THE STUDENTS' CONCEPTUAL SYSTEM RELATED TO CHEMICAL PARTICLES

PHD THESIS

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1. INTRODUCTION

Nowadays average people can hear news about the achievements and drawbacks of science on a common level, while at the same time the number of people who are able to interpret the incoming information has been decreasing. One of the reasons for this is that the fixation of scientific basic studies provided by primary and secondary education is incomplete, fragmented and without meaning. The rate of children suffering from learning difficulties is increasing, and more and more secondary school children are losing their motivation to get acquainted with sciences. For students science subjects are principally facts, masses of laws and ready-made frames, which seem to be absolute, rather than a system based on logical conclusions, which can be used by anybody.

Chemistry is the most complicated science subject in primary and secondary education, requiring the largest mental concentration and abstractive skills. It is the first subject in which students have to acquire a new – generally compulsory for everybody – language and abstract conceptual system, which are accompanied by a chemical symbol system, the elements of which they have never encountered in their studies or everyday life. Although, students' knowledge formation starts before entering school when children form their theory-like conceptual structures to explain the phenomena around them, the terms generally used in chemistry are hardly present in these primary concepts. The main point of chemistry education is both to define these new categories such as atom, molecule, etc. and to create the necessary framework to interpret concepts. The difficulty of the subject is that students adopt their self-created interpretation system, which is associated with their every day concepts rather than scientific definitions.

The only possible way of rational learning is if students are able to attach the freshly acquired knowledge to their already existing conceptual structure. If there is a significant difference in meaning and interpretation between the student's primary concept and the scientifically defined concept then interpretational difficulties might occur; the new information does not fit into the conceptual system. This time the concept fixes either without meaning or as a concept including contradictions. The failure of this irresolvable contradiction one for the supposed reasons of the falling popularity of scientific subjects is.

Knowledge acquired in a structural way can only be used, when the knowledge elements are connected to each other, they refer to each other creating a system in this way. The process of knowledge development means that the new piece of information is connected to the element or elements of the already existing system. As a consequence, knowledge is not a simple set of facts, but the extended network of concepts; the so called cognitive structure. To form a new concept we usually rely on more than one concept or building part already known. Among the elements there are logical sequences, some of which are parallel knowledge elements, while others are in inferior or superior positions to the others. To see the organization of elements in students' minds serves as important information for a teacher, it is feedback about the teacher's work and the students' thinking patterns.

Among the worked out methods to reveal the student's conceptual frames the most popular methods are those which can be depicted by graphs (Galois-graph, conceptual chart, knowledge-space theory). To reveal the conceptual structure and to follow its changes, we have developed a new method called ***knowledge space-theory combined with phenomenography***. After processing the answers given by a student group to a single open-ended question , this method can help us to come to a conclusion, about what the substantive elements are concerning a certain concept, and according to what hierarchy the elements complete the concept.

2. THE AIMS OF RESEARCH

There are two fields of my research:

1) In Hungary nobody has investigated: how students develop their concepts related to basic chemical particles; what interpretational difficulties they have to face during their studies, and how much their misconceptions are similar to those published in foreign literature. This work is both pioneer work in its kind and stop-gap work for the authors of textbooks, textbook developers and for experts working in teacher's training.
2) Knowledge-space theory combined with phenomegraphy is a new method in subject didactics. In my research I intended to prove the practicability and usefulness of the method in different educational and didactical issues.

Factual aims :

- To analyse the fixation of concepts related to basic chemical particles, the concept development, and the grade to grade fine tuned structural changes in the interpretation of concepts.
- To reveal those interpretational difficulties that students might face to during the teaching process, and which can be the causes of their learning failures in case of certain concepts.
- To analyse the concept development in chemistry textbooks published for students in the 7^{th} and 8^{th} grades in the last few years, and its connection to concept formation among those students.
- To reveal how much information the students possess concerning the components on symbol and molecular level, in addition to the macro world.
- To determine the facilities when and where knowledge-space theory combined with phenomenography can be applied in the frameworks of my research successfully.

3. THE PARAMETERS OF RESEARCH

A comprehensive analysis about Hungarian students' conceptions related to chemical particles has not yet been done. Data collected in a survey carried out in 2003 serves as the basis of this research work. This survey included 726 high school children from the 7^{th} and 11^{th} grades, from schools all across Hungary. All of them are from secondary schools with 6 or 8 classes. In the task sheet of the cross country survey there was the following range of subjects:

Task1:	The definition of atom, molecule, compound molecule, ion, cation, anion, simple ion, compound ion
Task 2-3:	The meaning of chemical symbols, formulas
Task 4-5:	The component analysis of substances
Task 6:	The charge analysis of chemical particles
Task 7-8:	The organisation of matter

The Cronbach-alfa score of the reliability analysis was 0.8992, which means that the test was homogenous and well designed..

