Thesis of Ph. D. dissertation

IMPROVING ANALOGICAL REASONING IN BIOLOGY TEACHING

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INTRODUCTION

In the last few decades the content of the knowledge-concept has gone through considerable changes. Content-knowledge and operational knowledge have received remarkable attention. Theoretical and empirical research have proved that acquisition and improving the abilities are equally important in the improvement of practical knowledge, which can be used in everyday life as well, so during school education a balance between these two must be reached. This integrating approach has also appeared in the knowledge-interpretation of the curricular conceptions.

It has been proven by our results, while analyzing the curriculum of biology, that central curriculums emphasize that teaching biology, as a subject should mean not only mediating knowledge, but that it should also improve thinking (especially systemizing), knowledge acquiring and study abilities. The following thinking operations are especially important: comparison, analysis, synthesis, generalization, classification, recognition of connections (especially recognition and understanding of causality), which are the fundamental components of analogical reasoning, in a wider sense of human cognition.

Our previous research studies, which examined the ontogenesis of fundamental biological concepts (*Nagy L-né*, 1999) have shown that one of the critical points of conceptual development is putting them in a system. Other research studies have also shown that conceptual development is largely influenced by the level of the individual's systemizing ability.

The aim of this research is to show the possibility of improving analogical reasoning in the biology subject with a complex thinking ability program integrated into the subject.

The thesis is divided into four chapters. In *Chapter 1* research studies on improving thinking abilities is discussed. Since this research field is comprehensive and complicated, only a brief description of the basic concepts and theoretical approaches will be presented. The intent of this research was not to analyze and compare them. In *Chapter 2* a detailed theoretical basis of the developing analogical reasoning, the interpretation and classification of analogies, the interpretation of analogical reasoning and its relation to other abilities, its components and development and the possible ways and strategies to improve it will be presented. *Chapter 3* will analyze the role of analogies in biology science and biology teaching. In this chapter the results of the analyses of analogies in our national biology textbooks will be presented. *Chapter 4* presents our program to improve analogical reasoning and discusses the results of testing it in an academic year in a longitudinal experiment. Finally, the possibilities of further development and practical application will be discussed.

RESEARCH ON IMPROVING THINKING ABILITIES

There are a lot of theoretical approaches towards human cognition and thinking. Previous research studies showed that the thinking action is a process; have revealed the relationships between certain phases and stages, and the macrostructure of the thinking process. Later research focused on the microstructure of the thinking process, and thinking operations. Researchers (e.g. *Lénárd*, 1987; *Nagy J.*, 2000) have developed different systems of thinking operations, which made planned, conscious development of thinking abilities possible.

These researchers have researched the general characteristics of development of cognitive abilities (e.g. logistic developmental curve, sensitive period, significant individual differences in the development), the differences between genders, and also the reasons for these differences (biological, cultural). They have developed theories of cognitive development, which are really varied, just like the sources of the limitations of development. The theorists have different perspectives about the role of nature (maturation) and education (learning, environment), the process of development (continuous or periodical/ stages), the nature of change (quantitative or qualitative), its characteristics (domain-general or domain-specific), and the process provoking change. The main theories on thinking include: cognitive development theory, following neo-Piagetian theories, Vygotsky's socio-historic theory, theories based on information processing paradigm, and constructivist development theories.

One of the most debated questions is the domain-general or domain-specific nature of thinking. According to the domain-specific hypothesis, knowledge is controlled by consistent principles, but they cannot be integrated into each other and the transfer between the topics is not possible. Thinking and within a specific topic differs from general forms of thinking and . According to most domain-general viewpoints some specific mental abilities do exist; however, they focus rather on higher order cognitive functions. Domain-specific views seem to be just the opposite. Supporters of this theory say that cognition has some domain-general forms, but the most essential activities, which happen in the mind, are modular. There have also been efforts to combine these two approaches (see e.g. *Ackermann*, 1998).

Research studies have shown that abilities can be improved only by exerting adequate activities. Factors – and most often their interaction – that basically influence the development and improvement of thinking abilities have been noted. These include: internal cognitive conditions (prior knowledge), affective conditions (e. g. motivation, interest, attitudes etc.), and external factors (e. g. characteristics of education, school, family, home etc.) (*Csapó*, 1992).

