Research Paper

Hungarian students' success rate, problem-solving strategy and knowledge structure in the problem of the shifting between the macro- and sub-microscopic levels

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Abstract

Recent research focuses on relationship between students' knowledge structure and problem-solving strategy in numerical chemical problem containing two different levels (macro- and the sub-microscopic or particulate levels). In the written test are one complex problem, which require the shifting between two different descriptions of the material systems, between the macro- and sub-microscopic levels and two simple problems similar to the steps of two solving pathways for solving the complex problem. Based on the strategy used in solving the complex problem students (N = 1160, graders 7-10) were divided into three groups: (1) "stepwise" solving pathway group; (2) "consolidated" solving pathway group; and (3) others (unidentified strategy or no strategy). Strategies were used by only a small part of the student groups (15-40%) to solve the joined item. The students reach the greater success (80%) using the "stepwise" method. The knowledge structure characteristic of each group was determined by using knowledge space theory. The level shifting between the two levels (macro- and sub-microscopic levels) is the determining step in all grades.

Keywords: education, science, chemistry, knowledge space theory, knowledge structure, problem-solving, numerical chemical calculations, problem-solving strategy, chemical concept, macro- and sub-microscopic or particulate level

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Introduction

One of the reasons of the chemistry's difficulty can be found its characteristic definition system. More research deals with comprehension difficulties and misconceptions related to the students' atomic concept (Lee et al., 1993; Harrison & Treagust, 1996; Taber, 2002; Cokelez & Dumont, 2005; Tóth & Ludányi 2007; Tóth & Kiss, 2009) and with issues and difficulties in the teaching of atomic concept (Tsaparlis, 1997; Toomey et al., 2001; Nelson, 2002, 2003; Tsaparlis & Papaphotis, 2002).

Typical property of the chemical definitions is the multi-level meaning. The chemical definitions can be interpreted on macro level (on the level of the perceptible reality), on sub-microscopic or particulate level (can not be perceptible by sense organs) and on symbolic level (level of the special notation of the chemistry). Simultaneous applying of the three levels occurs many problems, which happens in case of the chemical symbols and formula, the characteristic chemical symbol system. Qualitative and quantitative meanings of this symbol system are explained by the schoolbooks simultaneously on macro- and sub-microscopic levels in the grade 7 of the elementary school. For example the Mg chemical symbol means the magnesium element (macroscopic level) and the magnesium atom (sub-microscopic level) as well. Furthermore Mg means 24.0 g magnesium, 1 mole magnesium atoms on macro level and 6.00 x 1023 magnesium atoms on sub-microscopic level.

In the development of the material concept is a dominant step to understand that the materials consist of particles. Without understanding it is impossible to learn several chemical concepts (e.g. chemical reactions) (Lee et al., 1993; AAAS, 2001). The teaching of the sub-microscopic model has already started in the 7th grade. The students establish the perceptible macroscopic properties of the material using their sense organs. In this school year they are interested in details the structures of the atoms, ions and molecules. The atom structure seems to be far from the ordinary life, because in the world of the atoms and molecules there are very different scales compare to the world of the sense-perceptible things. They become acquainted with an abstract and invisible word, the world of particles. The students need to make connection between a sub-microscopic and a macroscopic world and they need to substitute the structure-connected continuous model with the particulate model. A group of researchers say, that the chemical particles should be taught in detail at the end of high school chemistry education, because previously only very few students able to create the right picture about these concepts (Taber, 2002; Wright, 2005).

The sub-microscopic model is used by the science in order to describe and interpret the materials and the transformation of the materials. The model contains the unique properties of the material-building particles and the characteristic interactions between them. The students for projecting the macroscopic properties to the particles use the particulate model. These particles are used to interpret the transformation and the properties of the materials (Taber, 2002).

The aim of this study

The goal of this study was to measure the chemical problems, which require the shifting between two different descriptions of the material systems, between the macro- and sub-microscopic levels. Changes in typical knowledge structures of different grade student groups were characterized by different chemical problems.

