THESIS OF A PhD DISSERTATION

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Issues in the application of science knowledge: Investigating the understanding of real-life phenomena 1996–2006

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INTRODUCTION

There is still an overt and widespread tradition of satisfaction concerning science instruction in Hungary today. This field of education is represented as the most successful branch of the Hungarian educational system in general public opinion and even in some professional minds. Science instruction is undoubtedly fairly efficient in a certain way, for instance, in transmitting science knowledge that can be easily reproduced in school contexts. – Hungarian 15-year-old students performed above the international mean in the science knowledge dimension of the OECD-PISA study in 2006 (*OECD-PISA*, 2007a, 2007b). – However, it was already tangible at the end of the last century that this academically oriented, discipline-based transmission of science knowledge, which has produced generations of distinguished scholars and has yielded remarkable achievements at student olympics, would not prove appropriate for satisfying the demands of mass education or those of modern economy.

Both Hungarian and international survey results suggest that the difference between our students' knowledge and that of their foreign peers is a problem of qualitative and not quantitative nature. Teachers experience day by day how much students struggle with transferring their knowledge even in theoretical contexts. For instance, they can hardly apply in physics what they have learnt in a chemistry or biology class. – It was this very discrepancy between students' outstanding theoretical disciplinary knowledge and its applicability outside the classroom which called for the investigation of the application of science knowledge in real-life situations.

The first, theoretical part of the present dissertation reviews the international literature on three central concepts: science knowledge and literacy, application and context. Additionally, it compares the underlying methodological conceptions of the IEA-TIMSS and the OECD-PISA assessments which served as a framework for the research presented. The empirical chapters report on three large-scale studies: 1. "*Az iskolai tudás*" (School-based knowledge), conducted in Szeged in 1995; 2. "*A természettudományi és matematikai tudás országos helyzete és összefüggése a készségek és képességek fejlettségével*" (The level of science and mathematics knowledge in Hungary and its relation to the development of skills and abilities), a national project carried out in 1999; and 3. "*A közoktatás szerepe az élethosszig tartó tanulásra való felkészítésben*" (The role of public education in the preparation for lifelong learning), a 2006 national survey. All three projects were carried out simultaneously with international assessments (1995 and 1999: IEA-TIMSS and 2006: OECD-PISA). Although the direct comparison of the results is not possible, the IEA-TIMSS and OECD-PISA findings enable an interpretation of the Szeged and the Hungarian results presented here in relation to international tendencies regarding the different aspects of science knowledge.

THEORETICAL FRAMEWORKS

Science instruction has gone through a peculiar course of development. Today it seems evident that, for the general public, valid and relevant knowledge is knowledge drawn from various sources, acquired through learning processes within and without the school and applicable in real-life situations. It is science literacy comprising the basics of science and technology, which does not correspond with scholarly knowledge. The term *scientific literacy* or *science literacy* used for indicating the principles, goals and duties of science education has been interpreted in diverse ways by different authors. There is only one common element to be found in each of the several various definitions. They all agree that without science knowledge there could not be literacy (*Roberts*, 2007).

Literacy conceptions are polarized into two well definable approaches: (1) a science oriented approach which prefers disciplinary literacy in individual fields of natural sciences; and (2) an everyday life oriented approach which focuses on the problem solving ability manifested in coping with real-life problems of the target group (*Roberts*, 2007). Lately a third line of thought has emerged belonging to the STS approach, which aims to integrate natural, technical and social sciences (*Aikenhead*, 2007). The positions of science teachers and those represented in the majority of the official educational documents in various school systems are mainly peculiar compounds of either the first two or all three formerly described standpoints. Basically the individual specifications of these "ways of perception" (*Roberts*, 2007) appear in the IEA-TIMSS and OECD-PISA assessments as well (*Roberts*, 2007; *Tiberghein*, 2007).