To reveal the didactogen causes I have analysed the concept formation of the Hungarian chemistry textbooks in the 7^{th} and 8^{th} grades, with the knowledge of the typical mistakes committed by students.

4. METHOD OF DATA ANALYSIS

4.1. Statistical analysis

In traditional statistical analysis the categorisation is completed according to a six-grade scale as it was used in the research of misconception.

Table 1. **The open-ended questions were analysed under the following categories**

Scoring	**0**	**1**	**2**	**3**	**4**	**5**
Degree of understanding	No response	No scientific understanding	Misconception	Partial understanding containing misconception	Minimum understanding with no misconception	Sound understanding

4.2. Method of 'Knowledge-Space Theory Combined with Phenomenography'.

In the analysis of concept development applied the traditional statistical methods as well as the knowledge-space theory combined with phenomenography. The stages of procedure are the following:

⓪ The research work step by step

The result of each step of the research

① Making a questionare on a certain concept – e.g. *atom*. Carry out the survey.

STUDENTS' RESPONSES:

- Atom is the smallest particle of matter.
- The atom could not be divided by chemical methods.
- An atom contains electrons, and a nucleus. In a nucleus there are protons and neutrons ….

② **PHENOMENOGRAPHIC ANALYSIS:**
Looking for structurally significant differences that clarify how students define the atom. Looking for major categories.

CATEGORIES:

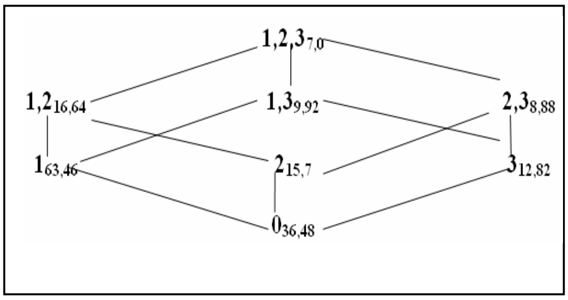
[1]Units of matter: The students define the atom as a constituent of matter. For example: „Atom makes up stuff."
[2]Constituents of an atom: The student states constituents of an atom. For example: „An atom contains electrons, and a nucleus. In a nucleus there are protons and neutrons"
[3]Model of an atom: The student describes some atomic model. For example: „An atom is made up of a nucleus with protons and it has electrons that circle around it."

③ **DETERMINING RESPONSE STATES**
Selecting each student's answer by these phenomenographic categories. Determining students' distribution in each category or combination of categories.

Response states	Number of students
[*1,2,3*]	6
[*2,3*]	8
[*1,3*]	2
[*3*]	11
[*1,2*]	11
[*2*]	14
[*1*]	81
Wrong answer	38

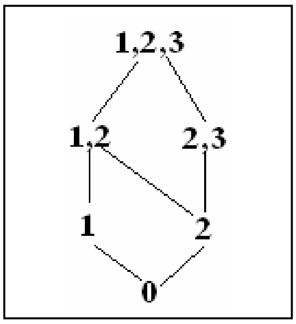
④ **DERIVING KNOWLEDGE STATE FROM THE RESPONSE STATES**

Knowledge State Theory Analysis using Potter's software .



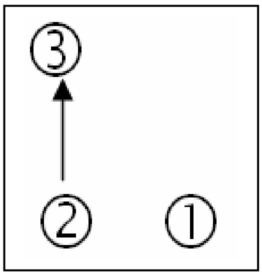
⑤ **DERIVING KNOWLEDGE STRUCTURE**

Determining the most probable stucture of the knowledge state by a systematic trial-and-error process to minimise the χ^2 values.



⑥ **CONVERTING THE KNOWLEDGE STRUCTURE INTO HASSE DIAGRAM**

Hasse diagram shows the hierarchy of the main categories.



