International Science Education Symposium on

Particulate and Structural Concepts of Matter

University of Athens

Central Historical Building, Panepistemiou Street

Athens, Greece, 5-8 November 2010

UNDER THE AUSPICES OF:

University of Athens and its Department of Primary Education

University of Ioannina

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ΣΩΜΑΤΙΔΙΑΚΕΣ ΚΑΙ ΔΟΜΙΚΕΣ ΕΝΝΟΙΕΣ ΤΗΣ ΥΛΗΣ (Particulate and Structural Concepts of Matter)

Υπό την Αιγίδα των ΠΑΝΕΠΙΣΤΗΜΙΩΝ ΑΘΗΝΩΝ και ΙΩΑΝΝΙΝΩΝ

Κεντρικό Κτήριο Πανεπιστημίου Αθηνών (Οδός Πανεπιστημίου)

5-8 Νοεμβρίου 2010

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Στο Συμπόσιο θα συμμετάσχουν ως ομιλητές οι παρακάτω (η σειρά αναγραφής είναι σύμφωνα με το πρόγραμμα του συμποσίου): Hannah Sevian (University of Massachusetts, USA), Philip Johnson (University of Durham, UK), Constantinos P. Constantinou (University of Cyprus), Ingo Eilks (University of Bremen, Germany), Dimitris Psillos (University of Thessaloniki), Marianne Wiser (Clark University, USA), George Papageorgiou (University of Thrace), Mirjam Steffensky (IPN Kiel Germany), Marijn R. Meijer (Utrecht University, the Netherlands), Bhawani Venkataraman (The New School for Liberal Arts, New York, USA), George Kalkanis (University of Athens), Sevil Akaygun (Bogazici University, Istanbul, Turkey), Avi Hofstein, Rachel Mamlok-Naaman, and Tamy Levy Nahum (The Weizmann Institute of Science, Israel), Georgios Tsaparlis (University of Ioannina), Joseph Krajcik (University of Michigan, USA), Ajda Kahveci (Canakkale Onsekiz Mart University, Turkey), Canan Nakiboğlu (Balikesir University, Turkey), Vicente Talanquer (University of Arizona, USA), Iztok Devetak (University of Ljubljana, Slovenia), Karina Adbo (Linnoeus University, Sweden), Constantine D. Skordoulis (University of Athens).

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Particulate and Structural Concepts of Matter

PROGRAM AND ABSTRACTS

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University of Athens, Athens, Greece
5-8 November 2010

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University of Athens
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International Science Education Symposium on Particulate and Structural Concepts of Matter

Athens Greece, 5-8 November 2010

Under the auspices of:

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University of Ioannina

SYMPOSIUM ORGANISERS:

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THIS BOOKLET WAS PRINTED AT
The University of Ioannina, Printing House

(The cost was covered by the University of Ioannina)

COVER PICTURE

Athena thinking or mourning

Athena, goddess of wisdom and war, bare-footed, with helmet, wearing a Doric veil, leaning against her spear, and looking thoughtfully at the column in front of her.

Marble Relief, ca. 460 B.C., *Acropolis Museum, Athens*

WELCOME

We welcome to Athens all participants of this symposium, who responded with enthusiasm to our invitation. We are confident that their expertise and experience, coupled with the discussions during the symposium, will contribute greatly to the understanding of the present state of knowledge with respect to the teaching and learning of the particulate and structural concepts of matter.

Athens, November 2010

George Kalkanis and Georgios Tsaparlis

Acknowledgments

We thank the *Rectors* and the other *administrative authorities* of the *University of Athens* and the *University of Ioannina* for the material and financial support to the organization of this symposium. Thanks are also due to the *Department of Primary Education* of the *University of Athens* for financial support.

G. K. and G. T.

PROGRAM

International Science Education Symposium on Particulate and Structural Concepts of Matter

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SHORT PROGRAM

FRIDAY, 5 NOVEMBER 2010

17.00-18.00 Registration
18.00-18.30 Addresses
18.30-19.50 ***Session 1:*** LEARNING PROGRESSIONS FOR TEACHING A PARTICLE MODEL OF MATTER, part I
20.00-21.30 Reception

SATURDAY, 6 NOVEMBER 2010

08.30-10.30 ***Session 2*:** STUDENTS' AND TEACHERS' MENTAL MODELS OF THE PARTICULATE NATURE OF MATTER, part I
10.30-13.30 Visit to the Acropolis Museum (including a lunch break)
14.30-16.30 ***Session 3*:** PRE-K, KINDERGARTEN AND PRIMARY SCHOOL
16.30-17.00 Coffee Break
17.00-18.20 ***Session 4:*** CONTEXT-BASED TEACHING AND LEARNING
18.30-19.50 ***Session 5:*** EDUCATIONAL TECHNOLOGY
20.00-23.30 Symposium dinner

SUNDAY, 7 NOVEMBER 2010

09.00-10.30 ***Session 6*:** CHEMICAL BONDING, part I
10.30-11.00 Coffee break
11.00-12.20 ***Session 7*:** CHEMICAL BONDING, part II
12.30-14.00 Lunch break
14.15-16.50 ***Session 8*:** LEARNING PROGRESSIONS FOR TEACHING A PARTICLE MODEL OF MATTER, part II / STUDENTS' AND TEACHERS' MENTAL MODELS OF THE PARTICULATE NATURE OF MATTER, part II
17.00-19.30 Social activity
20.00-23.00 Optional dinner at the 'Strofi' restaurant

MONDAY, 8 NOVEMBER 2010

08.30-10.30 ***Session 9*:** CHEMICAL REACTIONS, CHEMICAL PHENOMENA
10.30-11.00 Coffee break
11.00-12.30 ***Session 10**:* HISTORY AND PHILOSOPHY OF SCIENCE / QUANTUM MECHANICS, QUANTUM CHEMISTRY
12.30-13.15 Conclusions and closing of the Symposium