Responses were looking for these questions:

1. Which possible solving pathway was applied by the students in order to solve the complex problem?
2. Is there any verifiable difference between the efficiency of the different solving pathways' users?
3. How can the mentality of the students organize the knowledge, which is required to solve a chemical problem? This problem requires a shifting between the macro- and sub-microscopic levels.
4. What kind of knowledge structure can characterize the knowledge system of the students in different grades?
5. How the typical knowledge structure of the student groups can be formed using different solving pathways?

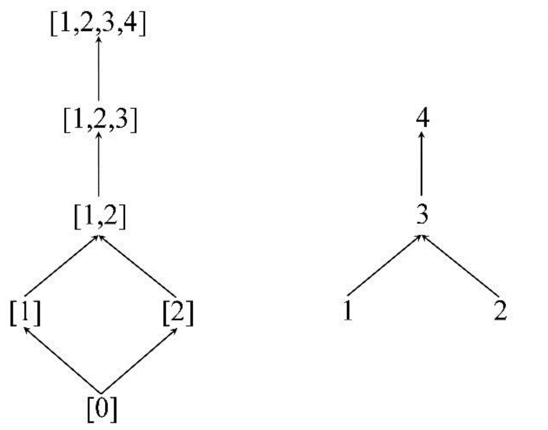
Background

Foundation and application of the knowledge space theory (KST), establishment of the knowledge structure

Study of the knowledge structure, the knowledge organization is basically important to clear up the impact of different factors to the efficiency of teaching-learning process. This can be carried out by the structural analysis of the students' answers. Structural analysis can be performed by the evaluations of different surveys as well as traditional statistical methods (Taagepera et al., 1997; Doignon & Falmagne, 1999; Tóth, 2007).

The organization of the knowledge is characterized by a well-graded knowledge space in the knowledge space theory (KST), which is a multi-dimensional model. This method has already been used to investigate the knowledge structure of a population. The knowledge space is all the necessary knowledge to understand a topic or a subject. Each student has a knowledge state including all of the answerable items. For example: [1,2,3]: the student could solve the problems No. 1, 2 and 3. The knowledge structure is all of the knowledge states, which are typical of a group. These knowledge states are parts of a hierarchical net, so-called Hasse-diagram. The base hypothesis of the knowledge space theory: If the student can solve a problem from a higher level of the hierarchy, then problems below this level will be solved as well. Hasse-diagram (Figure. 1) can be interpreted as follows: if the student can solve the problem No. 3, then he will possess the knowledge which solves the problems No. 1 and 2. It is necessary to know the knowledge elements of the problems No. 1 and 2 in order to solve the problem No. 3.

Figure 1. Relationship between the knowledge structure and the Hasse-diagram



The KST is suitable for individual analysis, for survey of students' knowledge statement, for definition of student groups' typical knowledge statement i.e. collective analysis.

Professional hierarchy of the problems being in the same knowledge space can be assigned by the base hypothesis, and the professional knowledge structure can be clarified. The most likely knowledge states (problems, which can be solved by the student) of the students can be established by the acquaintance with the knowledge structure. The knowledge structure can help to recognize, that the students are prepared to receive what kind of new knowledge. Typical knowledge structure of a student group can be determined by the basic hypothesis of the KST considering the instability of the knowledge (deforming effects of a lucky-guess and a careless error).

Effects of different factors (teaching and solving methods, gender and age) to the changing of the knowledge structure can be studied by the exploration of typical knowledge structure of the student groups. The typical learning pathway, which is a typical order of learning in a knowledge space, can be hunted by the knowledge structure. The most likely model of the knowledge organization so-called the most characteristic item hierarchy can be created by the knowledge structure as well. The analysis of the knowledge structure of the student group, the typical learning pathway and the knowledge structure modeling item hierarchy give opportunity to study the changes of the knowledge structure and the knowledge organization. The results can be compared to other student groups' and professionals' as well. The most critical problems and definitions of the knowledge space can be established by the professional knowledge- and the answer structure. The most members of the student groups have the crucial pre-knowledge to acquire them.