A lesson can be one of the most important organizational framework for improving abilities and mediation of knowledge (e.g. *Csapó*, 1987, *Lénárd*, 1982). Subject matters constructed in activity systems are most suitable for this purpose. It should not be forgotten that improving abilities requires a long, time-consuming process and pedagogical concern.

The differences in theoretical starting points have resulted in creating varied developing programs (see e.g. *Csapó*, 2003). Special programs, which use direct either formal or content-conscious strategies, have become widespread in different countries; throughout Hungary we can find examples mostly for the latter.

Guidelines for effective thinking-development programs (level of cognitive function, student's cognitive level, age, learning and teaching styles, general principles of training, selection of tasks) (e.g. *Gordon Győri*, 2001) and factors which influence the success of these programs (period, frequency, concrete preparation, adequate teaching methods, advantageous learning environment, feedback, evaluation, etc.) have been revealed in a number of works (e.g. *Hamers* and *Overtoom*, 2000). They have worked out the measuring tools suitable for numerical description of the effects (e.g. effect size) (e.g. *Adey* and *Shayer*, 1994; *Adey, Robertson* and *Venville*, 2002). With this help the efficiency of different programs can be measured.

Researchers also agree that thinking is a holistic process and can only be broken down artificially into different research and analyzing fields. Many authors contrast the two types of thinking (e.g. deductive/inductive); however, this is a simplification of the problem. When solving a task, one usually needs both types of thinking. Deductive reasoning and inductive reasoning are two of the thinking strategies that have attracted the attention of developmentalists. A component of the latter is the development of analogical reasoning, which has become an independent research field.

THEORETICAL BACKGROUNDS OF TRAINING ANALOGICAL REASONING

In literature analogical reasoning plays an important role in education and in the cognition of analogies (in the construction of new schemas, in developing new knowledge, and in promoting conceptual change).

Human reasoning is basically analogical (*Halford*, 1992); every new phenomenon is interpreted with the help of existing analogies containing cognitive structures. Even in the case of understanding directly experienced phenomena, we look for functional similarities with our existing knowledge. (*Holyoak*, 1984). This type of thinking influences most other fields of cognition helps understanding, conceptual acquisition, and problem solving (*Holyoak* and *Nisbett*, 1988; *Stepich* and *Newby*, 1988). Analogies can be found in scientific and everyday thinking as well; they appeared very early during ontogenesis. There can be different ways for the interpretation of analogies. An analogy can be described as a thinking operation, a way of the thinking, as one of the thinking mechanisms, structure-mapping, as one of kind of the similarity, as means and method of teaching. Analogies can be classified in various ways but the aspects of classification are often not mentioned. In this thesis the classification of analogies from different aspects is attempted. Metaphors are often mentioned with analogies. Some authors regard them equal with analogies while others identify metaphors as types of analogies. There is a long list of studies dealing with analogies as educational means of helping the learning process; most research studies use information processing paradigm as a frame (e.g. *Stepich* and *Newby*, 1988).

Although a lot is known about analogical reasoning processes, their more exact exploration and understanding needs further research, as in questions like information processing in analogy thinking. Researchers have different, sometimes opposite views and they have worked out several alternative theoretical models of thinking. The full understanding of the processes of analogical transfer requires the examination of a number of other fields.

Analogical reasoning, in a wider sense, can be interpreted as reasoning based on similarity (*Good*, 1981), or as reasoning about similarity relations among elements, in the narrow sense (*Rosser*, 1994). Similarity relation can relate to terms, figures, stories, systems, and problems. It has a number of types (for example belonging to a set, part-whole, chronological order, causal relation, opposite, synonym, functional relation, transformation, place, and belonging to the same set, functional part-whole) (*Csapó*, 1994a).

The essence of analogical reasoning is identification and transfer of related structures from a well-known system (from the base) to a less well-known system (to the target) (*Vosniadou*, 1995). When learning through analogies, it is very important that analogical relations are generally based on a symmetric relationship between base and target, so they may provide the possibility for simultaneous development of base and target, a process of “piggy-backing”. This is significant because it often happens that the base is equally unfamiliar to students (*Duit, Roth, Komorek* and *Wilbers*, 2001).

