7th ECRICE, Ljubljana

European Conference on Research in Chemical Education

3rd ECCE, Ljubljana

European Conference on Chemical Education

24th August – 28th August 2004

PROCEEDINGS

Edited by:

S. A. Glažar** and **D. Krnel

University of Ljubljana
Faculty of Education

Slovene Chemical Society

Federation of European Chemical Societies
(FECS)

Ljubljana, Slovenia

PROCEEDINGS
7th ECRICE and 3rd ECCE

Edited by:
Saša A. Glažar and Dušan Krnel

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Content

Foreword

It is an honour for the Faculty of Education of the University of Ljubljana to host the 7th European Conference on Research in Chemical Education – ECRICE and the 3rd Conference on Chemical Education – ECCE. First of all, we would like to welcome the participants from more than 25 countries in Europe as well as from other parts of the world. This international attendance will undoubtedly contribute to a rich exchange of ideas and the transfer of knowledge into education, with the focus on the development of critical thinking, which is a necessary precondition for problem solving and decision making.

The primary purpose of the meeting is to provide space for an exchange of findings and experiences dealing with the role of chemical education at the time of increasing global competition and demands to achieve sustainability of development, which will define our future living standards. We need to redefine the impact of new discoveries in the area of chemistry as well as border sciences, of the development of green chemistry and information communication technologies on the learning and teaching of chemistry, which should be geared by research in chemical education.

The leading themes of the conference are:

(1) Research in Chemical Education;

(2) Chemistry Curricula and Chemistry Teacher Training;

(3) Information Communication Technology in Learning and Teaching Chemistry;

(4) Chemical Literacy;

(5) Major Developments in Chemistry and How They Influenced Chemistry Teaching.

The present volume contains the selection of 116 contributions: plenary sessions (5), keynotes (2), oral presentations (17) and posters (6). The extended abstracts refer to oral presentations, short abstracts to workshops and posters.

In the name of the Organising Committee, I would like to thank all those who made this meeting possible and in particular the speakers themselves, the Scientific Committee and Peter Childs, the Chair of FECS Division of Chemical Education for his help in making this event possible. Thanks is also due to the Ministry of Education, Research and Sport of the Republic of Slovenia, to the Slovene Chemical Society, the University of Ljubljana, the Faculty of Education for providing the facilities, and to all the sponsors of the Conference.

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Plenary Sessions

Chirality and Molecules of Life

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To explain all nature is too difficult a task for any one man or even for any age. It is much better to do a little with certainty, and leave the rest for others that come after you, than explain all things.
(Sir Isaac Newton)

Life is chemistry and is based on chemical transformations. All living organisms on Earth depend on two fundamental chemical features of life: the phosphorus-oxygen bond (sometimes called »bond of life«) and chirality. The term chirality (from greek: *kheir* – hand) was first introduced by Lord Kelvin (William Thomson), a british physicist, in a lecture about crystals in Oxford in 1883. Chirality, handedness, is a geometrical attribute and whether or not a molecule or crystal is chiral is determined by its symmetry. A molecule is chiral if it cannot be superimposed onto its mirror image. Chiral molecules lack symmetry – they are necessarily asymmetric – but some asymmetric molecules are not chiral. A physical consequence of chirality is optical activity which started the development of stereochemistry, which can be static (molecules) or dynamic (stereochemistry of reactions).

Molecules of life are constructed from simple symmetric molecules to give either symmetric or asymmetric, chiral, organic compounds. Once a chiral molecule is incorporated in a biopolymer, chirality is incorporated in all further hierarchical levels of structures of living matter. This is outlined in the following scheme:

Symmetry				Asymmetry, chirality
H_2O, CO_2, N_2, NH_3 H_2S	⇒	organic molecules ↓ achiral molecules	→	chiral molecules ↓ biomolecules, macromolecules (informations) ↓ microfibrils, fibrils, filaments ↓
supramolecular chemistry molecular recognition self-assemblies				cells ↓ organs (morphology) ↓ living organisms, human brains ↓ cultures

The important natural biopolymers (proteins, nucleic acids, polysaccharides) must be homochiral, they must originate from either *L*- or *D*-precursors, i.e. all monomer components must have the same chirality. Homochirality is therefore a hallmark of life. Structures of higher order which are based on noncovalent interactions and self-assembly or form supramolecular aggregates must also have the ability of chiral recognition.