Relationship between the macro- and the sub-microscopic levels in the chemical calculations

Problems, originating from the connection between the macro- and sub-microscopic levels, appear in many field of the chemistry, including the calculation exercises. Two different levels can appear in the numeric exercises within a problem. The students need to distinguish and make connection at the same time between the quantities of the macro- and sub-microscopic levels. This makes trouble for many students. The students can not perceive the difference between the macro- and sub-microscopic level properties. The difficulty of shifting from the macro level (mass, volume, amount of substance) to the sub-microscopic level (particle number) in case of 1st semester university students certified by an earlier study. The aim of this study was to find the difficult knowledge elements in the calculation problems, which request shifting between the macro- and the sub-microscopic levels. Furthermore discovery and analysis of the knowledge structure, containing these knowledge elements, was executed and compared in circumstance of different student groups.

Research methodology

Instruments and subjects

A widely survey conducted in school year 2005/2006 in 42 Hungarian elementary and high school of 20 different townships. The total number of students involved in this survey was 1160 from the grade 7 to 10 (7th graders: 192, 8th graders: 198, 9th graders: 408, 10th graders: 362).

Self made, open-ended items containing written test was used in this survey. The survey contains four simple and four multiple items. The four simple items are the elemental steps of the four multiple items. The simple items are in connections with the knowledge elements. These elements are parts of the multiple item solving strategy. The worksheets were filled out during the lessons with the supervising of a subject teacher.

In this research three items were evaluate from the measured survey. Problems to be solved are following:

1. How much amount of substance is 48.0 g magnesium? MM
2. How many atoms are being contained by 2.00 mole magnesium atoms? MP
3. How many atoms are being contained by 6.00 g magnesium atoms? MMP

In the first problem (so-called MM) connection should be made between two macro level amounts (mass → amount of substance). There is a shifting from the macro level to the sub-microscopic level or particulate level (amount of substance → particle number) in the second problem (MP). The third item (MMP) is a multiple item, consists of two elementary steps. These steps appear as the first and second items before.

The solving pathways of the complex problem classified the student groups. The complex problem is as follows: How many atoms are being contained by 6.00 g magnesium atoms? There are two different solving pathways:

1. The problem can be solved using "stepwise" method as the solving pathway No. 1. The problem is solved according to two single steps and the second step is the shifting between the levels (mass → amount of substance → particle number).

2. Solving pathway No. 2 applies "consolidated" problem solving method. Connections between the macro- and sub-microscopic level can be realized in one single step (mass → particle number).

For the statistical analysis we used EXCEL and SPSS softwares, and knowledge structure characteristic of each group was determined by using knowledge space theory.

Results and discussions

Frequency and success rate of different problem-solving pathways

Analyzing of the surveys put the results together. The success rates were measured in case of each item. The performances of different groups using different solving pathways were compared by statistical analysis.

Figure 2 shows the success rate of the 7th-10th graders. Points 0, 1 and 2 rated the solving of the items. The perfect solving was worth 2 points; the students got 1 point for a partial solution. Naturally they got 0 point without any solving. 60-70 % of the students can solve the easiest problem, which does not require shifting between the levels. The complex problem is the most complicated item; only 30-40 % of the students can solve this problem. The performance is increasing with the increasing grade of the students. The data of the success rate is significant lower in the 7th grade compare to the other grades (Table 1.). All four grades are working with the success rate 45-50 % in case of the "level-shifting" problem, so there is no significant difference between the grades (Table 1). In case of the consolidated problem there is a well-marked week performance in the 7th grade. Only 10 % of the students can solve the problem. It can be generally explained by the fact, that the 7th graders have not already learned this kind of item. In the other hand the 7th graders can separately solve the other two problems, but they are not able to connect them. The connection requires a kind of ability and they do not have it.

