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USING PHENOMENOGRAPHY COMBINED WITH KNOWLEDGE SPACE THEORY TO STUDY STUDENTS' THINKING PATTERNS IN DESCRIBING AN ION

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Abstract. *This study compares Hungarian 7th to 11th graders' thinking patterns in describing an ion. The combination of phenomenography and knowledge space theory was used as evaluation method to explore students' reasoning and to follow the change in students' cognitive structures. According to the phenomenographic analysis of the responses, three main categories, 'ions are particles', 'charge of ions' and 'formation of ions', were identified. Connections between these categories were determined by adapting knowledge space theory to the hierarchy of categories. Results showed a typical shape of the process of conceptual change. The initial model for representation of students' knowledge structure is a simple one but during the instruction this model becomes more complex and finally 'crystallises' the new model. In the initial model, the 'charge of ions' category was independent of the 'formation of ions' category, and these both categories were built on the category 'ions are particles'. Significant change in connections among categories could be detected in 8th grade. From 8th grade the category 'ions are particles' as basic knowledge was changed into the category 'charge of ions'. At the end of the instruction (in 11th grade) – after mixing these models in 9th and 10th grades – a double model with basic category 'charge of ions' was found for representation of students' thinking patterns in describing an ion.*
Key words: *phenomenography, knowledge space theory, conceptual change, ion.*

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Introduction

From the viewpoint of teaching and learning difficulties the concept of ions is the less examined one among the concepts of chemical particles (atoms, ions and molecules). Research has focused mainly on the problem of the ionic bond. Two common alternative conceptions were explored regarding this topic: (1) the ionic bond is the electron transfer between the bonding atoms; and (2) in ionic compounds the oppositely charged ions neutralise each other forming molecules (or ion-pairs) (Taber, 2002; Barker, 2003 – and references therein). During our research on students knowledge about the chemical particles we studied students' description of an ion.

Recently Tóth and Ludányi (2007a) successfully used the combination of phenomenography with knowledge space theory for exploring students' thinking patterns in describing an atom. In this study we also used this combined method for exploring students' thinking patterns about the ion.

Phenomenography is an area of research which focuses on identifying and describing the qualitatively different ways in which people understand phenomena in the world around them (Marton, 1981, 1986). The major premise of phenomenography is that although individuals will have different experiences and conceptualisations of a phenomenon in a given context, the number of qualitatively different conceptualisations is limited. These different conceptualisations are the focus of a phenomenographic study rather than each individual learner's conceptualisations. One major assumption of phenomenography is that individuals can accurately express their experiences and conceptualisations.

Knowledge space theory (KST) was developed by Doignon and Falmagne (1999), and its application to science concepts have been previously demonstrated by Taagepera et al. (1997, 2000, 2002), Arasasingham et al. (2004, 2005), and Tóth et al. (2006,

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2007a, 2007b, 2007c). In this theory, the organisation of knowledge in students' cognitive structure is described by a well-graded knowledge structure. Although KST was originally developed for modelling the hierarchical organisation of knowledge needed to answer a set of problems in science and mathematics, the formalism of this theory can be extended to any hierarchically organised input data (see for example: Tóth and Ludányi, 2007a).

The aim of the study

We used knowledge space theory to explore the connections among the categories obtained from the phenomenographic analysis of students' description of an ion and to answer the following research questions:

1. What is the characteristic hierarchy of the categories regarding the concept of the ion?
2. Is there any change in students' thinking patterns during their instruction?

Research methodology

Instruments and subjects

Students were asked – among other items – to describe an ion on a paper-and-pencil questionnaire: 'Describe the following concepts: atom, molecule, ion etc.'

Data were collected at the end of the school year of 2002/2003. A random sample of 724 out of 2954 Hungarian secondary school students (grades 7 to 11, age 13 to 17) from 17 schools participated in the test. (7^{th} graders: 171, 8^{th} graders: 165, 9^{th} graders: 136, 10^{th} graders: 135 and 11^{th} graders: 117.) The 7^{th} graders had 1 or 2 chemistry lessons per week, and 8^{th} to 10^{th} graders had 2 chemistry lessons per week Just a few students had chemistry lessons in the 11^{th} grade. It is noted that in Hungary the concepts of atoms, molecules and ions are introduced in the 7^{th} grade. The different Hungarian chemistry textbooks give one of the following definitions of an ion in grade 7: (1) the ion is a chemical particle with positive or negative charge; (2) the ion can be formed from an atom by losing or gaining one or more electrons. Each book has the own definition, but later (in grades 8 and 9) each book completes the description of the ion without giving new, completed definitions.