It was a long way to recognize all features of chirality and the consequences as are known to chemists today. A chronological summary of the most important events in the development of our knowledge about chiral molecules is presented as follows:

1848	Pasteur separated crystals of tartaric acids
1858	Empirical formula of glucose was determined to be $C_6H_{12}O_6$
	Penicillium glaucum used for growth only (+)-tartaric acid – connection of chirality and biological activity
1866	Kekulé changes the name of glucose to *dextrose* because it rotated the plane of polarized light to the right
1874	Le Bel and vant' Hoff independently develop the theory of optical rotation caused by »asymmetric« tetrahedral carbon atom
1884	E. Fischer embarks on the determination of the structures of carbohydrates (24 years)
1888	Glucose is shown to be a six-carbon polyhydroxy aldehyde
1890	E. Fischer changes the name of dextrose back to *glucose* and levulose to *fructose*
1892-1900	Controversies develop about the structures of the carbohydrates, based on the formation of two methyl-*D*-glucosides, mutarotation, and other inconsistencies of a polyhydroxy aldehyde or ketone. Structures of carbohydrates are *relative configurations*
1909	C. S. Hudson proposed a nomenclature for the two isomeric methyl-*D*-glucosides and related hemiacetal isomers
1920-1930	W. N. Haworth definitively demonstrated the size of carbohydrate rings
1922, 1942	Chirality of compounds with no stereogenic centers, but with restricted rotation about single bond (biaryls. cyclophanes) was discovered
1951	Bijvoet determined by X-ray analysis the absolute configuration of (+)-tartaric acid. The *absolute* configuration of Fischer"s previously proposed *relative* configuration was thus confirmed.
1946	Bloch and Purcell independently applied NMR for analyzing liquids and solid compounds –structural determination of chiral compounds becomes thus facilitated

The highlight of application of this new instrumental method was at that time the establishment of equilibria and distribution of α/β-pyranose, α/β-furanose and open-chain forms of monosaccharides in water solution. The open-chain form as polyhydroxy aldehyde, as formerly proposed by Emil Fischer, was found to be present only in minute amount (less than 1%).

When chemists and chemistry historians have been asked to prepare a list and rank the top ten experiments in chemistry which have significantly contributed to the development of chemistry, Louis Pasteur's separation of tartrate enantiomers in the year 1848 was set on the first place. On third place was Emil Fischer's determination of the configuration of glucose, both experiments thus emphasizing the importance of chirality.

Although asymmetry is a sufficient criterion for chirality in a stationary object such as asymmetric molecules or helix, asymmetric systems are not necessarily chiral when motion is involved (rotation, conformers). A modern definition of chirality, taking into account also the fourth dimension, time, and possible motions, can be defined as follows: True chirality is exhibited by molecules that exist in two enantiomeric states that are interconverted by space inversion, but not by time reversal combined with any proper spatial rotation.

The key characteristic of chirality of biologically important molecules is enantiomeric specificity. Some examples, out of many, are presented as follows:

Sweetness of enantiomeric sugars and α-amino acids

Saccharose (sucrose)	100	(taken as standard)
α-*D*-glucopyranose	74	
β-*D*-glucopyranose	82	
α-*D*-mannose	32	
β-*D*-mannose	bitter	

	L-isomer	*D*-isomer
Alanine	sweet	bitter
Phenylalanine	bitter	sweet
Tryptophan	bitter	sweet
Tyrosine	bitter	sweet

Biological activity of enantiomeric pairs

Hormone tyroxine – *L*- is active, *D*- is inactive
Muscarine (*Amanita* mushrooms) – *L*- is toxic
D-Limonene (from oranges and lemon) has a citrus like smell
L-Limonene (from peppermint oil) has a turpentine like smell
D-Carvone has a spearmint smell and taste, *L*-carvone that of caraway

Different odours arise from the fact that our sense of smell in the olfactory membrane in the nose detects the three-dimensional shape of molecules and this can be represented with a key and lock model.

From a pool of twenty amino acids, which are encoded in the nucleotide sequence of messenger RNA, peptides and proteins are biosynthesized in a range of great diversity. However, biosynthesis does not end with transcription and translation, and amino acids in proteins are post-translationally modified during or after biosynthesis involving acylation, phosphorylation, glycosylation, methylation etc. In addition, there are many nonproteinogenic natural *L*- and *D*-amino acids. The latter are found in great number in nature, in the plant world and microorganisms. There is no obvious function for the majority of nonproteinogenic amino acids, but in plants their important role is to conserve nitrogen. The biosynthetic origin for the nonproteinogenic amino acids is not uniform since several pathways may be effective.

Some examples of natural compounds or polymers containing *D*-amino acids are outlined as follows.