Figure 2. Success rates of the 7th-10th graders

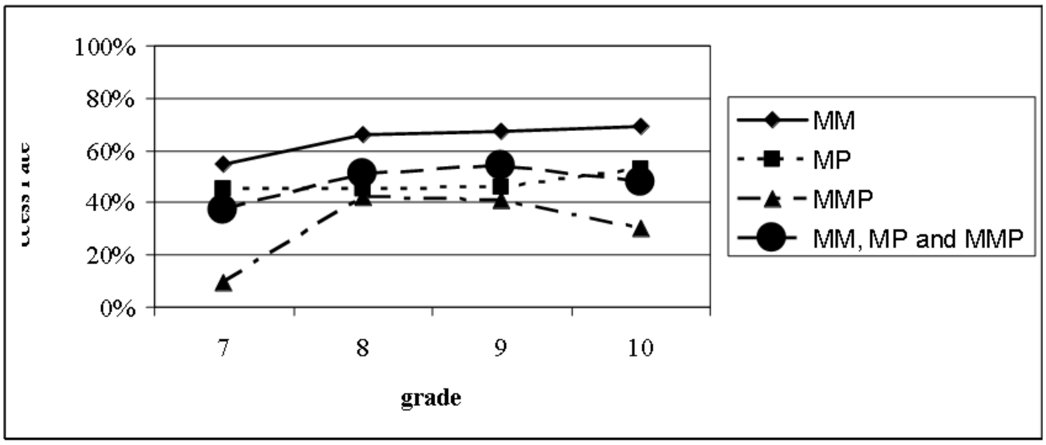


Table 1. Significance levels for three problems

Problem 1 – MM	grade 7	grade 8	grade 9	grade 10
grade 7	–	0.090	**0.022***	**0.005***
grade 8	0.090	–	0.999	0.909
grade 9	**0.022***	0.999	–	0.927
grade 10	**0.005***	0.909	0.923	–

Problem 2 – MP	grade 7	grade 8	grade 9	grade 10
grade 7	–	1.000	0.247	0.995
grade 8	1.000	–	0.203	0.988
grade 9	0.247	0.203	–	0.209
grade 10	0.995	0.988	0.209	–

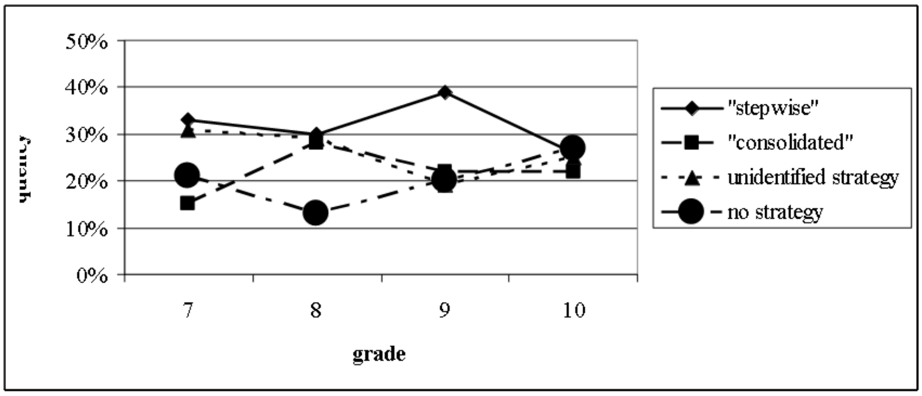
Problem 3 – MMP	grade 7	grade 8	grade 9	grade 10
grade 7	–	**0.000***	**0.000***	**0.000***
grade 8	**0.000***	–	0.938	**0.004***
grade 9	**0.000***	0.938	–	**0.004***
grade 10	**0.000***	**0.004***	**0.004***	–

*The mean difference is significant at the 0.05 level.