There are several types of tasks applied for the measuring of analogical reasoning (verbal analogies: multiple-choice and free association, geometric analogies, number analogies, sentence-completion and picture-completion tasks, problem analogies, metaphors). To measure domain-specific analogical reasoning verbal analogies are used which contain special phrases from a special field of knowledge (*Alexander* and *Murphy*, 1999).

Some research studies (e.g. *Goswami*, 1991) have found that, quite young children (already at the age of three) have an early competence of analogical reasoning. It has been proven that this early competence of analogical reasoning is influenced by a knowledge effect. It has been stated that we understand quite early the conceptual knowledge referring to working of the inanimate things, and analogical reasoning can be detected on these contents. The factors of progress in analogical reasoning and also the factors which determine its efficiency have been examined and it has been found that age influences performances. Older children often performed better; they were able to show analogical reasoning in several tasks compared to younger ones; and only they could recognize the higher order relations and use their explicit knowledge in their thinking strategies. Younger children may need more "hints" than older ones to facilitate generalization. The developmental shift in development of analogical reasoning happens at around the age of 12. The findings have been supported by research examining information processing inspired by Piaget. Young children often prefer thematic grouping to other forms of relationships. Insufficient knowledge, however, could constrain correct responding, facilitating a thematic choice as a fallback strategy (*Goswami*, 1991). Quality change is the result of domain-general cognitive processes. The analogical reasoning of the young is a domain-specific process determined by conceptual knowledge, and can only be applied in a certain group. In many research the children's knowledge was not checked, and it was not evaluated separately from thinking ability. Separating domain-general cognitive functioning from domain-specific one in development research is not an easy task, and they have not yet been clearly separated in measuring analogical reasoning (*Rosser*, 1994).

The results show that there are individual differences in analogical reasoning. The knowledge effects can give good explanations to individual differences in successful task-solving, as a function of expertise referring to task-content. Ontological knowledge – which gives the frame of conceptual knowledge, organizes and explains domain-specific theories and phenomena – is very important (*Rosser*, 1994).

It has been shown that the understanding of metaphors can be hindered by the lack of domain-specific knowledge. Furthermore, the solving of domain-specific problems does not only require adequate cognitive processes but also domain-specific knowledge. In addition, the performance of analogical reasoning depends on the task, the context and the situation (*Rosser*, 1994).

The results of empirical research show that analogical reasoning can be taught and should be regarded as an ability, which can be improved (e.g. *Antonietti*, 2001; *Csapó*, 1999a, 1999b). It has been proven that the subject material, learning and quality teaching has a developing effect.

We can help children to find relations between different things and phenomena with synectics, computerized teaching methods, solving proportional analogies, search and use of similarities, transferring ideas, with analogies integrated into the textbooks and with teaching explanations, association games, questions.

It is well-known that analogies are an integral and organic part of biology and biology education (*Venville* and *Treagust*, 1997). In this thesis this has been shown through examples. There are two important fields of the use of analogies in teaching biology: (1) using them in textbooks, and (2) using them in lecture and classroom explanations. Researchers have drawn our attention to the findings that in both fields the use of analogies requires careful planning and consideration. They have also revealed the problems, which might occur in biology textbooks in connection with analogies and described the effective use of analogies in classrooms. (*Stepich* and *Newby*, 1988; *Thiele, Venville* and *Treagust*, 1995; *Venville* and *Treagust*, 1997). It seems that by following FAR (Focus, Action and Reflection) guidelines and using a systematic structure the potential benefits of analogies used in biology education can be exploited.

The analysis of our biology textbooks has shown that our textbooks contain a lot of analogies although the average number of analogies per textbook ranges considerably. The results of categorization from the aspects of the type of analogical relationships, presentation format and condition are similar to that of foreign textbook-analysis. In foreign science textbooks analogies dominate as advance organizers, while in the national textbooks they appear as post synthesizers. In our biology textbooks we could find analogy types (e.g. pictorial analogy, abstract/concrete analogy) that are not present in foreign textbooks. Simple analogies can be found in great numbers in our textbooks while foreign textbooks contain a great number of enriched analogies. Because of the great number of simple analogies, fewer amounts of vehicle explanations is necessary in our textbooks, but we can detect description of strategy identification because of the great number of post synthesizer tasks. Post synthesizer analogy tasks are especially significant in improving thinking abilities. The differences between the use of analogies in foreign and national textbooks show the national tradition as well (*Curtis* and *Reigeluth*, 1984).