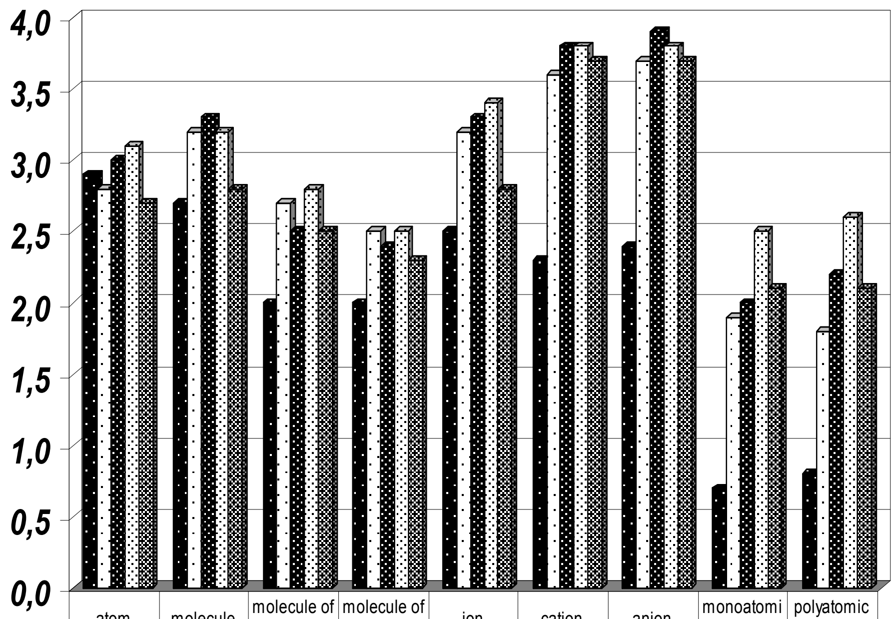
5. NEW SCIENTIFIC RESULTS:

5.1. Results related to students' concept definition

5.1.1. *Large percentage of students' definitions did not meet the formal requirement of a definition.*
A lot of them were incomplete, which missed the classifying definition or the relationship; many times they missed the name of the concept. On the one hand it means that students do not know what *defining* means, on the other hand they memorize only some parts of a formal definition that they think to be important. The definitions indicated clearly that the first two years in their studies were not enough to acquire the appropriate chemical terms, so students tried to replace them with words taken from everyday life.

5.1.2. *Generally it is true, that the definition which is fixed the first is the strongest*.
The method where the textbooks (teachers) entrust students to expand the definition alone is not efficient.

5.1.3. *The shortest definitions proved to be the most successful (ion, anion, cation)*.
Even so, the successfulness of defining did not correspond with the understanding of the meaning. Concepts not defined by textbooks (teachers) seemed to be the most difficult to define, and students tried to deduce the meaning from the elements of the compound word (molecule of element, molecule of compound, polyatomic ion). Students in the 10th grade were more successful in concept definition than 11th graders who are supposed to possess more chemical knowledge.



	atom	molecule	molecule of element	molecule of compound	ion	cation	anion	monoatomic ion	polyatomic ion
7th Grade	2,9	2,7	2,0	2,0	2,5	2,3	2,4	0,7	0,8
8th Grade	2,8	3,2	2,7	2,5	3,2	3,6	3,7	1,9	1,8
9th Grade	3,0	3,3	2,5	2,4	3,3	3,8	3,9	2,0	2,2
10th Grade	3,1	3,2	2,8	2,5	3,4	3,8	3,8	2,5	2,6
11th Grade	2,7	2,8	2,5	2,3	2,8	3,7	3,7	2,1	2,1

Figure 1. **A The sucess of giving the definition of chemical particles in each year (Max. score: 5)**

5.2. Results related to the definition of atom

5.2.1. *The content distribution of definitions has hardly changed in years.*
Fifty percent of the students gave the following definition of atom: '*Atom is the smallest (chemically undivided) particle of matter.*' 20 percent of the students could not give an appreciable idea about the definition of atom. Nearly 30 percent of students gave a complex definition including the components and mentioning one of the atom models.