D-amino acids are constituents of cell wall peptidoglycan, of over a hundred antimicrobial peptides which represent a defence system against infections (they are linear or helical and contain from 13 to 46 amino acids) were described from different sources of different animals (for example, cecropins from insects or magainins from amphibians). Moreover, they are part of the natural or semisynthetic antibiotics [valinomycin, gramicidin S, ampicillin (side chain contains *D*-phenylglycine) or amoxycillin]. An interesting case is represented by dermorphins and deltorphins which are opioid peptides and are present in frog skin. Dermorphine is a heptapeptide isolated from the skin extracts of the Argentinian frog *Phyllomedusa sauvagei* with *D*-alanine at position two from the N-terminal and is about 1000 times more potent than morphine in producing long-lasting analgesia. The unnatural all *L*-amino acids analog is inactive.

The amiloid plaques causing the neurodegenerative Alzheimer disease as consequence of reduced β-amiloid solubility have a fibril structure and contain a high level of *D*-aspartyl and *D*-isoaspartyl residues. Among the most stable proteins in the human body are crystallins in the eye lens, but at a rate of 0.14 % per year *D*-aspartyl residues are formed in a normal lens and are responsible for the cataract formation. High levels of *D*-aspartyl residues are also found in the dentine in teeth.

A peculiar example of a natural, but nonproteinogenic amino acid is represented by the amino acid *L*-mimosine (Fig. 1), a constituent of *Mimosa pudica*, a sensitive plant known by the rapid movement of the leaves when it is stimulated by touch. The amino acid acts as a protection against feeding by sheep, since it was demonstrated that administering sheep or goat with mimosine their fleece is completely removed. Mimosine is also contained in leucaena which is used as a livestock forage in subtropical and tropical regions.

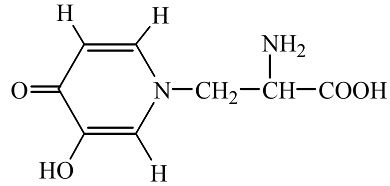


Fig. 1 *Formula of mimosine.*

L-monosaccharides as representatives of unnatural sugars are also found incorporated in several compounds or polymers. For example, galactogen is a *L*-galactose polymer and snails contain such a polymer composed from 85% *D*- and 15% *L*-galactose. Another example is the aminoglycoside antibiotic streptomycin which contains *L*-glucose.

Chemical communication represents a vast field of various organic compounds and most of them are chiral. In the body such compounds are participating in two of the body's control systems – the endocrine, where the production and transport of steroid hormones as signalling compounds is taking place, and in the nervous system which affects generally only muscles and glands. Compounds produced by the endocrine system belong to steroid hormones which are biosynthesized from the precursor cholesterol, and many proteins and biogenic amines are involved. All are chiral compounds. Neurotransmitters or chemical transmitters are released by neurons and pass in milliseconds across the synaptic cleft. For example, deficiency of dopamine results in Parkinson's disease, and an important group of neuropeptides composed of 14 to 28 amino acids is represented by somatostatin, having many regulative functions.

A large group of compounds for chemical communication are semiochemicals and pheromones. The first term relates to chemicals involved in animal communication, whereas pheromones represent a subclass of semiochemicals which act within the same species. Such compounds are intraspecific signals in terrestrial and aquatic habitat, they should be volatile or water soluble, they are single or composite organic compounds of insects, bacteria and fish.

Messages or chemical signals of such compounds include sex attractant pheromones, trail pheromones, signalling pheromones to locate prey, territory markers, aggregation pheromones (social recognition), alarm pheromones, defence pheromones. An example: in the *Lepidoptera* order (butterflies, moths) so far more than 550 pheromones were identified, they are compounds with a C_7 to C_{29} skeleton and 10% of them are chiral. A stereochemical specificity may be exemplified by 2,3-octanediol from the beetle *Xylotrichus pyrrhoderus.* Of the four stereoisomers only one, the 2*S*,3*S* is active.

The above example poses the question of how effective are the selectivity and stereospecificity of molecular interactions? How selective is Nature in making biopolymers from chiral building blocks? A simple structure of homochiral tetramers gives the following answer:

