was a reading test with different types of texts (table, diagram, and literary text) also included.

Similar to our previous studies, all variables were considered as dichotomous, for the purposes of quantitative analysis. The responses were coded as zero for a wrong response and one for the correct response. The test was analysed and the items were weighted according not only to the classical test theory, but to the modern one too. The anchor items of the second level made possible to bring the items on first, second and third levels to one scale and by this means compare the developmental level of problem solving ability of pupils of different age groups.

The research results call our attention to the importance of the real-life nature and variability of context, as performance on mathematics and natural sciences tests were far more better than results obtained on the analogous problems of the complex problem-solving tasks on the one hand, and pupils do not find sense in solving tasks deprived of content, converted to "pure" figures, on the other. Pupils' knowledge is content-bound; the transfer to other, novel situations is difficult. The selection after primary school increases the extent of achievement-differences among the grades. Even the 9^{th} graders in secondary grammar schools achieve better than 11^{th} graders in vocational schools. In secondary schools a similar trend is noticeable by gender. Achievement differences within the same gender decrease and between genders increase.

To sum up results, it is the solving of mathematical problems we could find the most significant development in. Pupils' level of reading skills was the most influential factor to performance on complex problem solving tests in secondary school still. Besides reading, the determinal effect of the developmental level of inductive reasoning that helps the realisation of relationships proved to be important. We have seen, that school marks of pupils indicate the application ability of acquired knowledge only to a lesser extent, though problem solving ability, if implicitly, but plays an important role in school selection. This is proved by the fact that in the secondary school application tests of recent years tasks measuring the development of thinking and different competences have also appeared (*Csapó*, 2002). The role of family background, which in theory defines the developmental level of pupils' thinking skills, were not proved to be considerable by these studies as well.

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Research into knowledge acquisition, problem solving abilities acquired outside of school and research into school curriculum related knowledge and skills have highlighted phenomena that are not visible from school marks and achievements directly. The assessment and monitoring of application and applicability, the demand and supply of the acquisition of key competences integrated into school curriculum, essential to successful conduct of life is important at school already.

As we could see, transfer, problem solving, expertise and quality of knowledge are closely related concepts, corresponding research results can often been found in problem solving and school improvement studies (*Csapó*, 1999b, 2001; *Csapó* and *Korom*, 1998). The common aim of the present and other studies is to lead to knowledge applicable for education

that outside of school ensures ability for pupils to solve problems they have never encountered before. To achieve this aim we have to provide pupils with an ever growing variety of tasks fully integrated in the curriculum, because it is only through providing variety and letting them experience it we can prepare them in "dull" classrooms for the colourful diversity of life (*Marton*, 2000).

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