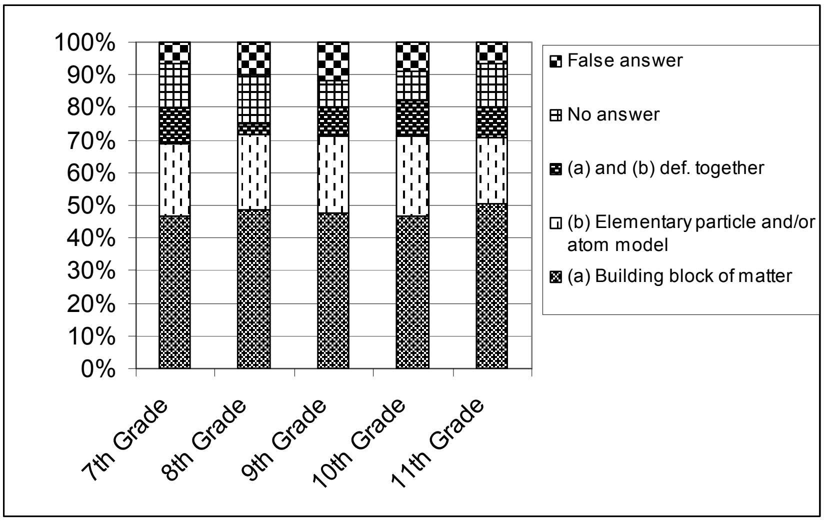


Figure 2. **The distribution of the elements of the definition of atom**

5.2.2. *The most common mistake of the definition of atom is to declare the atom to be an elementary particle.*
Over a quarter of 11 graders defined it in this way. This specific misinterpretation does not exist in scientific literature so far. It can be connected to the everyday interpretation of the Hungarian word '*elemi*'. The students use this word as the synonym of 'basic' and 'originated from an element'.

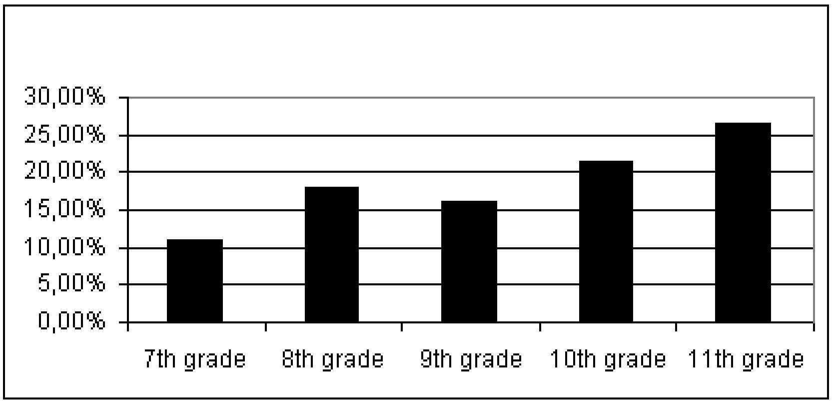


*Figure 3***.** **The percentage of students who think the atom is an elementary particle**

5.2.3. *Phenomenographical analysis of the students' definition of atom*
According to the phenomenographical analysis of the definition, the students' definition was made up of three definition forming basic categories, such as:

1, Units of matter, e.g.: '*Atom is the smallest particle of a matter.*'

2, Constituents of atoms, e.g.: '*Atom is a neutral particle, which consists of a proton, an electron and a neutron.*'

3, Model of atoms, e.g.: '*Atom consists of a nucleus and an electron cloud.*'

5.2.4. *Knowledge structure of the students' groups*

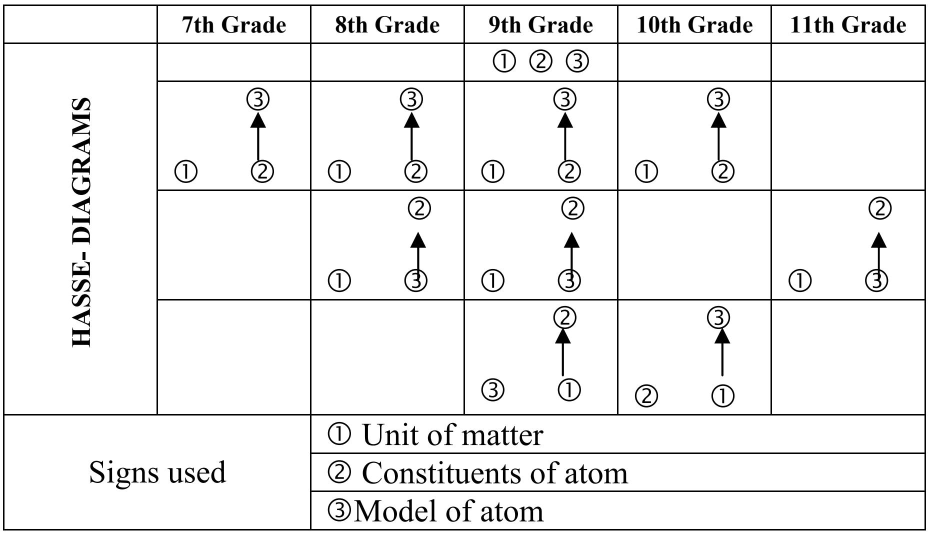


Figure 4. **Hasse diagrams which describe the students' knowledge structure of the atom**

Models worked out on the base of knowledge-space theory combined with phenomenography represent the fixation of a structure among the 7th graders, where the 'atom as a building unit' separates from the 'components of the atom'. In the 8th grade there is a spectacular reorganization among the components, where the reorganization finishes with a structure where the atom as a model is emphasized.