PROGRAM [1]

FRIDAY, 5 NOVEMBER 2010

17.00-18.00 Registration

18.00-18.30 Addresses

Session 1 (18.30-19.50): LEARNING PROGRESSIONS FOR TEACHING A PARTICLE MODEL OF MATTER, part I

(Chair: Avi Hofstein, Discussant: Constantinos P. Constantinou)

18.30-19.00 *Hannah Sevian and Marilyne Stains*
Mental models held by students and cognitive constraints hindering progress in understanding of the structure and motion of matter for students aged 13 through undergraduate level *(p. 12)*

19.00-19.30 *Philip Johnson*
How students' understanding of particle theory develops: a learning progression *(p. 13)*

19.30-19.50 Discussion

20.00-21.30 Reception

SATURDAY, 6 NOVEMBER 2010

Session 2 (08.30-10.30): STUDENTS' AND TEACHERS' MENTAL MODELS OF THE PARTICULATE NATURE OF MATTER, part I

(Chair: George Papageorgiou, Discussant: Marianne Wiser)

08.30-09.00 *Constantinos P. Constantinou, Michael Michael, Loucas Louca*
A modeling scaffolded approach to promoting the active invention and elaboration of interpretive particle mechanisms by students aged 10 – 12 years old: the impact of epistemological frames on the invention of conceptual models as interpretive frameworks *(p. 14)*

[1] In case of multiple-author papers, the presentation will be made by the first author. After the title of each presentation, the page number of the abstract is given as *(p. X)*.

SATURDAY, 6 NOVEMBER 2010 (continued)

09.00-09.30 *Ingo Eilks, Janina Bindernagel*
Teachers' ways through the particulate nature of matter in lower secondary chemistry teaching: a continued change of different models vs. a coherent conceptual structure? *(p. 14)*
09.30-10.00 *Eleni Petridou, Euripides Hatzikraniotis, Maria Kallery, and Dimitris Psillos*
A study on exploratory use of microscopic models as research tools: the case of polarization *(p. 15)*
10.00-10.30 Discussion

10.30-13.30 Visit to the Acropolis Museum. Transfer by metro.* (Including lunch at the museum restaurant - participants must pay for themselves.)

* At Panepistimio Metro Station, take Line 2 of Metro, direction Aghios Dimitrios, and get off at 'Acropoli' station (the second stop). Ticket price: 1 euro.** Validate your ticket on entering the station.
** A 1 euro ticket allows unlimited travel for 90 minutes on all Athens means of transport, including metro, excluding the Airport-Athens bus service. A 3 euro/10 euro ticket allows unlimited travel as above for one day/one week.

Session 3 (14.30-16.30): PRE-K, KINDERGARTEN AND PRIMARY SCHOOL

(Chair: Tami Levy Nahum, Discussant: Dimitris Psillos)

14.30-15.00 *Marianne Wiser and Victoria Fox*
Quantifying amount of material: a teaching intervention in preK and kindergarten *(p. 17)*
15.00-15.30 *George Papageorgiou*
Explanations of chemical changes in relation to the structure of substances in young ages *(p. 18)*
15.30-16.00 *Mirjam Steffensky and Ilka Parchmann*
Do we need particulate concepts in primary science? *(p. 18)*
16.00-16.30 Discussion

16.30-17.00 Coffee break

Session 4 (17.00-18.20): CONTEXT-BASED TEACHING AND LEARNING

(Chair: Karina Adbo, Discussant: Ingo Eilks)

17.00-17.30 *Marijn R. Meijer, Astrid M.W. Bulte & Albert Pilot*
Macro – micro thinking: implementation of meso–structures in secondary chemistry education *(p. 19)*

SATURDAY, 6 NOVEMBER 2010 (continued)

17.30-18.00 *Bhawani Venkataraman*
Chemical origin of life as a context for teaching introductory chemistry *(p. 20)*
18.00-18.20 Discussion

Session 5 (18.30—19.50): EDUCATIONAL TECHNOLOGY
(Chair: Canan Nakiboglu, Discussant: Constantine Skordoulis)

18.30-19.00 *George Kalkanis*
From scientific to educational Monte Carlo simulations of microKosmos in the frame of scientific/educational methodology *(p. 20)*
19.00-19.30 Sevil *Akaygun and Loretta Jones*
The effects of computer visualizations on students' mental models of dynamic equilibrium *(p. 21)*
19.30-19.50 Discussion

20.00-23.00 Symposium dinner

SUNDAY, 7 NOVEMBER 2010

Session 6 (09.00-10.30): CHEMICAL BONDING, PART I
(Chair: Ajda Kahveci, Discussant: Vicente Talanquer)

09.00-09.40 *Avi Hofstein*
Teaching and learning the concept of chemical bonding *(p. 22)*
09.40-10.10 *Rachel Mamlok-Naaman*
The bonding concept: twenty years of misconceptions of chemistry high school students *(p. 23)*
10.10-10.30 Discussion

10.30-11.00 Coffee break

Session 7 (11.00-12.20): CHEMICAL BONDING, PART II
(Chair: Sevil Akaygun, Discussant: Rachel Mamlok-Naamann)

11.00-11.30 *Tami Levy Nahum*
New directions for teaching the chemical bonding concept - A new bottom-up framework *(p. 23)*

SUNDAY, 7 NOVEMBER 2010 (continued)

11.30-12.00 *Georgios Tsaparlis and Eleni Pappa*
Intra- and inter-molecular bonding: learning hierarchies in the literature of general chemistry and in the States-Of-Matter Approach (SOMA) *(p. 24)*
12.00-12.20 Discussion