The approaches to the *application of knowledge* are numerous as well. Some perceive it as thinking skills (*Kagan*, 2005; *Sternberg*, 1985), others compare it conceptually with abstraction and transfer (*Passeym*, 1999). The literature on education refers to application as the synonym of the functioning or the instrumental usage of knowledge, hence considers knowledge applicable if present and concrete situations might be handled successfully with it. In the taxonomies aiming at the sophisticated declaration of curriculum objectives, application (apply, applying) represents an independent level in the hierarchy of cognitive activity (*Bloom*, 1956; *Anderson and Kathwohl*, 2001; *Johnson and Fuller*, 2006; *Mollis et al.*, 2005; *Madaus et al.*, 1973; *Nagy*, 1979). *József Nagy* uses it as a synonym of operation or usage and describes four levels (recognition, connection, execution and interpretation) depending on the depth of acquisition and knowledge-representation (*Nagy*, 1993). In the first three IEA-TIMSS assessments, application as a parameter of tested knowledge is manifested in such concrete activities as problem solving, integration of facts and related concepts, hypotheses, estimation, formulating conclusions, observation, design of investigation, use of instruments and execution of different procedures (*Beaton et al.*, 1996a; *Martin et al.*, 2000; *Mullis et al.*, 2001; 2005). In OECD-PISA, application as a separate level of cognitive behaviour is not present, since its concept of literacy incorporates applicable knowledge.

The interpretations of context, the third parameter of relevant knowledge, cover a wide scale, similarly to the previous ones (*Butterfoworth,* 1993). Context is represented mostly implicitly in educational studies and research by such dichotomies as "known – unknown/new", "school-based – non-school-based" or "scientific – real/realistic/life" situations (*Butterfoworth,* 1993). In the educational research addressing the functioning and applicability of knowledge, context means the situation or environment in which knowledge as an instrument would be used. According to the widely accepted terminology applied in various disciplines, context is by definition the framework of interpretation for the given activity, the set of such characteristic parameters of a situation – as tasks or problems – that fundamentally determine the activation and combination of relevant pieces of knowledge.

The idea of knowledge application in new, real-life situations can be found in both previously cited international assessments. But whereas in IEA-TIMSS the task environment is scientific, resembling to school context, in OECD-PISA it is replaced by realistic, real-life context. The first international assessment program to target knowledge in assignments representing realistic, everyday situations was IEA-TIMSS. However, the elaborated system of different contexts appeared only in the science literacy survey of the OECD-PISA programme (OECD-PISA, 2000; 2006).

HYPOTHESES

- Everyday teaching experience clearly indicate that there are problems with the application of science knowledge in real-life contexts. Hungarian natural science curricula claim the role of science instruction to be the transmission of large quantities of comprehensive knowledge, therefore the influence of school-based instruction on the development of the investigated literacy is presumably low, although it is not possible to completely disregard it.
- Hungarian science instruction, being centred around the viewpoint of academic knowledge transmission, is not expected to display a high level of variance. Supposedly, the applicability of particular elements of science knowledge would show a high degree of similarity regarding both age and school-type.
- Since the ongoing changes in the Hungarian educational system have not brought along a conceptual and methodological renewal, we hypothesize that the students' ability to apply their knowledge in real-life situations has not changed significantly, either.
- International surveys as well as achievements in student olympics indicate that Hungarian science instruction grounded in a positive tradition is still effective in teaching disciplinary scientific knowledge. It seems probable that knowledge is not the weakest link in the applicability of acquired information. We can assume that the application of knowledge in contexts differing from that of the original learning context depends on the development of cognitive abilities that should operate on science knowledge. (In such cases the task environment does not facilitate the recall of relevant information and transfer is necessary). Of these abilities, the roles of inductive thinking and complex problem solving are investigated in the present studies.
- On the basis of previous research results we expect the assessed knowledge application, similarly to other student variables, to be influenced by the parents' level of education.
- Experience allows the assumption that non-cognitive features (e.g. subject attitudes, mastery motivation, self-concept and learning strategies) do not affect the application of the assessed science knowledge in realistic task environments significantly.