5.3. Results related to the definition of molecule

5.3.1. *Problems related to understanding of covalent bond.*
At the definition of a molecule the students did not mention the chemical bonds among the atoms; they treated them as group of atoms, as a 'unit stuck together' E.g.: '*[A molecule] is a unit consisting of more atoms*.' A number of people could not define covalent bond; they explained it as a material realization. E.g.: '*[Molecules] they consist of atoms and covalent bonds*.' The number of students who recognised the bond inside the molecule rather as a primary bond, or secondary bond, or ionic bond instead of covalent bond increased grade to grade.

5.3.2. *Phenomenographical analysis of the students' definition of molecule.*
According to phenomenographical analysis of the concept the students' definition was based on the combination of the three basic categories, where:

1, Molecule is a particle, e.g.: '*Complex particle*.'
2, Molecule consists of atoms, e.g.: '*It consists of more atoms*.'
3, Molecule is held together by covalent bonds, e.g.: '*A particle formed by covalent bonds*.'

5.3.3. *Knowledge structure of the students' groups.*

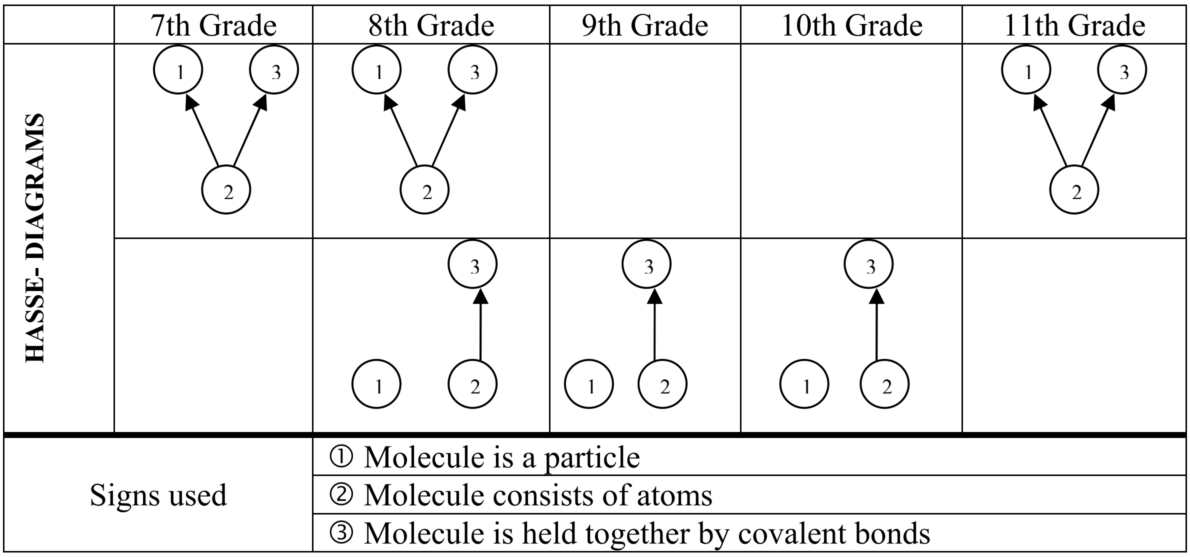


Figure 5. **Hasse diagrams which describe the students' knowledge structure of the molecule**

The result of the knowledge-space theory combined with phenomenography shows that by the 8th grade the definition of molecule, which is founded on the atom emphasized definition of a molecule formed in the 7th grade has been rearranged. By this time the definition of a 'molecule as a chemical particle' is separated from the 'formation of a molecule' and 'its components'. By the 11th grade students return to the definition based on the definition of atom, though.

5.4. Results related to the definition of ion

5.4.1. *Problems related to understanding of ion-concept.*

- The successfulness of the definition of ion is the worst in the 7th grade. One possible reason is that students lack the necessary basic physical studies to understand the definition.
- For some students the definition of ion is the synonym of 'being charged'. For more of them the word ion means the indicated charge symbol in the corner of the chemical symbol.
- The most typical mistake of incomplete definitions was the absence of the attributive word '*chemical*' before the word '*particle*'. E.g.: '*Particle with charge.*'
- Some of the students mix up the formation process of simple and polyatomic ions resulting in an incorrect definition. E.g.: *'Composed of ions by electron or proton loss or gain.*'

5.4.2. *Phenomenographical analysis of the students' definition of ion.*
According to the phenomenographic analysis of the concept students' definitions were based on the combination of three concept-forming basic categories, such as