The student groups are classified by the complex problem. They can solve the item in two pathways: "stepwise" or "consolidated". Of course some students were not able to solve the problem, and some answer was not identifiable. The classified groups are: "stepwise", "consolidated", unidentified strategy and no strategy.

On Figure 3 can be seen the frequency of the above-mentioned solving pathways in concerning of the complex problem for all grades. Small group, 15-40 % of the students use one of the solving pathways. The complex problem is the most characteristic in the grade 8. This solving method requires the prescribing of the direct proportion. The stepwise method was preferred in the 9th grade. The students use the conception of the mole during the solving of this method. Compare to the other grades of the school, in the grade 9 the most characteristic method is the calculation using the mole conception. Generally 20 % of the students do not solve any problems. This data is less than 12 % in the grade 8, and almost 30 % in case of the 10th. This can be explained by the curriculum typical to the grade. The students learn to solve a joined problem in the grade 8. Probably the knowledge is more up to date in this age. The students are learning another field of the chemistry in the grade 10.

Figure 3. Frequency of different solving pathways of complex problem used by all of the grades



On Figure 4 can be seen the success rate of the students. They used different solving pathways to solve the problem. Points 0, 1 and 2 rated the solving of the items. The perfect solving was worth 2 points; the students got 1 point for a partial solution. Naturally they got 0 point without any solving. The success rate is the lowest in the grade 7. There is no significant difference between the students applying the different solving methods. There is a raised success rate (about 75 %) of the other grades students using the "stepwise" solving method. They applied the mole conception. This solving method did not separate from the other methods in the grade 7. The calculation applying the mole concept is not typical. The success rate of the stepwise solving method shows a decreasing tendency to the 8th-10th graders because the learned algorithm is blowing over (Table 2.).

Figure 4. Success rate of the 7th to 10th graders in solving of the complex problem

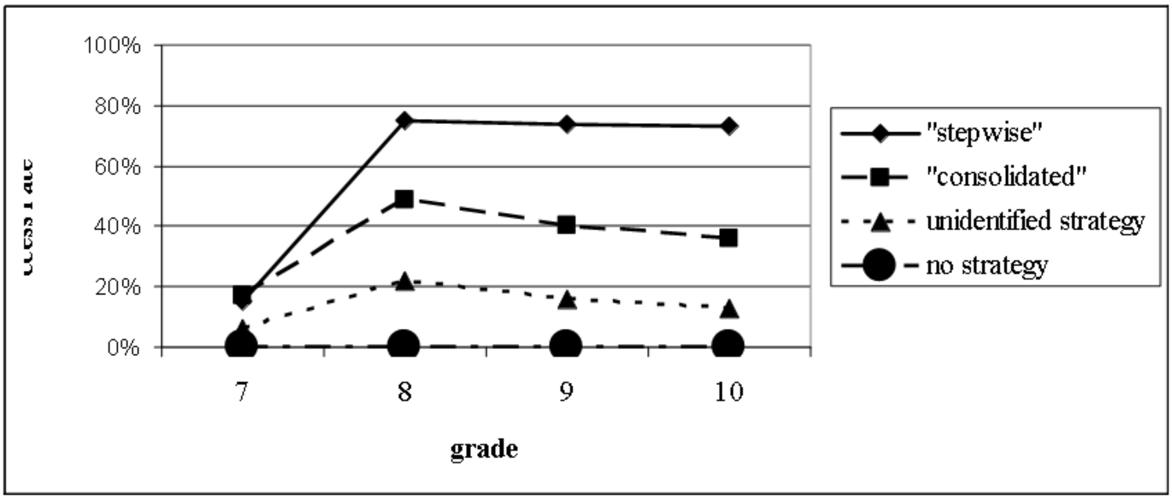


Table 2. Significance levels for two problem solving pathways of the complex problem

"stepwise"	grade 7	grade 8	grade 9	grade 10
grade 7	–	**0.000***	**0.000***	**0.000***
grade 8	**0.000***	–	0.999	0.999
grade 9	**0.000***	0.999	–	0.989
grade 10	**0.000***	0.999	0.989	–

"consolidated"	grade 7	grade 8	grade 9	grade 10
grade 7	–	**0.022***	0.133	0.284
grade 8	**0.022***	–	0.652	0.405
grade 9	0.133	0.652	–	0.960
grade 10	0.284	0.405	0.960	–

*The mean difference is significant at the 0.05 level.