12.30-14.00 Lunch break

Session 8 (14.15-16.50): LEARNING PROGRESSIONS FOR TEACHING A PARTICLE MODEL OF MATTER, part II / STUDENTS' AND TEACHERS' MENTAL MODELS OF THE PARTICULATE NATURE OF MATTER, part II

(Chair: Mirjam Steffensky, Discussant: Philip Johnson)

14.15-15.30* *Joseph Krajcik*
Supporting students in building a particle model of matter *(p. 11)*
***** (including a discussion part at the end of the presentation)
15.30-16.00 *Ajda Kahveci*
Assessing student conceptions of the particulate structure of matter: two-tier testing *(p. 16)*
16.00-16.30 *Canan Nakiboglu and Keith S. Taber*
Turkish students' perceptions of the atom in relation to a common teaching analogy *(p. 16)*
16.30-16.50 Discussion

17.00-19.30 Optional social activity: Transfer by metro to Monastiraki* and walk toward Theseion, with stop (around 17.45) for coffee at a Cafeteria.
* At Panepistimio Metro Station, take Line 2 of Metro, direction Aghios Dimitrios, and change (at the first stop) at Syntagma for line 3, direction Egaleo. Monastiraki is the first stop. Ticket price: 1 Euro.**
** A 1 euro ticket allows unlimited travel for 90 minutes on all Athens means of transport, including metro, but excluding the Airport-Athens bus service. A 3 euro/10 euro ticket allows unlimited travel as above for one day/one week.

20.00-23.00 Optional dinner at participants' expenses in 'Strofi' restaurant, 25 Rovertou Galli Street and Propylaion Street (across the Herodeion Theatre at the foot of the Acropolis). À la carte menu. Cost per person around Euro 25.00. Participants, who will have taken the previous social activity, will walk from Theseion to the Strofi Restaurant along the Apostolou Paulou Street, followed by the Dionysiou Areopagitou Street. The others can go to the restaurant by taxi or by bus No. 230 or by the Metro (Acropoli Station).

MONDAY, 8 NOVEMBER 2010

Session 9 (08.30-10.30): CHEMICAL REACTIONS, CHEMICAL PHENOMENA

(Chair: Bhawani Venkataraman, Discussant: Hannah Sevian)

08.30-09.00 *Vicente Talanquer*
How do chemistry students design chemical substances and processes? *(p. 25)*

09.00-09.30 *Iztok Devetak, Janez Vogrinc, and Saša A. Glažar*
The influence of submicrorepresentations on pre-service primary school teachers' understanding of the chemical reactions between halogens *(p. 25)*

09.30-10.00 *Karina Adbo and Keith S. Taber*
Developing chemical understanding in the explanatory vacuum: Swedish high schools students' use of an anthropomorphic conceptual framework to make sense of chemical phenomena *(p. 26)*

10.00-10.30 Discussion

10.30-11.00 Coffee break

Session 10 (11.00-12.30): HISTORY AND PHILOSOPHY OF SCIENCE / QUANTUM MECHANICS, QUANTUM CHEMISTRY

(Chair: Iztok Devetak, Discussant: Marijn R. Meijer)

11.00-11.30 *Constantine D. Skordoulis*
Investigating the historical development of the concept of matter from ancient atomism to quantum mechanics *(p. 27)*

11.30-11.50 *Canan Nakiboğlu*
The relation of prospective chemistry teachers' working memory capacity with their cognitive structure variables: the case of quantum mechanical theory of atom *(p. 28)*

11.50-12.10 *Georgios Tsaparlis, Georgios Papaphotis, and Christina Stefan*i
Teaching and learning the basic quantum chemical concepts: conceptual versus algorithmic learning, students' levels of explanations, models, and misconceptions, and attempts at conceptual change *(p. 29)*

12.10-12.30 Discussion

12.30-13.15 Conclusions and closing of the Symposium

INDEX OF PRESENTING AUTHORS

INDEX OF OTHER AUTHORS

International Science Education Symposium on

Particulate and Structural Concepts of Matter

ABSTRACTS

Co-Organizers: University of Athens and University of Ioannina

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Students' and teachers' mental models of particulate nature of matter

Supporting students in building a particle model of matter

Joseph Krajcik
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Learning progressions (LPs) depict how students' ideas about of a particular domain of science become increasingly more specific over time. They are also a means for helping both students and teachers track developing understanding (Duschl, Schweingruber, & Shouse, 2007; Smith et al., 2006). Although only hypothetical, LPs describe levels of understandings that learners need to develop to move to more sophisticated understandings of an idea. Moreover, they provide a means for thinking about how to present important science ideas to students so that the ideas build on each other within a year or across the year. As such, learning progressions are also particularly helpful to both teachers and curriculum developers in designing instructional materials.

Over the last several years, we have built on and refined the work of Smith and colleagues to develop a learning progression for the nature of matter (NofM) that spans from grades 5 – 12 (Stevens, Delgado & Krajcik, in press; Shin, Steven & Krajcik, in press). The NofM is a critical idea that students must grasp if they are to be scientifically literate as it is necessary to explain a range of phenomena. Our view of learning progressions also include assessments to measure students' understanding and that allow teachers and researchers to place students at particular levels, and key instructional components that can help students move from one level to the next.

In this session, we will explore how to support moving students from a descriptive model of matter to a basic particle model – two key levels in our learning progress of NofM. We will share our overall learning progression of the NofM as well as zoom into the section that describes student understanding of a descriptive model to the robust particle model (Merritt & Krajcik, 2009). In a descriptive model, students describe objects as they appear at the macroscopic level. Smaller and smaller pieces of a material are similar to the larger piece. Thus, materials, no matter how small, even those submicroscopic, always have the same properties as larger macroscopic pieces. In a beginning particle model, students use a particle view to describe materials. Initially, students do not identify the particles as atoms or as molecules made of atoms, but just particles with no substructures. However, there is empty space between the particles. Students may describe the motion of the particles on the particle level, but it is relative to the other states of matter. They explain the different states and the transition between states using the particle model. With more experiences, students differentiate the particles into atoms and molecules that have unique identities and properties. As such a basic particle model serves as an important stepping-stone for students to develop more robust understandings of particle model of matter – the next higher level in our learning progression that we call a complete particle model. We conclude by sharing instructional ideas to move students from one level to the next as well as show data that supports the use of these levels and instructional ideas.