1, Ion is a (chemical) particle. E.g.: '*It is a chemical particle*.'
2, Charge of ion. E.g.: '*It shows, what the charge of an element is*.'
3, The formation of ion, the formation of ionic bonds. E.g.: '*Ions are formed by losing or gaining protons.*'

5.4.3. *Knowledge structure of the students' groups*

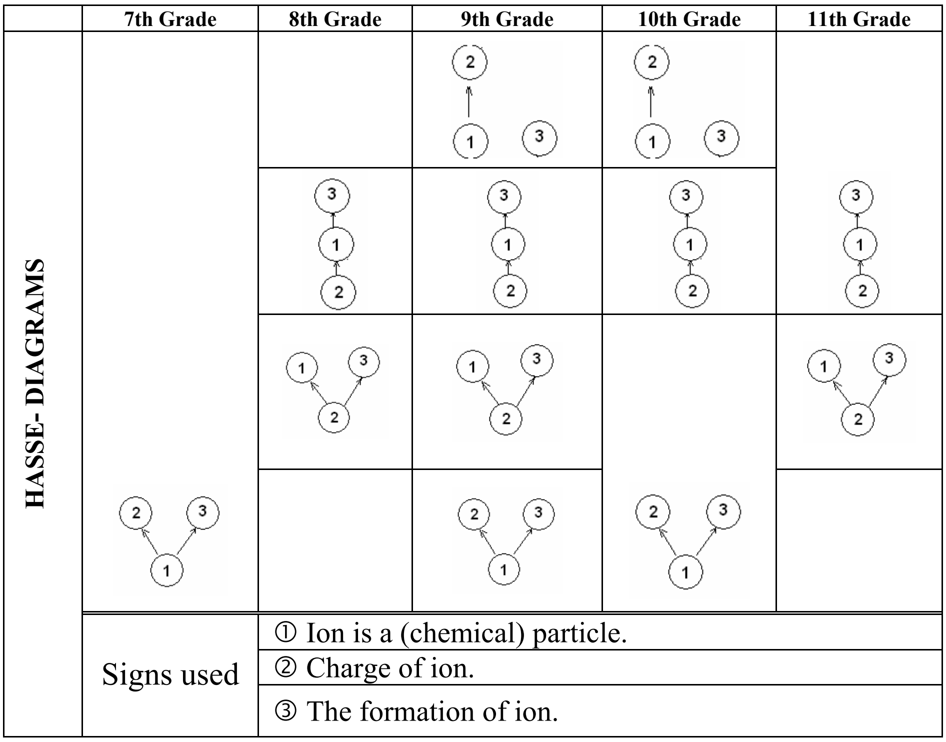


Figure 6. **Hasse diagrams which describe the students' knowledge structure of the ion**

According to the knowledge-space theory combined with phenomenography, in the 7th grade the ion appears as a chemical particle which has charge and this particle is formed by electron loss or gain. Getting through transitional stages this knowledge structure passes into a linear knowledge-chain, where the charge of the ion is getting decisive, which is followed by ion as a chemical particle, and the next is the knowledge of ion formation.

5.5. Results related to the electrical charge of chemical particles

- To understand what the charge of a particle is, or when a particle is neutral can cause difficulties mainly in the 7th grade. Until the 9th grade 10 percent of the students were not able to interpret how an atom can be neutral, if it had positive and negative charges.
- 50 percent of the 7th graders gave the wrong answer regarding the charge of a molecule, and even among higher year students only 70 percent knew the correct answer. The wrong answers were due to the confusing effects of the dipole molecule.

5.6. Results related to the knowledge of chemical symbols

- The knowledge of chemical symbols looks promising; students successfully recognised the symbols of basic chemical particles. Most of the students interpreted the meaning of symbols on molecular level: '*H: hydrogen atom*' ; '*H_2: hydrogen molecule*', '*H^+: hydrogen ion*'. The rate of students mentioning the quantitative meaning at the description of the meaning of a symbol is less than 10 percent.
- The most typical mistake was that the meaning of a symbol was limited only to the name given by the periodic table. E.g. '*H: Hydrogen.*'
- The classification of the sulphate ion as a molecule or as an ion caused problems for 13 percent of the students in the 7th grade, and 15 percent in the 8th grade. The reason

for it was that students' classification was performed depending on the placement of the indexes (the right top index is an ion, while the right bottom index is a molecule).