METHODS

Samples

The data collections for the research presented on science knowledge application in real-life task environments took place at three different times on samples of 7th and 11th graders, selected with different considerations. The unit of sample selection was the school class in each of the described projects. In the "*Az iskolai tudás*" (School-based knowledge) programme the sample was provided by a so called culture bearing unit: Szeged and its agglomeration. The samples of the other two projects were national. In the 1999 assessment, the sample was representative of settlement types in grade 7 and of school types and regions in grade 11. In the 2006 assessment both age-groups were representative of school types and regions. The instruments were administered to 363 7th and 486 11th graders in 15 and 24 classes in the Szeged assessment, respectively. 1704 and 3457 students in 76 and 178 classes took part in the national assessments in the two grades, respectively.

Instruments

A természettudományos tudás életszerű feladatkörnyezetben való alkalmazásának The investigation of the application of science knowledge in real-life task environments was framed by research programmes aiming at the exploration of different layers of knowledge, their relationships and background factors. With each assessment, data were collected on the subjects' inductive thinking, which plays a crucial role in the acquisition of knowledge and its application in unfamiliar situations. This test correlates highly with measures of intelligence. All three research projects investigated students' subject attitudes and parents' education, which are variables generally included in the analyses in noteworthy Hungarian and international knowledge assessments as well. Additionally, in 1995, subject knowledge was measured in biology, physics, mathematics and chemistry. In 1999, the "Math and science (TIMSS)" test based on the published items of IEA-TIMSS was administered. In 2006, the instruments included problem-solving tests (*Molnár*, 2006) based on OECD-PISA experience as well as the student questionnaire of the OECD-PISA study itself.

The "*Természettudományos tudás alkalmazása*" (Science knowledge application) is an isomorphically constructed test which consists of open ended questions similar to the IEA-TIMSS items. To successfully solve the tasks students needed to connect the facts or concepts previously learnt in one or more of their disciplinary science classes in primary or secondary school to the observed or deduced characteristics, behaviour or use of relevant things, phenomena, materials or living beings. The everyday phenomena presented in the tasks are the sources of natural, outside-school experiences for the students. These tasks were embedded in a context of living environment/daily activities, traffic, nutrition, health, free time activities and sport. The answers were scored in a manner comparable with international assessments, i.e. wrong solutions were given 0, partly correct ones 1 and perfect ones 2 points.

RESULTS

The development of science knowledge application

The outcome of all three assessments showed a similar picture about the applicability of Hungarian students' science knowledge in real-life contexts from several respects. Therefore, essentially the same conclusions can be drawn from the results of each project. With the mean achievements of 26.3-30.8%p and 38.7-55.5%p, neither the 7th nor the 11th graders' science knowledge seems sufficient when it should be applied in task environments different from school-based ones. It has to be considered, though, that the classifications of students' achievements as poor, medium or high cannot be clear-cut in the given framework of assessment, because of the lack of curriculum-like legitimate standards, which could serve as natural points of reference. Furthermore, there is also lacking an objective conceptual system which could promote the proper selection of the pieces of science knowledge consistently representing the variety of that knowledge. Moreover, the "*Természettudományos tudás alkalmazása*" (Science knowledge application) test – in accord with research objectives – measures only one aspect of science knowledge, its functioning in a given context, and thus it can not be perceived as a general measure of science knowledge.

The frequencies of test achievements and percentiles support the diagnosis arrived at by the criterion-based interpretation of percentage points. Although on the basis of the data it can not be established to what extent the knowledge of the target group measured with the "*Természettudományos tudás alkalmazása*" (Science knowledge application) test would correspond to externally based expectations, the insufficiency of the achievements in both age-groups can be stated with certainty. Students do not know several things that could be expected, especially in the light of science curricula.

There is a significant, but rather small difference in the science knowledge application of the 7th and 11th graders. The students are closer to each other in terms of the measured knowledge within the age groups, the variance being lower in case of the older sub-sample. Concerning school types, students performed according to expectations, i.e. their achievements increased in the following order: primary school < vocational school < technical secondary school < academic secondary school. The data, however, implies that the differences in achievements are only partly the result of the knowledge acquired in the four years that separates the two age-groups. They are partly resulting from the selection mechanisms working at the transition to secondary education.