Evaluation method

First, the categories were identified according to the phenomenography. Responses were evaluated not as 'right' or 'wrong' but by identifying categories using an iterative process. Once the data for the students' groups has been collected, it was then organised and reviewed several times in order to identify the limited number of ways an ion had been described. There were three main principles for this identification process: (1) categories should be extracted from the students' responses; (2) categories should not be mutually exclusive or inclusive, but distinguishable; (3) responses must be explicit to be capable of being categorised.

After identifying categories, knowledge space theory was used to explore the connections among the categories. For the KST analysis, responses were scored in a binary fashion, according to whether they contained the given category (1) or not (0). Theoretically we can have 2^n possible response states (where n: the number of the categories), from the null state where none of the identified categories were used to the final state where all the categories were appeared in the student's description. A set of response states gives the response structure. Starting from this response structure, one can recognise a subset of response states (so called knowledge structure) fitted to the original response structure at least at the $p = 0.05$ level of significance. There are several methods to find the knowledge structure from the response structure. These methods have two common features: (1) lucky-guess and careless-error parameters (most often 0.1) are estimated for each item; (2) the knowledge structure has to be well graded (e. g. each knowledge state must have a predecessor state and a successor state except the null state and the final state). Based on the knowledge structure we can determine the most probable hierarchy of the categories (represented by the so-called Hasse diagram) by a systematic trial-and-error process to minimise the χ^2 values. The χ^2 value was calculated on the basis of the difference between the predicted and the real populations on the knowledge states in the assumed knowledge structure. For the calculations, a Visual Basic computer program (Potter) was used. Details of the KST analysis were published earlier (Tóth et al., 2006, 2007a, 2007b, 2007c).

Results and discussion

Categorisation of the students' responses

According to the phenomenographic analysis of the students' responses, students' descriptions of an ion fell readily into six categories: (0) No response; (1) I don't know; (2) Ions are particles; (3) Charge of ions; (4) Formation of ions; (5) Other. Among these categories 'Ions are particles', 'Charge of ions' and 'Formation of ions' were used for further analysis.

Category was marked with 'Ions are particles' (P) if the student described the ion as a small particle. For example, 'It is a particle.' 'It is a chemical particle.' 'A particle derived from atoms.'

The 'Charge of ions' (C) category includes students' responses referring to the charge of the ion. For example, 'It is the charge of the substance.' 'It shows the charge of the elements.' 'it has charge.' 'It may be positively or negatively charged.'

When the student described the genesis of the ion his or her response was listed into the category 'Formation of ions' (F). For example, 'Ions are formed by losing or gaining protons.' 'It is formed by losing electron or proton.'

All possible combinations of the above three categories (P, C, F, P+C, P+F, C+F, P+C+F) were detected in the students' responses. For example, 'It is a particle with charge.' (P+C); 'It is formed from an atom by losing or gaining electrons.' (P+F); 'It is charged and formed by losing or gaining electrons.' (C+F); 'It is a negatively or positively charged particle formed from atoms or molecules by losing charge.' (P+C+F).

Frequency and distribution of the students in the categories and their combinations

Table 1 shows the students' distribution in each category and combination of categories. It is seen that most of the students describes the ion as a charged particle (P+C) in all grades.

Table 1. Students' distribution in each category or combination of categories (%).

Categories	7th graders	8th graders	9th graders	10th graders	11th graders
None + other	36	14	13	7	23
'Ions are particles' (P)	2	2	1	4	2
'Charge of ions' (C)	0	8	2	7	6
'Formation of ions' (F)	3	2	4	2	2
P + C	40	56	53	61	49
P + F	9	6	9	9	3
C + F	3	1	3	1	2
P + C + F	7	11	15	9	13

Figure 1 shows that percentage of students giving no answer or non-categorised answer decreases with the grade except of the grade 11. At the same time the number of the students giving more complex description of the ion (responses containing 2 or 3 categories) increases from 7th grade to 9th grade. On

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the basis of these tendencies we can establish that the students' description about the ion becomes more complex during the instruction. The recession observed in case of 11th graders can be explained by the lack of chemistry lessons.