Reference:

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.

Mental models held by students and cognitive constraints hindering progress in understanding of the structure and motion of matter for students aged 13 through undergraduate level

Hannah Sevian[1] * and *Marilyne Stains*[2]
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[2] Center of Science and Math in Context and Department of Chemistry, University of Massachusetts Boston, Boston, USA
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The development of conceptual understanding is influenced by the mental models learners hold and use to explain and predict scientific phenomena. The development and transformation of these mental models is constrained by common-sense reasoning and intuitive knowledge. Thus, characterizing students' understanding and the implicit assumptions that constrain their development is crucial to designing instruction, assessments, and instructional materials that anticipate and address barriers to student learning. A student questionnaire, the Structure and Motion of Matter (SAMM) survey, along with a scoring scheme, were developed, validated and shown to be reliable in characterizing students' development along four dimensions in a particle theory of matter learning progression: structure of solute, structure of solvent, origin of motion of particles, and trajectories of particles. This survey was administered to students in middle school, high school, community college, and lower- and upper-level undergraduate university courses, across biology, chemistry and physics courses. Five distinct mental models emerged from analysis of the data. All five models were present among students at every level. Further analysis of the data and additional interviews revealed some persistent implicit assumptions based on common-sense reasoning that constrain the mental models students developed. Implications for instruction, assessment, and the design of instructional materials are discussed.

How students' understanding of particle theory develops: a learning progression

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Students' problems with the particle theory are well known. Rather than bundling these together we can ask if some components are more challenging than others. Do ideas locate on a hierarchy of difficulty which charts how understanding develops; i.e. a learning progression? This article presents findings from a large-scale study which suggests there is a hierarchy with general application. Data were collected from 4450 students, aged 11-14, across 30 secondary schools in England using a computer-based assessment instrument. The construction of the items was informed by the research literature on students' understanding. Thirty eight fixed response items explored the following aspects:

- the relationship between 'basic' particles and the substance

- the nature of particles
- the spacing of the particles
- the intrinsic motion of particles
- the use of a basic particle model to explain physical phenomena
- the use of ideas of atoms to explain chemical changes

Distracter options were based on likely misconceptions. Insights from the development of items are discussed. Scored dichotomously, Rasch modelling was used to measure item difficulty and conformity to a single dimension. Overall, the data show a good fit to the Rasch model. Item difficulties have a high degree of invariance across ability, schools, gender and year group. Conceptually, when items are placed in order of difficulty, a coherent progression of ideas emerges. The progression will be presented and discussed. The sequence matches the findings of a previous small–scale three year longitudinal study (ages 11-14). Therefore, there is reason to suppose the progression tracks the development of individual thinking. Other items explored students' macroscopic understanding of physical and chemical phenomena and the relationship between macroscopic and particulate understanding is also considered. Independent, nationally standardized data allow tentative projection of student performance to the wider UK population. In line with the wider literature, the average 14 year old is relatively low down on the scale. Implications for teaching are discussed. A cumulative approach to particle theory is argued for.

A study on exploratory use of microscopic models as research tools: the case of polarization

E Petridou[1], *E. Hatzikraniotis*[2], *M. Kallery*, *D Psillos*[1 *]
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As research shows that the knowledge and use of microscopic models is rather limited the present paper focus on the use of microscopic models as research tools by students in a specific area. Multiple representations of a didactically transformed simulated microscopic model were used in the context of teaching units which focused on phenomena and concepts related to polarization. Affordances of the simulated model showed structural and behavioural aspects of atoms. Subjects used the model in an explorative way as a research tool in order to predict electric interactions. The teaching units were applied to one group of lower secondary students as well to one group of student-teachers. Data were obtained by the analysis of written answers and related transcribed interview protocols taken in the course of teaching. Results showed that both students in university and students in lower secondary school quoted and detected different elements of the model that helped them to predict the evolution of polarization phenomena at study and seem to have understood aspects of the function of microscopic models as research tools.

A modeling scaffolded approach to promoting the active invention and elaboration of interpretive particle mechanisms by students aged 10–12 years old: the impact of epistemological frames on the invention of conceptual models as interpretive frameworks.

C. P. Constantinou, M. Michael, L. Louca*
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We have investigated the classroom use of graphical programming software in facilitating the ability of upper elementary school children in inventing and elaborating a particle model for the interpretation of a range of phenomena. Nine students participated in this study, in which they were engaged in a constructionist process of using a graphical software tool to develop their own interpretive mechanisms for a sequence of phenomena including diffusion, filtration and dissolving. The teaching and learning framework was designed following the modeling-based learning cycle. Students used Stagecast Creator as their modeling software. We collected data through classroom video and dynamic computer screen capture. We have used discourse analysis to document the process of model development and identify instances of collaborative invention of conceptual models as well as transition from one conceptual model to another. We have also used artifact analysis of the student generated models to identify student conceptions of the nature of material processes in these phenomena and the epistemological frames that have facilitated the invention of particle based models and their use in generating mechanistic interpretations of the phenomena.

Teachers' ways through the particulate nature of matter in lower secondary chemistry teaching: a continued change of different models vs. a coherent conceptual structure?