AIMS AND HYPOTHESES OF THE RESEARCH

The aim was to study the effect of a thinking-development program integrated in the biology subject on the mental capacity and analogical (inductive) reasoning of 13-14-year-old students in normal classroom settings.

As the basis of analogical reasoning is the recognition and use of relations between things, concepts, and information, we aimed to develop with the possible means (textbook analogies, classroom analogies, tasks based on comparison, problem-tasks, and test-analogies) the students' comparison-based thinking. According with the curricular purposes of biology teaching, we aimed the recognition and use of relationships in analogical reasoning and the creation of relationships between different contents i.e. school and everyday problem situations.

Taking into consideration the above during the period of the experiment we could measure the development in the recognition and use of analogical relationships with the help of verbal analogy tasks.

The hypotheses were the following:

- *The hypothesis of the program's developmental effect*

Thinking abilities can be improved (with tasks based on analogies, comparison, recognition and application of relationships, concretization and generalization, etc.) in biology teaching in an integrated and complex way.

Teaching according to the program does not only develop thinking operations, but also helps subject's understanding and deeper acquisition.

- *The hypothesis according to different improving of students with different genders and prior-knowledge*

We expected that the thinking development program would show different degrees of development in the case of boys and girls, students with less or more prior knowledge, less successful and successful students.

- *Hypotheses of the positive effect on attitudes*

It has been proven that cognitive performance depends on students' attitude (e.g. *White*, 1988) in this case, on the attitude towards biology as a subject, and the interesting tasks, which motivate students, might result in a more positive attitude towards the subject. It is supposed that in the experimental classes the students' attitude towards biology as a subject and towards the school in a positive change or at least does not change for the worse.

- *The hypothesis of domain-specific effect*

Topics (content) – general knowledge or biology – influences the student's cognitive performance.

- *The hypothesis relating to role of the context and situation*

Several studies have dealt with cognitive performance based on context and situation (e.g. *Butterworth*, 1993). The students show different performances in tasks using the same thinking operations in different context.

METHODS

The sample

The experiment was carried out in 7 primary schools in 16 classes (students aged 14) (7 experimental, 9 control) in, and around Szeged, Hungary. The sample, based on the local area, can be considered representative. On the national level the sample can be considered representative because of previous experiments in and around Szeged, which measured students' performance on knowledge and abilities tests. These earlier experiments' results did not differ to a great extent from the national average. This way Szeged and its immediate surroundings characterize the teaching practice and pedagogical culture in Hungary; it is a so-called cultural unit. In the sample there were 405 14-year-old students (185 experimental, 220 control) boys and girls were approximately equal in number in the survey.

Analyzing the sample from the point of view of educational and background factors (e.g. parents' qualification, students' grades, school results, their attitude towards subjects and the school), we can say that they are almost the same in most conditions except for the experimental condition.

Design of experiment

The effect of teaching can be examined according to the development program on the students' level of thinking, level of subject knowledge, and attitude with experimental/control pre-test, post-test experimental design. The developing effect can be measured if the degree of thinking abilities we want to develop and the acquisition of the subject at the beginning of the school year (pre-test) and at the end of the school-year (post-test) is measured and this development in experimental and control groups is compared. We must take into consideration that learning and teaching is a rather complicated multi-factor process and it is very difficult (almost impossible) to pick out the role of one factor. We can say it is proven with statistical methods that the difference between the two groups is the result of the factor used in the experimental group.

In experimental classes in biology lessons, instruction was according to the intervention program for six months, while in control class's students received the regular instruction. The measures were implemented immediately before and after the intervention program.

The instruments of the research

During the experiment three types of paper and pencil tests and a background questionnaire were applied. Pre- and post-tests assessed inductive, analogical reasoning, and biology subject knowledge of students.

To examine inductive reasoning we used the *Inductive reasoning test*, which has already been used in a number of studies (*Csapó*, 1994b, 1998). This test consists of three sub-tests: (1) number analogies, (2) verbal analogies, and (3) number series. The first two examine analogical reasoning with analogy pairs in domain-general content.