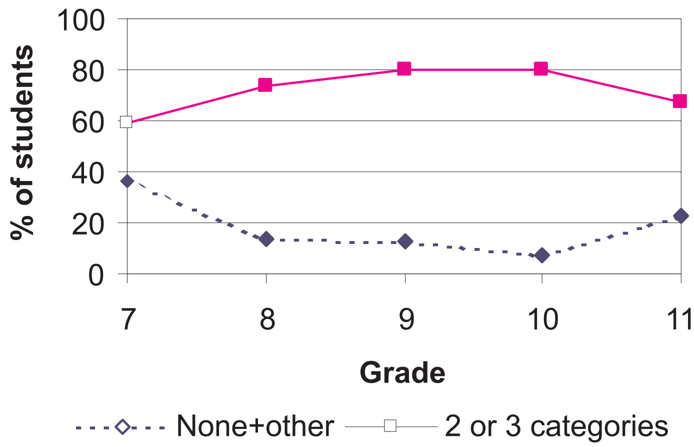

Figure 1. Effect of the instruction on the percentage of students giving more complex response and giving no answer or non-categorised answer.

The connection between categories – modelling students' knowledge structure

We are interested in the hierarchy of the categories which is characteristic of the students' group at different grade levels. Theoretically there are 19 possible connections between three categories (Figure 2) from the totally separate state (A) to the strictly hierarchical order (E). Among these schemas we tried to find the one(s) fitted best to the input data (response structure of the students' group) using KST analysis written in details in the literature (Tóth and Ludányi, 2007a).

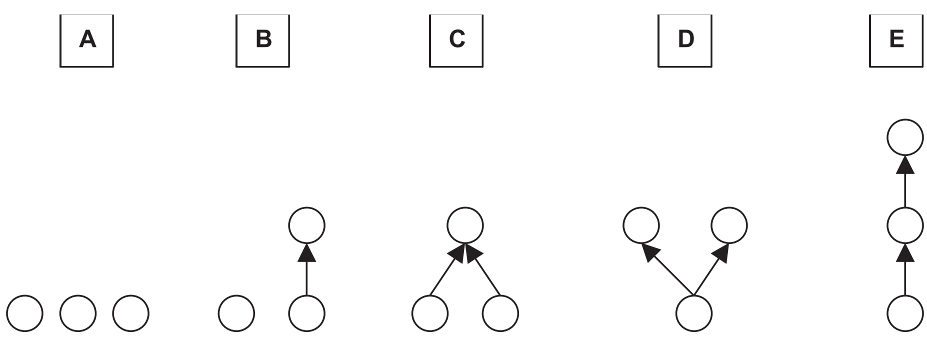

Figure 2. Theoretically possible schemas for connection between three categories. (Number of variations in schemas: A = 1; B = 6; C = 3; D = 3; E = 6).

Figure 3 summarises the results of the KST analysis. As usual we use Hasse diagrams for presenting the hierarchy between categories. How should these Hasse diagrams be read? The hierarchy in the first row (similar to schema E) means that the knowledge (category) 'Formation of ions' is built on the categories 'Charge of ions' and 'Ions are particles', while the category 'Ions are particles' is built on the category 'Charge of ions'. In this hierarchy the category 'Charge of ions' is the basic knowledge in the description of the ion. The other hierarchy in the second row (similar to schema D) means that also the 'Charge of ions' category is the basic one, but the other two categories building on the 'Charge of ions' are separated from each other. In the hierarchy similar to schema B (third row in Figure 3) the category 'Formation of ions' is separated both from the 'Ions are particles' and 'Charge of ions' categories, and the knowledge regarding the category 'Ions are particles' is only necessary knowledge of category 'Charge of ions'.

Figure 3 shows that there are some significant changes in the best models through the grade levels. Results show a typical shape of the process of conceptual change. The initial model for representation of 7th graders' knowledge structure is a simple one. This suggests that from the viewpoint of knowledge structure students' group is uniform at the beginning of the chemical studies. Moving forward in their instruction students' knowledge structure becomes more complex, and in grade 9, where students study the formation of ions and the characteristics of the ionic bond in detail, this organisation of knowledge is the most complex one. In grades 10 and 11 a unification process is taking place and at the end of their chemistry studies (in the 11th grade), the knowledge structure of the students can be represented by a double model.