5.7. Results related to the macro and molecular level of chemistry

- The correlation between the molecular and macro level was weak, or weak-modest ($p<0.001$). Although the students appropriately described the definitions of basic chemical particles, they could not apply the acquired knowledge and name correctly the different entities of a given matter (e.g.: sand, air, salt, and diamond).
- The most typical mistake was, that instead of giving the right entity type they answered by giving formulas, or they 'stripped-down' their answers to atoms. E.g.: '*Sugar consists of C, H and O.*'
- To define the components of ion-bonding substances (salt, gypsum, chalk) caused the largest difficulties for students. The revealed misconceptions correspond to the international experiences.
- At the components of air the dominating presence of water and H_2 was a typical mistake.

5.8. Knowledge-space theory combined with phenomenography

The advantages of the method are the following:

a) It is able to reveal the structural construction of a concept.
b) It makes it possible to demonstrate the forthcoming changes in the structure of the conceptual system.
c) The causes of the inappropriately fixed conceptions can be investigated.
d) It makes it possible to point out fine-tuned structural changes, which are invisible in the case of traditional statistical analysis.
e) By the application of Hasse diagrams the results can be interpreted and illustrated well.

The disadvantages:

a) It means the combination of two methods, which are both work and time consuming.
b) To find the phenomenographic categories requires the proper expertise.
c) The computer program which serves the mathematical base of knowledge-space theory enables to evaluate tasks with limited pieces of item.
d) As a result of the freeware program, the manual completion of graphs after 7 items can be beyond the human eye and brain capacity.
e) In the absence of a computer program which would be able to convert graphs into Hasse diagrams, the number of which increases in exponential rate by the growing pieces of item, it is a hard job to find the corresponding graphs, and the good choice requires certain experience.

As long as there is not a user-friendly program for the graphic demonstration of the results gained by knowledge-space theory, and to convert these graphs into Hasse diagrams and because of the above listed hindering factors, the method can be applied primarily in pedagogical-methodological researches.

5.9. The connection between the students' mistake and textbooks

The appearing interpretational difficulties of concept definition can obviously be brought into connection with the emphasis-shift of definitions, and the methodical pitfalls of concept formation given by textbooks.

6. THE PRACTICAL APPLICATION OF THE RESULTS

The results of my research are a warning for those who work in chemistry teaching. They prove that the traditional method in chemistry education related to the teaching of basic chemical concepts led to unsatisfactory result even in the best sample taken from students studying in secondary grammar schools with 6 or 8 classes. Point out the fact that the abstract feature of chemical concepts, the introduction of a new, yet non known attitude and the acquirement of a new special terminology demand more attention and more careful examination of the applied methods. The only way to achieve more efficient chemistry teaching in the 21st century is the change of attitude in education. This change of attitude should have an influence on methods rather than content. Nowadays the introduction of the constructivist attitude looks to be the most promising. The theory with its supplementary methodology could help the most in teaching scientific subjects if it replaced the academic attitude by a student-centred attitude so as not to alienate students from chemistry.

The revealed interpretational difficulties of the concepts in mind, my research work can give guidance to the authors of textbooks, researchers of special methodology, and teachers alike. There is a warning; even the methods of long standing have their difficulties, so working as a teacher requires constant self-checking and methodical renewal. As far as there are interpretational problems relating to the most essential chemical concepts, we can not expect a positive attitude on our student's side.

To control the teaching process, a teacher must gather information about the student's conceptual structure at the beginning of the learning process, and later about the changes of the conceptual system during the teaching process. In possession of this information the teacher can form the lesson plan to find linking points to the students' conceptual system, and check the results of his own work. In my work I have presented the various applications of knowledge-space theory combined with phenomenography, and its successful application to answer different pedagogical-methodological questions. Besides the tested methods it is able to assist teachers and researchers to describe the process of changes in the interpretation of a given concept within a student group.

Most of the results of my research have already been introduced in pedagogical and methodological literature and conferences. Its further, indirect application could ensue if the revealed interpretational difficulties on the student's side got into the curriculum of teacher's training, and future teachers could start their work by keeping the knowledge of the methodical pitfalls in mind.

7. PUBLICATIONS

7.1. Publications connected to this thesis:

7.1.1. Papers published in international referred journals:

1. Tóth Zoltán, Ludányi Lajos: **Combination of Phenomenography with Knowledge Space Theory to Study Students' Thinking Patterns in Defining an Atom** *Chemistry Education Research and Practice*, 2007; **8** (3), 327-336.

2. Tóth Zoltán, Ludányi Lajos: **Using Phenomenography Combined with Knowledge Space Theory to Students' Thinking Patterns in Describing an Ion** *Journal Of Baltic Science Education* 2007; **6** (3), 27-33.