The results of the three studies, similarly to assessments of other aspects of science knowledge (e.g. IEA-TIMSS; *Martin et al.*, 2008), show a negative tendency. In respect of the measured knowledge application a decline was found in the achievements of both age sub-samples as well as of each school type. Moreover, the variance of students increased, just as the rate of underperforming students, and, consequently, the rate of well-performing students decreased as did the level of development between the two age-groups. The explanation of the weaker results of nationally representative samples compared to the Szeged sample is relatively simple. Szeged represents a sub-sample of the national sample, the cities between 35 and 225 thousand inhabitants, and as it is clear from other research (e.g. *Vári*, 1994; 1997) that student achievements increase with settlement size. In addition, in the “*Az iskolai tudás*” (School-based knowledge) programme vocational schools were absent from the sample, i.e. 11th graders' results reflected only the achievements of the higher, more qualified levels of the population, from four-year secondary schools leading to the matura exam. However, the data do not make it possible to explain the reasons of the significant decrease in the results between the 1999 and 2006 assessment on the common subtest. The only conclusion that can be drawn at this point is that the content and structural changes of the Hungarian school system and the working models of science instruction do not promote the acquisition of applicable, functioning knowledge. The analysis of the data suggests that students possess mainly theoretical knowledge which they project with low efficiency to everyday situations dissimilar to the school-based task environment they are used to. The results indicate that the application in realistic task environments of the enormous amount of knowledge studied in the four year period between grades 7 and 11 is very inefficient.

Content features of applicable science knowledge

The applicability of the elements of knowledge in the test showed a high level of resemblance in the sub-samples by school type and grade, with the same tasks proving easy or difficult to solve for each sub-group. Although the academic secondary school offers much more, more complex and comprehensive science knowledge than primary or technical high schools, its contribution to the application of that knowledge in realistic task environments is at the same level as seen in student achievements in the latter school types. This indicates that the methodology of science instruction is not much varied among different types of education. – The class means reveal the same tendency, with most of the class-level achievements not differing significantly either from each other or from the age-group mean.

The analysis of the best selling science textbooks lead to the conclusion that, at times, the students faced the biggest difficulties in applying the facts, rules, laws and relations that appear in more than one disciplinary subject, only in different contexts. The elements of knowledge necessary to solve the tasks that proved the easiest, however, cannot be found in explicit form either in curricular objectives, or in the best selling textbooks. They often occur, however, as instances in students' everyday experiences.

Item means clearly show that students can only activate their knowledge in certain contexts, mainly in those they have already met in school. From the responses it is also clear that they are based on everyday experience and naïve conceptions, rather than on what students have learnt in school. Since Hungarian schools teach scientific knowledge dissimilar to students’ general experience, with the rhetoric of disciplinary sciences, the knowledge used in everyday orientation does presumably not derive from school-based instruction.

Relationships with background variables

The achievements of the various sub-samples, the item means and the actual responses all clearly indicate that Hungarian school instruction does not contribute much to the application of science knowledge in realistic task environments, since the present practices, methodology and curricula of science instruction do not promote the development of transfer skills. Thus it is not surprising that no close relationship was found between the application of science knowledge and academic achievement in this field as represented by school grades. The correlations of the knowledge application tests and the school grades show a similar trend in all three projects. They are significant and strong in both age-groups, though somewhat weaker in grade 11. The results suggest that academic achievement as shown by school grades is not a reliable indicator of how well science knowledge is applied in tasks dissimilar to school contexts.