It is also seen that there is a change in the knowledge organisation from 7th to 11th grades. In the initial model, the 'Charge of ions' category was independent of the 'Formation of ions' category, and these both categories were built on the category 'Ions are particles'. This model fits to the two types of definition used the textbooks in grade 7. Significant change in connections among categories could be detected in 8th grade. From 8th grade the category 'Ions are particles' as basic knowledge was changed into the category 'Charge of ions'. At the end of the instruction (in 11th grade) – after mixing these models in 9th and 10th grades – a double model with a fundamental category 'Charge of ions' was found for representation of students' thinking patterns in describing an ion.

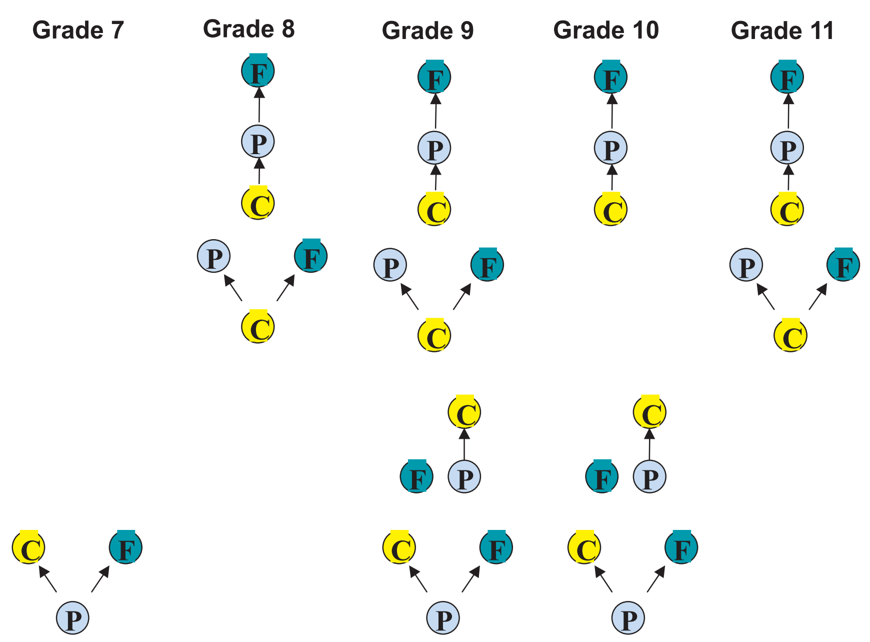

Figure 3. The best models for representation of students' knowledge structure.

Conclusions

Using phenomenography combined with knowledge space theory we could study the main categories of students' descriptions about an ion and the characteristic hierarchies between these categories. Our results can be summarised as follows.

1. Students' responses to describe an ion fell readily into six categories: 'No response'; 'I don't know'; 'Ions are particles'; 'Charge of ions'; 'Formation of ions' and 'Other'. From these categories 'Ions

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are particles', 'Charge of ions' and 'Formation of ions' were used for further analysis.

2. We established that most of the students describe the ion as the charged particle in all grades. We also found that the students' description about the ion becomes more complex during the instruction and the recession observed in case of 11th graders can be explained both by the lack of chemistry lessons, and by the lack of interest for the subject of chemistry.

3. Using knowledge space theory we could find the best models among the theoretically possible schemas for representation of connection between the three categories. Results show a typical shape of the process of conceptual change. The initial model for representation of students' knowledge structure is a simple one but during the instruction this model becomes more complex and finally 'crystallises' the new model.

4. In the initial model, according to the definitions in the chemistry textbooks, the 'charge of ions' category was independent of the 'formation of ions' category, and these both categories were built on the category 'ions are particles'. Significant change in connections among categories could be detected in 8th grade. From 8th grade the category 'ions are particles' as basic knowledge was changed into the category 'charge of ions'. At the end of the instruction (in 11th grade) a double model with fundamental category 'charge of ions' was found for representation of students' thinking patterns in describing an ion.

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