Ingo Eilks and Janina Bindernagel*
University of Bremen, Institute for the Didactics of the Sciences (IDN), Chemistry Education
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The paper reports a study from research-based learning in chemistry teacher education. Advanced student teachers interviewed 23 experienced chemistry teachers concerning their practices of how to deal with the particulate nature of matter in lower secondary science education (grade 5-10, age 10-16). The study revealed a predominant belief of the teachers that chemistry teaching has to encompass a continued change of different historic models of the particulate nature of matter itself, atomic structure and bonding theory. But, the study also revealed that this concept in a lot of cases is not well developed, justification is not reflected, and teaching approaches represent inconsistencies in the teachers' knowledge base and PCK itself. Only few of the teachers described other approaches. This difference is connected to insights into a 7-year Participatory Action Research project, in which a group of teachers accompanied by chemistry educators developed an alternative approach through the particulate nature of matter. This approach is characterized by the development of an in itself coherent conceptual structure of

how to deal with the particulate nature of matter, atomic structure and bonding theory in the course of lower secondary chemistry teaching.

Assessing student conceptions of the particle structure of matter: two-tier testing

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The particle structure of matter is a fundamental topic constituting the basis of more advanced subjects such as chemical bonding and reactions. Student understanding in this area has been the subject of extensive research for decades. Various alternative probing techniques have been developed and used in many chemistry subjects. However, the use of two-tier diagnostic testing in the subject of the particle structure of matter has been scarce. In this study, two-tier diagnostic test items were developed by integrating alternative conceptions drawn from the literature as distracters. The items were pilot tested with 164 ninth graders from a high achieving school to utilize student feedback for item improvement and the validity of the inferences. After the revisions a total of 129 ninth graders from three different lower achieving schools answered the items. Results indicate a wide gap between the high and the relative low achievers in terms of correct answer percentages, in spite of item improvement. Also, a distracter-level analysis shows that the lower achievers possess more of the integrated alternative conceptions. The study confirms the importance of student feedback in item development, and points to the potential of diagnostic testing in the subject of the particle structure of matter.

Education technology

From scientific to educational Monte Carlo simulations of microKosmos in the frame of scientific/educational methodology

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Since microkosmos is eminently a stochastic system, simulation / visualization / animation of the processes of microkosmos must be attempted with the use of Monte Carlo methods / techniques. The author –inspired by some applications of those techniques which he designed / realised / used for scientific high energy research– supervised the creation of some “views” of microkosmos. These views which are presented in the form of static captures or/and computer animated simulations of some processes / models of microkosmos may offer to the students (and teachers as well) the opportunity of an imaginary journey into the interior of the matter, getting a glimpse of the microscopic processes.* Views of the structure of matter, the interactions between the particles and the movements of the particles –based on the relevant models of microkosmos–

can explain most of the macroscopic concepts and phenomena. Furthermore, microkosmos is the part of the world where the wave-particle duality comes up vigorously and such computer simulations / animations may wipe out some students' misconceptions and clarify some quantum "paradox" such as the paradox of wave-particle duality, enhancing the traditional way and thematology of science education. The use of those views of microkosmos is advised to be embedded to the steps of the scientific / educational methodology, which is an attempt to apply the scientific methodology for research (and) as a didactical methodology for education by inquiry.

* http://micro-kosmos.uoa.gr

Context-based teaching and learning

Macro–Micro thinking: implementation of meso–structures in secondary chemistry education

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Students often experience that it is difficult to relate (sub) microscopic models to macroscopic phenomena. In line with the works of Millar (1990) and Besson& Viennot (2004), we have proposed to break up this 'huge' gap into smaller steps, that is, to make use of intermediate 'meso' structures such as: a weaving patters, a thread, smaller filaments within fibres, amorphous and crystalline parts that become manifest when using a lens, a microscope, an electron scanning microscope to investigate the nature of materials (Meijer, Bulte & Pilot, 2009 These structures at the 'intermediate' meso levels are related to its emergent properties. The following strategies for designing a teaching-learning process were used (Meijer et al., 2009): 1. use system thinking by considering a material as a system of sub systems with intermediate meso levels, 2. use students' intuitive notions, stimulating them to find the cause of a property within the material or sub system, and 3. use students' intuitive notions about 'structure' and 'property'. However, when exploring such a new approach, we have come to understand that the precise scaling of representations of different sub structures and the use of metaphors need careful attention. We show how these aspects are integrated within two new units which were implemented within a recent context-based chemistry curriculum for secondary education: a unit about ceramic materials and a unit on the development of fire-resistant materials.

Chemical origin of life as a context for teaching introductory chemistry

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The steps through which life is believed to have emerged on earth are rooted in fundamental chemical processes. Atoms formed in stars ultimately led to the formation of complex macromolecular systems that life depends on. The basic framework of atoms to small molecules, larger molecules, macromolecular systems to life provides an intriguing context for teaching chemistry. An introductory undergraduate course, "Chemistry of Life", has been developed that uses the chemical origin of life on earth as a context to introduce fundamental chemical principles. The framework of atoms to complex macromolecular systems makes it possible to present the course as a continuous "story" with concepts building on each other and emphasizing the interconnection between concepts. The context also helps students to appreciate that chemical behavior is dependent on the atomic makeup of a molecule and the resulting bonding, structure and three-dimensional shape. The context also explicitly demonstrates that molecular scale processes govern macro-scale outcomes - in this case establishing life itself. Assessment data indicate that the course provides an intellectually stimulating framework for students to learn fundamental concepts.