For measuring analogical reasoning on domain- and curriculum-specific content a *Biology analogy test* was used which had been devised for the present study and consisted of 28 multiple choice A : B :: C :? type biology verbal analogy tasks selected to cover the pre-knowledge and the subject matter of a concrete topic of biology (The build and the function of the human body). *Biology analogy tests*, which were used in pre- and post-measuring, included "chain-tasks" or "bridge-tasks". These tasks were either totally identical in the two tests or were similar only in the first or second analogy pair. This test-constructional process helped to assess more reliable measure of development.

For measuring the understanding of biology subject matter (in pre-measuring the previous knowledge and in post-measuring the subject matter, which was taught during the experiment) traditional question-answer and multiple-choice biology knowledge tests were used. The content of *Biology knowledge tests* are identical with the content of the *Biology analogy tests*.

The above-mentioned instruments were completed by a background questionnaire (*Csapó*, 1998) about the students' school achievements, grades, attitude towards the subject and their parents' school achievements. This way the relationships between the test results and background factors list above could be examined. This complementary information helped more discrimately analyze the results, answer the occurring questions and explain reasons.

THE INTERVENTION

Preparing the intervention program, the aims and requirements of biology subject were taken into consideration; the concept structure of the subject material was worked out; and, the analogies of the textbooks were analyzed. After considering the operations of analogical reasoning the ”curriculum of thinking" was worked out, that is we combined biology content with the thinking operations to be developed by adequate activities. They were the bases for the developing tasks, the auxiliary materials for teachers and students.

The aims, the theoretical background, the didactic principles, the contents and the activities of the intervention program were described in detail and the structure and task-types of the auxiliary materials were shown.

Instruction according to the intervention program meant regular but at the same time free and flexible use of the teachers' and students' auxiliary material.

MOST IMPORTANT RESULTS OF RESEARCH

Comparing effect sizes and achievements on the tests in experimental and control groups it was concluded that the use of curriculum- and subject-specific intervention program may contribute to the development of the operations of analogical reasoning and at the same time to a deeper knowledge of biology subject matter. The effect size based on statistics is satisfactory. Histograms of scores of the different tests and the results of bridge-tasks of *Biology analogy tests* confirm these results.

On class level the results of the program have shown differences, which is the natural effect of the complicated multi-factor teaching and learning process. With increasing the number of experimental and control groups these effects can be reduced or eliminated.

It has been proven that the results of the intervention program is basically influenced by the initial level of the ability and knowledge to be developed; however in some cases the plateau-effect must be taken into consideration and in some cases the gain-score originating from the repeated tests might be a limiting factor as well. The research has confirmed the importance of domain-specific previous knowledge in the results of the *Biology knowledge tests* and explains the differences in test performances among students of the same age group.

In normal classroom settings the program had different effects on boys and girls, students with high and low previous knowledge, successful and less successful students. During one year of experiment boys and less successful students showed a greater degree of development; however a positive effect on successful students can be detected as well especially in *Number analogies* and *Biology knowledge tests*. The results of the survey have drawn our attention to the biopsychological differences between girls and boys in instruction and education. However, if we look at the total results it can be seen that generally gender does not play an important role in test performances, which can be seen on international level as well. Girls have slightly better test performances than boys, with the exception of *Number analogies sub-test* in pre-test.

This study has not been able to prove the program's positive effect on the attitudes towards biology subject with statistics. However, we suggest that the results indicate that those students not in the control groups did not appear to have a more negative attitude toward the biology subject than those in the control group. It is also a success, that there have been positive changes in the proportion belonging to certain attitude-categories during the year of experiment.

The experiment has shown the changing nature of cognitive performance influenced by content and task-context. The results have shown that students identify and transfer more difficult types of relationship (belonging to set, causal relation, transformation, belonging to the same set) through domain-general content. Through biology subject content other types of relationships (chronological order, opposite, functional part-whole) especially relationships determined as the aim of biology subject were identified and transferred.