On Figure 5 shows the success rate of the students in all grades concerning to the whole worksheet. The students obtained the best result with 80 % success using the stepwise method. This data is significantly better as well. There is a significant increasing in the success rate in the grade 8 compared to the grade 7. Above the 8th grade the data of the success does not change significantly (Table 3.). The number of the students, who are not able to solve the problem, increases in the grade 9 and 10.

Figure 5. Success rate of the 7th-10th graders using different pathways in solving of the complex problem to the whole worksheet

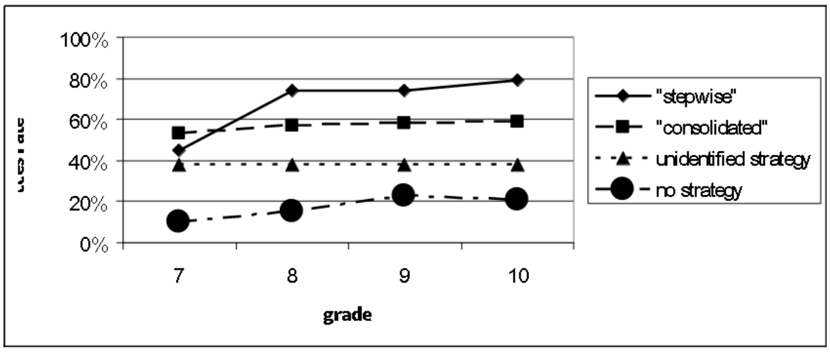


Table 3. Significance levels for two problem solving pathways of the complex problem to the whole worksheet

"stepwise"	grade 7	grade 8	grade 9	grade 10
grade 7	–	**0.000***	**0.000***	**0.000***
grade 8	**0.000***	–	0.999	0.698
grade 9	**0.000***	0.999	–	0.628
grade 10	**0.000***	0.698	0.628	–

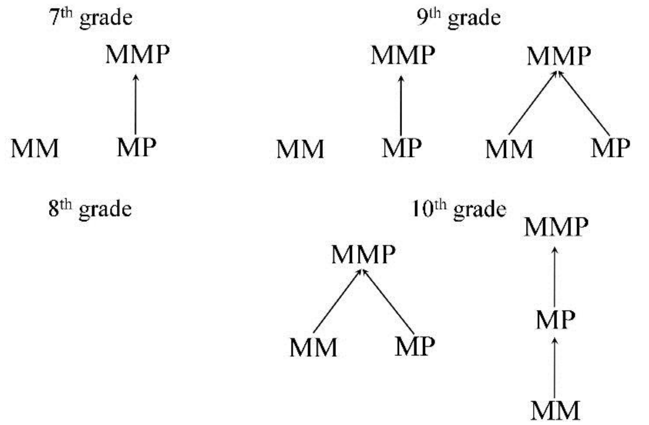
"consolidated"	grade 7	grade 8	grade 9	grade 10
grade 7	–	0.961	0.944	0.889
grade 8	0.961	–	1.000	0.995
grade 9	0.944	1.000	–	0.995
grade 10	0.889	0.995	0.995	–

*The mean difference is significant at the 0.05 level.