Pre-K, Kindergarten and Primary School

Quantifying amount of material: A teaching intervention in preK and kindergarten

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Young students' conceptualization of matter and its behavior at the macroscopic level is profoundly different from a scientific view. In particular, young children know some materials but do not yet have the concept *made of material X* nor distinguish between accidental and inherent properties of materials. They also do not quantify nor conserve amount of material. Reconceptualizing matter at the macroscopic level is in elementary school is therefore essential to making sense of the atomic molecular theory in middle and high school. In this intervention involving 25 children ages 4-6, children learned 1) to distinguish between objects and materials; 2) to use the locution "made of"; 3) to focus on properties of material. They also explored the effects of spatial transformations on number and weight of Lego constructions and cups of rice Pre- and post-tests show significant gains in conceptualizing material and amount of material, as well as in number knowledge. A control group who explored materials informally in the context of art lessons showed no significant gains.

Explanations of chemical changes in relation to the structure of substances in young ages

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Since the meaning of an explanation of a chemical change is related to both, an evaluation of the macroscopic changes and a work on the microscopic level, any satisfying explanation needs the development of a particular model describing the structure of substances. A number of such models have been already developed in relation to corresponding educational levels, providing bases for explanations of chemical changes respectively. In this paper, after an attempt to generally categorize such models in relation to educational levels, some thoughts are presented, concerning the general context, the possibilities and the usefulness of an introduction of such a particle model and possible corresponding explanations to young ages. Although skeptical to a certain degree, the idea to work for satisfying explanations of chemical changes even from the upper grades of primary school is supported. Some preconditions concern a curriculum carefully designed along with the development of appropriate teaching methods for its better implementation.

Do we need particulate concepts in primary science?

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Science is accepted as an educational goal in primary school and even in preschool. However not very much is known about the development of particulate concepts of younger children. There are very many and controversy opinions about using particulate concepts in this age, and in different countries we find various approaches to introduce this basis concept. In contrast, empirical data about the effects is rare; especially studies with a longitudinal design are seldom. It seems to be evident that in carefully designed learning environments where scaffolds are used younger children can acquire sufficient (basic) understanding of the structure of matter (Novak, 2005; Johnson, 1998). Nevertheless a proposed problem is for example that younger students tend to think of particles as grains of matter that e.g. can dilate or change state (Piaget, 1972; Claxton, 1994). Most studies have been performed under rather special conditions, thus it is not clear what happens if not specially trained primary teachers introduce particulate models in science lessons. Besides a conceptual understanding of the structure of matter, first and basic particulate concepts can also be introduced in primary science with a focus on learning of modeling processes. Particulate concepts afford the use of mental models. Mental models refer to personal knowledge and not necessarily to scientifically accepted knowledge (Glynn & Duit, 1995). Some authors suggest therefore a focus on learning modeling processes in primary science as a first basic step (Eskilsson & Hellden, 2003), which is necessary for the later use of conceptual models. Modeling is an important step in scientific processes and learning to use models and learning about models is accordingly a part of understanding the nature of science. The present paper illustrates examples of the introduction of particulate concepts in primary science and discusses which typical topics of primary science could be suitable for the introduction of particulate concepts and which problems can occur within an early introduction. We than discuss how children can work with mental models und how this can be helpful for further learning science.

Chemical bonding

Teaching and learning the concept of chemical bonding*

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Chemical bonding is one of the key and basic concepts in chemistry. Clearly, many of the concepts taught in chemistry in both secondary schools as well as in the colleges are highly based on understating the fundamental ideas related to this concept. Nevertheless, the concept is perceived both by the teachers as well as by learners as difficult to teach and as causing many misconceptions regarding the students. Many of these misconceptions result from wrong models used in text books, by the use of traditional instructional techniques that present a rather limited and sometimes wrong picture of the issues related to chemical bonding, and by assessment of students' achievement that influence the way the topic is taught. In addition, there are discrepancies between scientists regarding the definition of the topic and regarding models to teach it. In this review-type lecture I will try to present an up-to-date and coherent picture regarding the research and developments of the chemical bonding.

* This lecture is highly based on a recent review to be published in: Studies in Science Education, by: Tami Levi Nahum, Rachel Mamlok-Naaman, & Avi Hofstein,The Weizmann Institute of Science, Israel, and Keith Taber, Cambridge University, UK.

The bonding concept: twenty years of misconceptions of chemistry high school students

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In Israel, the central developed Matriculation Examination in chemistry is one of the main sources for information on misconceptions of students. The analyses of the Matriculation Examinations in chemistry, over a period of almost 20 years, revealed each year that students have a fundamental misunderstanding and difficulties regarding concepts such as *chemical structure and bonding*, which are essential for understanding many concepts and topics in chemistry. No doubt, that the teaching and learning of these concepts is a serious and continuous problem. In this study we will present several factors leading to these misconceptions. More specifically, we will focus on how the structure and content of the National Matriculation Examinations conducted in Israel influence chemistry teaching and learning. We think that this type of assessment can be a major factor in the development of students’ learning difficulties and alternative conceptions.

This presentation is based on a paper published in Chemistry Education: Research and Practice in Europe.

New directions for teaching the chemical bonding concept
A new bottom-up framework

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Based on a long-term collaboration between prominent scientists, researchers in chemistry education, and expert teachers, an innovative program aimed at teaching the chemical bonding concept, which follows a holistic approach to curriculum was developed and implemented in 11th-grade chemistry classes in Israel since the academic year 2005/6. Its general approach relies on basic concepts such as Coulombic forces and energy at the atomic level to build a coherent and consistent perspective for dealing with all types of chemical bonds. During my presentation, I will try to encourage the audience to believe that it is possible to show how the diversity of bond types arises from a *small number of fundamental principles* instead of presenting it as a large number of disparate concepts. The framework proposed by Levy Nahum et al. (2008) introduces the elemental principles of an isolated atom; this is followed by discussions of general principles of chemical bonding between two atoms; the primary purpose of this stage is to provide a qualitative description which gives a very clear, intuitive answer to the question which puzzles many students, 'what *really* causes atoms to interact and form a chemical bond?' The general principles are then used to present the different traditional categories of chemical bonding as extreme cases of various continuum scales. Equipped with this knowledge, students can then construct a coherent understanding of different molecular structures and properties.