We have found significant differences in the identification and application of the subtypes of relationships. In domain-general content naming the part, while in biology subject content naming the whole proved to be quite difficult. Independently of the content naming lower order concepts proved to be more difficult than naming higher order concepts, and naming the later proved to be more difficult than naming the former state. Through distractor analysis of *Verbal analogies sub-test* and *Biology analogy test* we could identify four types of faults independently of the content: (1) preferring the already known relationships, (2) uncertain knowledge, (3) wrong identification and/or application of relationships (4) lack of concretion. Hierarchical cluster analysis of the tasks seems to confirm the results of the above examinations: tasks do not belong closely together on the basis of analogical relationships (thinking operations).

When tasks were clarified measuring knowledge according to different topics of the biology subject, the results found differences, as well. This indicated that performance was also influenced by the difference in content within a specific content. Cluster analysis of *Biology knowledge tests* has shown that tasks may belong together on the basis of different aspects (content, level of application and abstraction, thinking operations, type of task). When the results of the experimental and control group were examined separately, it was learned that in the experimental group tasks in post-tests belonged together on the basis of thinking operations, while in the control group they belonged together on the basis of the theme or the level of abstraction. Error-oriented analysis of *Biology knowledge tests* has shown that students have made the same mistakes in and committed similar operational mistakes as in the case of verbal analogies tasks measuring analogical reasoning.

This study has examined performances on tests with the same biological content and the same thinking operations but different types of tasks (verbal analogies or traditional knowledge tasks). Students performed better in the case of chronological order, opposite, functional relation in verbal analogy tasks while in the traditional knowledge tasks students performed better in belonging to set, causal relation, synonym, transformation, and belonging to the same set. A significant difference in performance could not be detected in the case of part-whole, place, and functional part-whole types of relationships in the two types of task-context. Identification and application of functional part-whole relationship proved to be the most difficult type in both task-contexts because of its complexity.

Correlation calculation and regression analysis of the test results confirmed that analogical reasoning is a generalized component of reasoning and besides domain-general characteristics it has a number of domain-specific characteristics. The conceptual knowledge, the elaboration and the level of the development of a specific topic can limit the development of both domain-specific and general analogical reasoning ability. Furthermore, the results have shown that content, task-context, and thinking operation applied in the tasks play an important role in achievements on the tests.

The results of correlation measuring between test results and background variables (parents' qualification, school achievement, grades of subjects, attitudes to subjects) prove that there are significant correlations. Correlation between test results and parents' qualification and students' attitude towards biology subject was not too strong, not as in the case of school achievement and grades of subjects, where the existence of a strong relationship could be shown. The empirical survey has shown the critical points of analogical reasoning (recognition and application of relation types) among 14-year-old students, the lack of their general and biology vocabulary, the characteristics and lack of their biology knowledge; thus as a result the objectives of biology education can be stated.

SUMMARY

Theoretical results and further research problems

The results of the research showed that a thinking development program integrated in the subject material in accordance with the biology subject domain- and curriculum-specific aims in normal classroom settings is able to influence positively the development of thinking ability or subject knowledge. The effect of this kind of program plays an important role in understanding, acquisition and use of the subject material.

The main theoretical outcome of the experiment is that it has worked out a system, a model, which in normal classroom settings is not only able to realize the aims of the subject, deepen subject knowledge, but also develop thinking abilities. It has shown how we can work out a program developing abilities on the basis of the curriculum's goals and requirements, and tasks based on the subject material. Revealing the concepts of the biology subject in the 8th class the concrete activities combined with the elements of the subject and the thinking operations might pave the way to the curriculum of thinking in biology subject.

It should be noted that when planning the experiment, we relied on auxiliary materials (e.g. textbooks) as auxiliary materials developing thinking. In addition to the students acquiring a deeper knowledge of the subject, the development of thinking skills could be achieved through the planned use of the available auxiliary materials for students and teachers (textbooks, workbooks, tests, problems, etc.). Future planning should include introducing these materials to teachers and helping them to implement them in their classrooms.

The experiment's preparatory work included: detecting and analyzing analogies in the existing biology textbooks. Analyzing textbooks according to this point of view may contribute to enriching coursebook-analyzing concepts, qualifying textbooks according to didactical point of view and finally to developing textbooks. A further task can be analyzing workbooks and other auxiliary materials from this point of view. The purposive use of the present educational materials could be the simplest and most cost effective way of developing abilities.