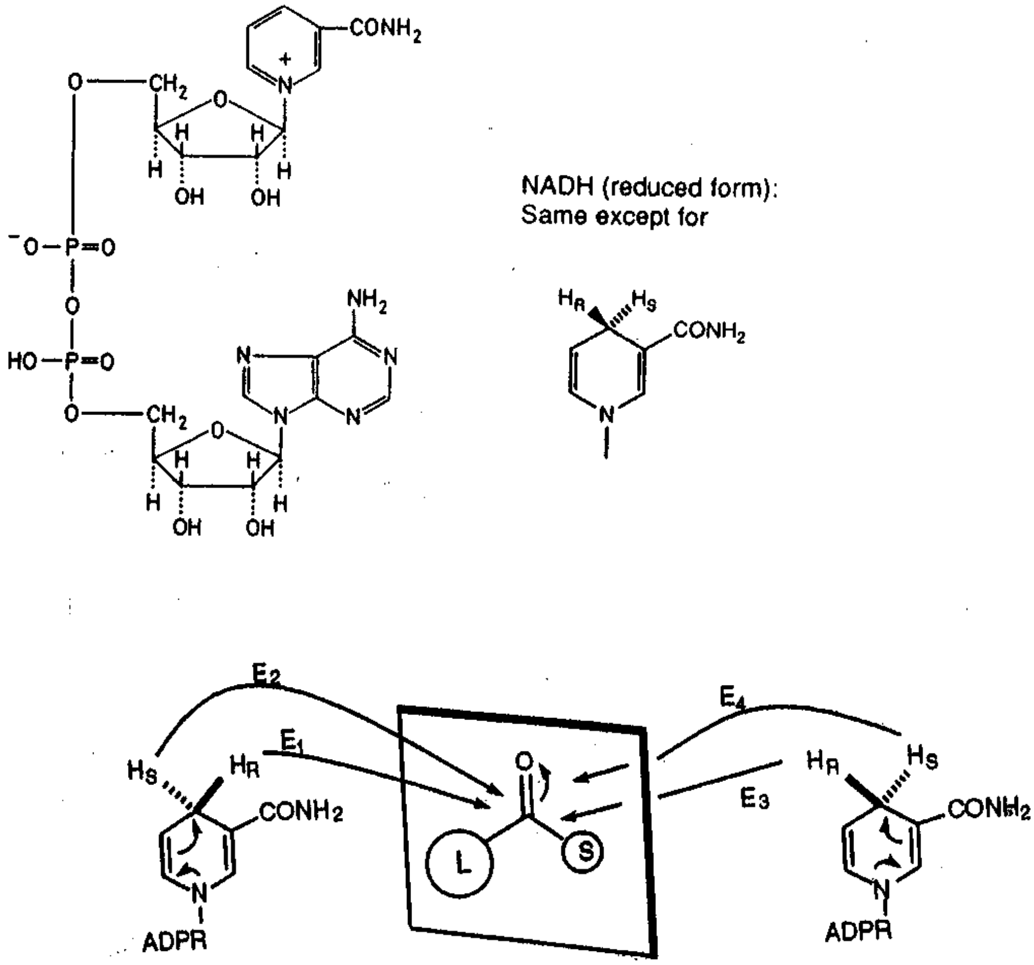
Product	Structure	Number of isomers	
		Peptides, Nucleic acids	Saccharides
Tetramer	AAAA	1	1424
	ABCD	24	34560

Whereas the composition of a tetramer (or any polymer) as shown in the second case is characteristic for proteins and nucleic acids, polysaccharides contain in most cases only one kind of monosaccharide as a building block. A simplification of the possible complexity is in the choice of bonding since 1,4, 1,1, or 1,6 bonds are mainly involved in polysaccharide structures.

However there are many cases of extremely high specificty for correct biological action. For example hemoglobin (molecular weight about 68.000) consists of 96% of globin with α- and βsubunits. Replacement of just one amino acid, *L*-glutamic acid, with *L*-valine at position 6 in the β-subunit causes sickle-cell anaemia, a hereditary disease with life-expectancy of at most 45 years.

Another example is the antibiotic erythromycin which is build up from 118 atoms and has 18 stereogenic centers giving thus theoretically 262,144 possible stereoisomers. Only one stereoisomer, the natural compound, is biologically active.

Oxidation of ethanol to ethanal and reduction of the latter to ethanol in the presence of NADH (reduced form of nicotinamide adenine dinucleotide) or NAD^+ takes place stereospecifically with only one of the methylene hydrogen atoms (Fig. 2).