This presentation is highly based on a paper by Levy Nahum, Mamlok-Naaman, Hofstein & Kronik, published in *Journal of Chemical Education* 2008, *85*(12), p. 1680.

Intra- and inter-molecular bonding: Learning hierarchies in the literature of general chemistry and in the States-Of-Matter Approach (SOMA)

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The aim of this study is to identify and compare the method of presentation of intra- and inter-molecular bonding in general chemistry textbooks (but also in books that target high-school students and teachers). Nineteen books made the convenience sample for the comparison. Similarities and differences were identified with regard to the following aspects: presentation order of intra-molecular bonds; placement and method of presentation of inter-molecular bonds; physical states and their connection with the types of bonding; metallic bonding; semi-covalent (dative covalent) bond; the bond continuum; the octet rule. In 13 out of 19 textbooks, reference was made to the continuum in covalent and ionic bonding; only in six books, these two types of bonding are treated as autonomous types. Electronegativity is presented within polar covalent bonding. In most books only intra-molecular bonding is considered true chemical bonding, while inter-molecular bonding is referred to as inter-molecular forces or bond-forces. The octet rule is assumed a sine qua non for intra-molecular bond formation. We have also checked the extent to which the findings confirm relevant work of the Weizmann science education group ("A new 'bottom-up' framework for teaching chemical bonding"). Finally, we present the corresponding learning hierarchy of the States-Of-Matter Approach (*SOMA*) to introductory high-school chemistry.

Atomic structure

Turkish students' perceptions of the atom in relation to a common teaching analog

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Introducing the atom concept in secondary education is problematic from a number of perspectives. For one thing, the concept itself is rather complex (having shifted significantly since its initial historical introduction), and is modelled in a variety of not entirely consistent forms. It is also an entity which not available to direct perceptions and so is outside the direct experience of learners. The nature of the atom as key concept in learning about chemistry in school science has also been questioned. School teachers are charged with 'making the unfamiliar familiar' for learners, and when an unfamiliar concept cannot be demonstrated directly to a class the teacher introduces it by comparison with what is already within students' experience. One way of doing this is the teaching analogy, and in the case of the atom a common teaching analogy is that '*the atom is like a tiny solar system'*. Whilst this comparison has merit, it relies on students having sound knowledge of the structure of the solar system and being able to distinguish positive and negative aspects of the analogy: both assumptions that may be unfounded with many students. A diagnostic instrument designed to test out student understanding of the (planetary model of the) atomic system and the solar system was published as part of a project sponsored by the UK's Royal Society of Chemistry. In the present study a translated version of that instrument was administered to 458 15-18 year olds in Turkish schools. It was found that there were strong parallels in the patterns of responses for the two systems, but that only a minority of the students could give an adequate characterisation of the type of forces operating in either system; and only a minority acknowledged that a force between two bodies acts with equal magnitude on both bodies (Newton's third law – implied in both Coulomb's law and the Universal law of gravity). Examples of student comment illustrating their thinking will be discussed, and the implications for teaching (and in particular the use of the teaching analogy) will be considered.

Chemical reactions, chemical phenomena

How do chemistry students design chemical substances and processes?

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Many undergraduate students have serious difficulties understanding and applying particulate and structural concepts to build explanations and make predictions about the properties of diverse chemical systems. These problems seem to be related to the existence of cognitive constraints that guide and facilitate their reasoning but also restrict its range. In our work we have argued that core learning constraints in chemistry can be conceived as sets of interrelated implicit assumptions about the properties of substances and processes at the different representational levels in chemistry, together with heuristic reasoning strategies to make quick predictions and decisions. In this seminar, I will present and discuss the results of our research on the implicit assumptions and heuristics that seem to constrain chemistry students' reasoning and decision-making when asked to design chemical substances and processes.

The influence of submicrorepresentations on students' understanding of the chemical reactions between halogens

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Educational strategies in chemical education should lead to knowledge with understanding. To achieve this it is necessary to connect the macroscopic (observable), submicroscopic (particulate) and symbolic (symbols, formulae, equations) levels of chemical concepts. Submicrorepresentations (pictorial elements presented in 2-D static form) and the symbolic level are used by scientifically literate people to easily communicate about chemical phenomena at the abstract (particulate) level. Reasonable understanding of the chemical phenomena is established when all three levels of the concept cover each other, supported by visualization elements. After processing this information in students' working memory, the mental image - misconception free - is incorporated in students' long term memory storage and is prepared for reuse in new learning situations. The other, very important, aspect of using submicrorepresentations in chemical education can be related to the stimulation of students' motivation for learning chemistry, because they comprehend realize the significance of chemistry learning. The halogens are an important group of elements. Their compounds are important substances in nature (i.e. they can be found in organisms, dissolved in the sea, or they can form minerals) and for our way of living. Because of their importance, the parts of the school chemistry curriculums are distributed all across the educational vertical. Students usually learn about their properties and, accordingly an educational strategy has been developed to illustrate halogens' properties through students' experimental work. The basic research question asked in this study is: "Is there a statistically significant difference in understanding the properties of halogens between the students who used submicroscopic explanations of laboratory observations and those who did not?" For the purposes of this research the lab work was developed for illustrating halogens' chemical properties, and also a specific educational strategy for explaining the submicroscopic level of the experimental observations. Altogether 328 students participated in the study and conducted their laboratory work in pairs following the written instructions. Students were divided into two groups: experimental and control. Laboratory observations were explained using submicrorepresentations in the experimental group but not in the control group. Students spent on average 60 min on laboratory work. Four instruments were applied in both groups of students; three knowledge tests (pre-test, test and post-test) and TOLT (for evaluating students' formal reasoning abilities). Pre-test and the TOLT were applied before the educational strategy was carried out in both groups of students. The test was conducted immediately after the laboratory work and the post-test fourteen days after the laboratory work was finished. The preliminary data analysis showed that students have different misconceptions about the reactivity of halogens. Students' achievements on the test and post-test are statistically significantly higher in the experimental group than in the control group. It can be concluded that systematic use of submicrorepresentations could lead to students' better understanding of halogen reactivity.