Knowledge structures of the student groups using different problem solving methods

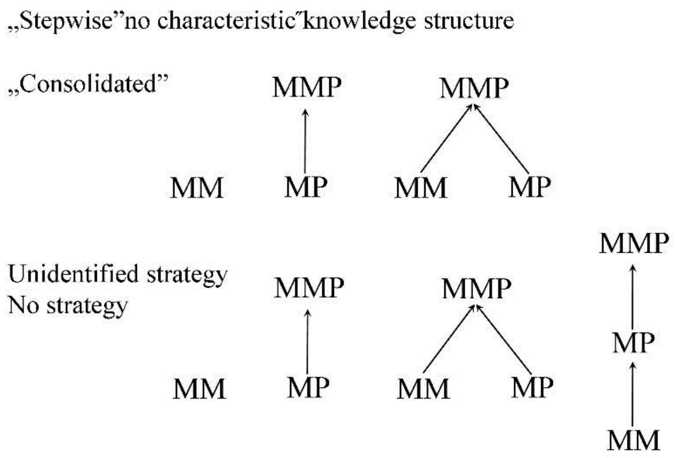
The knowledge system of the students was prescribed by using the KST in each grade. In the course of the structural analysis the most typical knowledge states were taken into consideration. Knowledge systems of student groups were established and compared to each other. A dichotomy scale evaluated (0,1) the solving of the items. The students got 1 point for the correct answer and 0 in every other case.

Figure 6. Hasse-diagrams of the graders (p<0.05; >95%)



The typical knowledge systems of all grades (Figure 6) show that the level shifting as a knowledge element is a predicate to solve the complex problem. The easiest item without level shifting is isolating. The students were not able to calculate the joined item without solving the problem so-called MP. This item contains the critical knowledge element, the level shifting. Another structure appeared in the grade 9. Solution of the most complicated item is as important as solving the two other problems. The shifting between the two levels is getting easier and this is the professional knowledge structure. A teacher as a professional could solve the items in this order. This is characteristic of the grade 10 as well. The other structure shows the following order on the ground indices of the difficulty. The characteristic study method is the order of the difficulty at the same time. The success rate of the items shows, there is no significant difference between the four grades in concerning of the success of the level-shifting problem. This is supported by the dominant knowledge element, the level shifting in every grade.

Figure 7. Hasse-diagrams of the solving pathways (p<0.05; >95%)