The analysis of school grades shed light on a new aspect, the relationship between mathematics and science knowledge. The correlation coefficients of the math grades and the science knowledge test are as high at each assessment point as those of science grades. – The mathematics test targeting curricular contents and the mathematics comprehension test are also closely connected. – In the given frameworks of investigation, however, these correlations are difficult to interpret, since mathematics subject matter seems irrelevant from the point of view of the assessed science knowledge application. It appears therefore plausible that high performance on the “*Természettudományos tudás alkalmazása*” (Science knowledge application) test items requires such abilities and strategies which are characteristic of students performing well in math. The connection between mathematics and science knowledge is implied by the TIMSS findings (*Martin* et al., 2008) as well. The results of mathematics and science studies conducted between 1995 and 2007 show that without a certain level of mathematics knowledge science literacy is unable to develop.

The results indicate that, in the 11 years between the first and the last project presented here, the aversive attitudes of students toward science subjects increased. All three studies showed a weak, in some sub-samples undetectable correlation between the application test and subject attitudes. In sub-samples created by subject attitudes, the difference in the achievements of those thinking positively about science and those rejecting it was very low, in some cases under the statistical margin of error. This means it hardly affects students’ knowledge application in everyday situations whether they like studying biology, physics, chemistry or any of their combinations.

The regional distribution of science knowledge application and its correlation with the mothers' education are different from other fields of knowledge (e.g. math or foreign language). The results here did not conform to the pattern of more developed regions and more educated mothers corresponding to higher achievement on the knowledge application test. The sub-samples based on regional distribution and mothers' education imply that other variables, which are traditionally not tapped in large scale studies, may too have an influence on the quality of science knowledge application. Factors connected to regional features, such as economic development, educational levels of the population, cultural and infrastructural characteristics seem to have a varied effect.

The correlation analyses show that in the measured application of science knowledge the development of inductive reasoning and complex problem solving skills play a significant role. The correlations of the inductive reasoning and the complex problem solving tests with the “*Természettudományos tudás alkalmazása*” (Science knowledge application) test suggest the strong influence of the recognition of analogies, rules, similarities, disparities and relationships just as that of the development of problem solving strategies. Consequently, in the design of instructional programs, problem solving strategies should also be included along with the presentation of a variety of learning contexts, experiences and the development of the given abilities.

The 2006 study, “*A közoktatás szerepe az élethosszig tartó tanulásra való felkészítésben*” (The role of public education in the preparation for lifelong learning) explored the role of non-cognitive factors as well. The analyses indicated the influence of self-confidence, and especially mathematical and academic self-concept on application achievement. Positive attitudes toward reading had a greater effect on student achievement than traditionally measured affective elements. This is well interpretable with some theoretical considerations. The students who like reading read more and therefore are more well-informed and likelier to meet certain pieces of information in various contexts. Consequently, they are more likely to acquire useful knowledge outside the school as well. As a result, it can be concluded that in designing instructional programs and in everyday teaching it is worth paying more attention to offering opportunities for gaining individual experiences in the classroom, for they provide a feeling of achievement and so contribute to confidence-building in solving previously unknown problems.

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The presented studies suggest that while pragmatic knowledge applicable in everyday situations is valued more and more internationally, Hungarian science instruction insists on an academic perspective and a disciplinary methodology. The results clearly show that – irrespective of the successful training of “little scholars” and the constantly well-performing participants of student olympics – science instruction fails to satisfy the needs of the majority of students. Since interest in science is decreasing and only a small minority chooses a profession connected to natural sciences, the theoretical, scientific knowledge offered by schools is highly irrelevant for the masses.

The research projects presented here were based on the emphatic role of context in knowledge acquisition and application. Additionally, they revealed that transfer and the connection of theory and practice are not automatic processes, for the acquisition of sophisticated theoretical knowledge does not necessarily involve applicable knowledge as well.

The findings suggest the necessity of forming a regular objective evaluation system that enables the measuring of various layers of knowledge. At present, the value system of Hungarian education is lacking essential constituents of knowledge, which results in the rejection of learning, especially of natural sciences, even by talented students. A more exciting and life-like school emphasizing the development of thinking and centred on relevant, up-to-date components of knowledge in its evaluation system could not only be more efficient, but it could make learning more attractive, too.

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