7.1.2. Papers published in Hungarian referred journals:

1. Ludányi Lajos: **Kémiai fogalmak jelentésváltozásai a diákok gondolkodásában** *Magyar Kémikusok Lapja* 2006. 61. szám 173-178 o.
2. Ludányi Lajos: **Kémiai Bábel** *Iskolakultúra* 2007. 1. szám 3-18.
3. Ludányi Lajos: **A levegő összetételével kapcsolatos tanulói koncepciók vizsgálata** *Iskolakultúra* 2007. 10. szám 50-63.

7.1.3. Papers published in Hungarian no-referred journals:

1. Ludányi Lajos: **Az atomfogalom tanításának lehetőségei és problémái I. Elméleti alapok** *KöKéL* 2006/5 340-350.

2. Ludányi Lajos: **Az atomfogalom tanításának lehetőségei és problémái II. Hazai tapasztalatok** *KöKéL* 2007/1 68-84.

7.2. Lectures presented at conferences:

1. Ludányi Lajos: **Kémiai fogalmak jelentésváltozásai a diákok gondolkodásában** *III. Országos Neveléstudományi Konferencia, Budapest, 2003. (Tartalmi összefoglalók: 346. oldal)*

2. Ludányi Lajos - Tóth Zoltán: **Kémiai fogalmak jelentésváltozásai a diákok gondolkodásában** *XXI. Kémiatanári Konferencia, Pécs, 2004. (Előadás-összefoglalók: 84. oldal)*

3. Ludányi Lajos: **Hogyan képzelik el a tanulók a részecskéket?** *IV. Országos Neveléstudományi Konferencia, Budapest, 2004. (Tartalmi összefoglalók: 308. oldal)*

4. Ludányi Lajos: **Az iskolatípus és a tanítási módszer hatása a tudásszerkezetre** *V. Országos Neveléstudományi Konferencia, Budapest, 2005. (Tartalmi összefoglalók: 161. oldal)*

5. Ludányi Lajos - Tóth Zoltán: **Tanulók részecskékkel kapcsolatos definícióalkotásának vizsgálata** *XXII. Kémiatanári Konferencia, Veszprém, 2006. (Tartalmi összefoglalók: 48. oldal)*

6. Ludányi Lajos: **Kémiai Bábel**
VI. Országos Neveléstudományi Konferencia, Budapest, 2006.
(Előadás összefoglalók: 48.o)

7. Tóth Zoltán – Ludányi Lajos: **Új lehetőség a tudás szerveződésének vizsgálatában: a fenomenografikus elemzéssel kombinált tudástér-elmélet**
Pedagógiai Értékelési Konferencia Szeged, 2007. (Előadás összefoglalók: 75.o)

8. Ludányi Lajos: **Horror Vacui** *VII. Országos Neveléstudományi Konferencia, Budapest, 2007. (Előadás összefoglalók: 75.o)*

9. Ludányi Lajos: **Didaktogén tévképzetek**
XXIII. Kémiatanári Konferencia, Budapest, 2008. (Előadás összefoglalók: 70-71. oldal)

7.3. Posters presented at conferences:

1. Ludányi Lajos – Tóth Zoltán: **How do students define the concept of the atom**
8th ECRICE, Budapest, 2006. (Előadás összefoglalók: 151.o)

2. Ludányi Lajos - Tóth Zoltán: **Kémiai fogalmak jelentésváltozásai a diákok gondolkodásában**
XXI. Kémiatanári Konferencia, Pécs, 2004. (Előadás-összefoglalók: 165. oldal)

3. Ludányi Lajos- Tóth Zoltán: **Az atom fogalmának változása a tanulói definíciókban**
XXII. Kémiatanári Konferencia, Veszprém, 2006. (Előadás összefoglalók: 94.o)

4. Tóth Zoltán – Ludányi Lajos: **Using phenomenography combined with knowledge space theory to study students' thinking patterns in defining an atom**
12th Biennial Conference for Research on Learning and Instruction, Budapest, 2007.

7.4. Publications not connected to this thesis:

1. Tóth Zoltán – Ludányi Lajos: **A new 'challenge' in balancing redox equation**
Education in Chemistry, Vol. 43, Number 2 (March), 2006, p. 38.

2. Ludányi Lajos: **Gondolatok a Sligo-projekt kapcsán** *Új Pedagógiai Szemle* 2005. június 65-79.o

3. Ludányi Lajos: **Tábla és kréta vagy PowerPoint?** *KöKéL* 2007/2. szám 154-168.

4. Ludányi Lajos: **A kőolaj és földgáz jelentősége**
In: *Informatikai eszközök a kémia oktatásában*, Nemzeti Tankönyvkiadó, Budapest 2003.

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