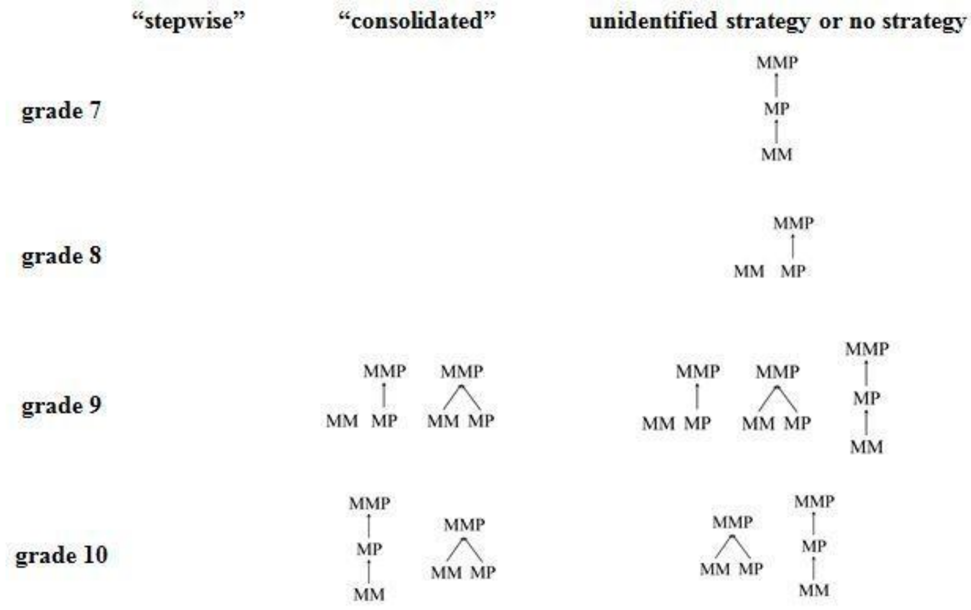


Three knowledge systems of the students groups were analyzed in concerning of the solving pathways (Figure 7). The students who were not able to solve the problem, and students who applied unidentified solving method formed the same group. Following observations were observed by the knowledge structures characterizing the solving pathways. Characterized knowledge system was not found in case of the stepwise solving method. All of the knowledge systems unambiguously show that the solution of the level-shifting item is necessary to solve the complex problem. The second knowledge system of the contracted solution pathway user students shows, both two items are necessary to solve the complex problem. This is live up to the expectations. All of the prescribed solving pathways appear in the unidentified knowledge system because this is the most heterogeneous group.

Varied knowledge systems are formed by the ungrouping on the basis of solution methods as well on the basis of the grades. The students are not to be handled in a uniform way, and the knowledge system can be influenced by both factors (grade, solving method). The performed $\chi 2$ test supported that these factors are depend on each other. There is a significant difference between the presence frequencies of the solving pathways in some grades. Groups must be formed by the solving methods within the grades.

Typical knowledge structure cannot be generated by the stepwise solving method even in concerning the grades. There is no characteristic knowledge structure in the grades 7 and 8 in case of the students, who used the consolidated solving method. The knowledge structure of the grades 9 and 10 students is similar. The professional knowledge structure turned into typical. Solving of both problems is necessary to solve the complex problem. This is supported by the knowledge structure of the consolidated solving pathway user students, which lives up to the expectations. Characteristic knowledge structure can be created for all grades in case of the "no strategy" and "unidentified strategy" group. The superposition of the items is shown by the knowledge structure in concerning the difficulty of the problems in the grade 7. All of the knowledge must be produce by the student in order to solve the problem. This is the professional knowledge structure because he teacher would build the items upon each other using the same way. Reorganization happens in the grade 8, the level-shifting knowledge element will be the determinant element. Two other knowledge structures can be created in the grade 9. These knowledge structures will be characteristic in the 10th grade and the professional knowledge structure appears again (Figure 8). Typical knowledge structure of some student groups can not be created so there are empty spaces on the figure.

Figure 8. The best models for the organisation of knowledge in students' mind in student group 1 ("stepwise" solving pathway), group 2 ("consolidated" solving pathway), group 3 (unidentified strategy or no strategy) for all graders (p<0.05; >95%)



Conclusions

The success rate is increasing with the increasing grades of the student groups. Most of the student can successfully solve the easiest item because the solving of this item does not require level shifting step. The most difficult item was the joined problem. The success rate is the lowest in the grade 7 in concerning both items. There is no significant differences in the success of solving the level-shifting item compared all of the grades.

1. Solving pathways were used by only a small part of the student groups to solve the joined item. The "consolidated" solving pathway is more characteristic to the 8th graders. The 9th graders preferred the "stepwise" solving pathway and this is the most effective pathway to solve the items.

2. The students reach the greater success using the stepwise solving method. The students, working with the stepwise method have a raised performance except the 7th graders. This solving method still not separated from the other methods in this grade. The success rate is higher in case of the students using known solving methods in concern with the students, who used unidentified methods.

3. The statements above are supported by the Hasse-diagrams originated from the solving pathways of the grades.

4. The determining knowledge element, the level shifting, makes difficulty for all grades, supported by the identified knowledge structures.

5. The level shift containing items are necessary to solve the joined problem. Clearly shown by all of the knowledge structures, which are typical to the solving pathways.

Following statements were clarified in this work: The most difficult knowledge element is the item, which requires level shifting between the macro- and sub-microscopic levels. The level shifting as a knowledge element is a requisite to solve a problem with success. The knowledge structure inquiry verifies this statement in most cases. The level shifting between the two levels is the determining step in all grades. Creating of the student groups' characteristic knowledge structures is influenced by the problem solving strategy as well as the grades.

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