Developing chemical understanding in the explanatory vacuum: Swedish high schools students' use of an anthropomorphic conceptual framework to make sense of chemical phenomena

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The results presented here derive from a longitudinal study of a group of ten 16 to 18 year old Swedish upper secondary science students' development of understanding of key concepts for matter and phase change. Data was collected by using semi-structured interviews. In the Swedish educational context there is limited prescription of what is taught and in which grade levels, consequently students may only meet scientific models of the submicroscopic structure of the matter some years after considering the phenomena which these models have been developed to explain. Students may develop alternative and sometimes idiosyncratic imaginative notions to populate this 'explanatory vacuum'. In the present paper we focus on student notions of the interactions between molecules (inter-molecular bonding) used by students in their explanations of phenomena such as change of state. For the students included in this study, the formally presented target models for intra and intermolecular bonding were separated in time with almost a full school year. This approach left the students in an explanatory vacuum with respect to intermolecular bonding that lasted for the major part of the first year of upper secondary school studies. Results suggest that these students commonly filled the 'explanatory vacuum' by the use of anthropomorphist and teleological explanations. Findings indicate that, when not addressed, these types of explanations may impede students' development regarding the target models for intermolecular bonding.

Quantum mechanics, Quantum chemistry / History and Philosophy of Science

Particle and/or Wave: investigating the historical development of the concept of matter

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This paper explores the origins and development of the concept of matter and the controversies surrounding it. The apparent contradictions of particle and wave reflect very different ways of understanding the physical world. The dichotomy between particle and wave reflects the controversy about the continuous or discrete form of matter originating in antiquity when natural philosophers first speculated about the constitution of the physical world. Starting with the ancient Greek atomists who attributed all physical phenomena to atoms and their motion in the void, the paper examines the contributions of thinkers like Descartes, Newton, Huyghens and Maxwell and shows how Quantum Mechanics by postulating the coexistence of the particle and the wave descriptions pushes scientific thinking to a different and renewed conception of the physical world.

POSTERS

Quantum mechanical models

The relation of prospective chemistry teachers' working memory capacity with their cognitive structure variables: the case of the quantum mechanical theory of atom

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The current sophisticated quantum mechanical theory of atom is part of the upper secondary curriculum and general chemistry courses in many countries. The quantum mechanical model of the atom is one of the most difficult topics for students to understand at all levels of chemistry. One of the problems about atomic theories is that the atom concept is presented as a confused amalgam of historical models. The learners construct knowledge in their conscious working memory, and store that knowledge in long term memory. The knowledge students acquire in science classrooms is stored in long term memory in a hierarchically organized form, and can be represented as a *cognitive structure* in their memory, which is a hypothetical construct representing the organization and relationships of concepts in a learner's long term memory. In the present study the relation of 42 Turkish prospective chemistry teachers' working memory capacity with their cognitive structures concerning quantum mechanical theory of atom were examined. For probing students' cognitive structures, a flow map method coupled with a meta-listening technique was used based on Tsai, 2001. Working memory was assessed using digit-

span task according to multiple-component model. Analysis of flow maps was provided the following quantitative variables cognitive structure: extent (ideas), richness (recurrent linkages), integratedness, information retrieval rate, flexibility. In addition to quantitative variables, flow maps were used to acquire content analyses of students' information processing operations. The information processing was analysed into the following categories: defining, describing, comparing and contrasting, conditional inferring, and explaining. Finally, the flow maps were examined to find out whether quantum mechanical theory of atom was hold in students' cognitive structure. The relation of working memory and cognitive structure variables were analysed by calculating Pearson *r* correlation coefficients. It was found that there was significant correlation between working memory capacity and extent, and between working memory capacity and richness. However there was no significant correlation between working memory capacity and integratedness, information retrieval rate, flexibility. It was also found that only 13 of 42 students hold quantum mechanical theory of atom in their cognitive structures. Examples of students' flow map will be discussed by taking quantum mechanical theory of atom into account, and the implications for teaching will be considered.

Teaching and learning the basic quantum chemical concepts: conceptual versus algorithmic learning, students' levels of explanations, models, and misconceptions, and attempts at conceptual change

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Basic quantum-chemical theories and models are basic components of the general chemistry and the introductory inorganic (but also organic) chemistry courses. They are also part of the upper secondary curriculum in many countries. In this paper, we review a number of our studies on misconceptions and learning difficulties occurring with students at the high school and at the university level. For many students the orbitals represent a definite, well-bounded space; also, they do not realize the approximate nature of atomic orbitals for many-electron atoms. The planetary Bohr model is strongly favored, while the probabilistic nature of the orbital concept is absent. Other students hold a hybrid model. A notable difference has been identified in performance in questions that tested recall of knowledge or application of algorithmic procedures with that on questions that required conceptual understanding and/or critical thinking. Four levels of students' explanations as well as three levels of models have been reported based on Ausubel's theory of meaningful learning. By combining levels of explanations with levels of models, we derived four categories. Two of the categories are in the rote-learning part of a continuum, while the other two categories are in the meaningful-learning part. Finally, we have tested for deep understanding and critical thinking about the basic quantum chemical concepts taught at twelfth grade with the aim to achieve conceptual change in students. The method proved effective in a number of cases, and ineffective in others.