The results have indicated the importance for educators to make students aware of the characteristics of the applied thinking strategies, and operations of thinking (metacognition).

During the research study teachers received minimum instruction in the experimental groups. Our experiences show that with a more intensive theoretical and practical training for teachers – including different areas of developing abilities – better results can be achieved in the development of abilities. These types of teachers' training programs are essential and necessary.

During teachers' training meta-knowledge and methods of mediating meta-knowledge should be emphasized.

The tests that were developed and used in the experimental program are important from a theoretical point of view as well, especially in the case of tests measuring curriculum and domain-specific analogy thinking.

Boys and girls showed different intensity of development in the program; the results of this study indicated the effect appears to be more significant for boys. This experimental result again draws our attention to the difference between boys and girls, and suggests that we should consider applying subject matter and teaching methods considering this difference.

The use of the thinking development program in normal classroom settings is confirmed by the experience that it had a positive effect on students with both less and more previous knowledge, less successful and successful students; though it had a greater effect on the earlier. The program is suitable for instructing students with different abilities and because of its complexity, gives a certain freedom to both teachers and students.

The experimental program has had a number of results, which might help arrange similar further experiments. For example, despite the fact that the so called test-analogies were only a small part of the development program, and were used only as alternative tests, when assessing the results, we have to take into consideration the effects derived from their solutions. We can conclude that for measuring the degree of development of abilities different types of tests should be used.

The questions of domain-general and domain-specific development are the most important ones in research studies dealing with developing abilities. The results may help answer the following questions: What may result in terms of learning outcomes by using different approaches in teaching? How do these approaches influence learning and experiments examining knowledge?

A further research can be a repeated test of the intervention program to see its long-term effects and examining different transfers. It is also possible to work out similar intervention programs in other science subjects, and to examine the degree of development in thinking abilities with the simultaneous use of programs in different subjects. It seems practical to supplement the instruments with a general and a biology subject vocabulary test so that we could place our results in a wider context, and that we could show more relations.

Practical application of research results

The aims of school education and teaching different subjects are the following: develop the student's personality, the acquisition of adequate quality and quantity of subject knowledge and developing abilities, which make this acquisition possible. The best is when these three aims all appear in a lesson. Any thinking development should be built in a lesson in a way that it does not limit the acquisition of knowledge (the quantity of knowledge), but it should help understanding, acquisition, and its application in different situations.

To achieve the above aims we have worked out an experimental intervention program in the biology subject in a specified topic. A similar development is possible in most subjects. To transfer this experimental intervention program to other academic subjects, there needs to be an analysis of subject aims, etc. The "curriculum of thinking" with some critical analysis can be modified and adapted to other subjects. Of course, the specialities of different subjects must be taken into consideration.

Improving analogical thinking ability is very important. An initial specialized literature review, prior to beginning this research, further supported the need to improve thinking skills in all subjects.

The analogical thinking of students with different previous knowledge can be developed to a different extent in lessons. As our results have proven students with high or medium level knowledge can be improved to a greater extent than the ones with very low abilities. The research has proven that students', especially boys, interest towards biology subject material, subject and learning can be increased with interesting and demanding tasks. Furthermore it draws attention to the necessity of differentiation in a lesson.

The tasks and exercises of the intervention program can be used directly in a lesson and they can be integrated into lessons, textbooks, and workbooks. This way the auxiliary materials' effect on improving thinking abilities can be enlarged besides deepening subject knowledge.

Presenting in our experiment from one perspective the lack of quality characteristics in biology knowledge (organization, depth of understanding, applicability and from another perspective the characteristics of analogical thinking in the biology subject may be instructive in teaching biology. Concerning the results, the objectives of biology education have been formulated with the goal of contributing to increasing the standards of biology education, regenerating and modernizing methods and concepts.

Several competitions have helped our work. *OTKA T030555* has helped printing auxiliary materials, arranging school experiments. *OTKA U041081*, *MEC-00622/2002, KOMA XXIX/026, Oktatáselméleti Kutatócsoport* have helped arranging the intervention program and demonstrating the results in national and international conferences. The infrastructure of *SZTE-MTA Képességkutató Csoport* was used.

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