E_1 : Alcohol dehydrogenase from *Pseudomonas sp.* ($NADP^+$) or *Lactobacillus kefir* ($NADP^+$)
E_2 : from *Mucor javanicus*
E_3 : from yeast, horse liver, and *Thermoanaerobium sp.*
E_4 : unknown

Fig. 2 *Stereospecificity of methylene hydrogens in NADH.*

Chirality also controls the shape of self-assembled molecules, and if there are several different kinds of molecules whose form aggregates, the phenomenon is described in terms of supramolecular chemistry. Molecular recognition represents key chemical processes in life. Self-assembly takes place in solution of amphipatic (amphiphilic) molecules which can form bilayers, vesicles and further helical ribbons and tubules. Self-assembly of molecules into helical aggregates is ubiquitous in nature. Peptides of alternating hydrophilic and hydrophobic amino acids tend to adopt a β-sheet structure, and the hydrogen bonding between the amide and carbonyl groups in the backbone of neighbouring peptides leads to higher order assembly. Short peptides are found to self-assemble into helical filaments in polar solvents. Helical ribbons and tubules occur naturally in bile. For example, a supramolecular aggregate of this kind consists of a bile acid, phosphatidylcholine and cholesterol. This is also the way to prevent cholesterol from crystallizing and forming gallstones.

Why do some molecules form helical aggregates while others do not? Molecular chirality is certainly part of the answer. Another contribution is coming from the formation of hydrogen bonds. Nevertheless, some molecules do not form helical aggregates, e.g. most lipids.

An interesting case is represented by the structure of tobacco mosaic virus. It consists of a molecule of RNA (a strand of 6400 nucleotides, about 2 million Dalton) and is surrounded by a coat of 2130 identical polypeptide chains of 158 amino acids forming a right handed helix. Why there are so many polypeptides instead of one big protein molecule? The answer is in the error rate of biological protein synthesis which limits the size of proteins. The genetic sequence is misread in ~ 2000-3000 amino acids. In response to these intrinsic limits, average protein chains fall within the range of 200-500 amino acids. An exception is titin, a protein in muscles which contains about 27,000 amino acids. If the RNA of this virus is separated from the polypeptide coat and then the two parts are mixed, a self-assembly to the virus occurs in about 10 minutes.

Can we expect self-assembly of amino acids into proteins? The probability of spontaneous formation of *any* homochiral protein from 100 amino acids is 10^{-30}, while that of forming a *functional* homochiral polymer is much lower. Chance is thus not an option.

Proteins of helical chains are also involved in directional transport as molecular motors in controlled unidirectional motions on molecular level. Biological molecular motors can produce rotary (ATP synthase) or linear motions (cilia). The cilia – hairlike appendages (for example, in air passages of the lungs) – execute a coordinated sequence of movements, the molecular engine is a protein *dynein*. There are nine paired microtubules per axoneme (central tube), interconnected by dynein molecules, protruding at regular intervals like the legs of a multipede. In the movement the microtubules walk over one another. Each dynein molecule consumes ATP and changes shape. (Fig. 3). After this power stroke follows a slower recovery stroke.

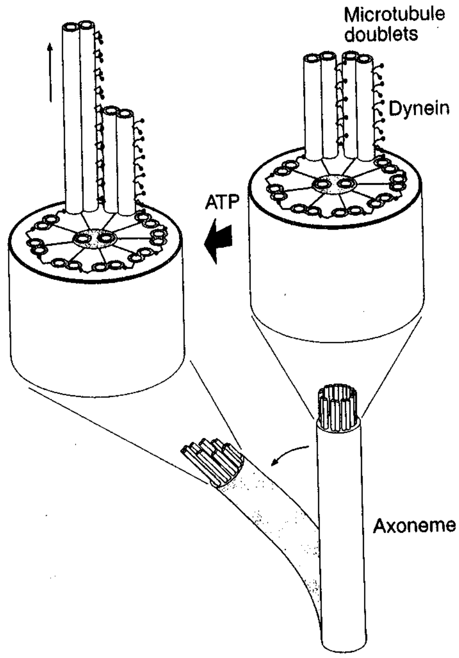


Fig. 3 *Schematic representation of dynein action.*

Dynein is also an engine that shuttles molecules in the cell towards the minus end of a microtubule; responsible for the transport in the plus direction is *kinesin*, another motor protein for transport from one organelle to another. As an example, proteins must be sent from their point of manufacture to the parts of the cell where they are needed. In the muscle power the motor protein *myosin*, a long chain protein with helical chains, is involved.

Recently, efforts have being made to prepare synthetic molecular motors. These are responding to the input energy (light, heat, chemical energy, etc.). They are aimed at assembling molecular devices capable of processing and storing data. Rotary motors must be chiral to produce unidirectional motion. Several existing motors are based on the *cis-trans* isomerization of a crowded double bond. Practical use of such molecular motors is anticipated for programmable medicine delivery, for storage and retrieval of data, for solar powered motors, etc.

A widely accepted application of both natural and synthetic (or semi-synthetic) optically active polymers is that for the chiral separation of racemic compounds by HPLC, using these polymers as chiral stationary phases, and chiral GC. Both methods account for ~ 62% of methods for the determination of enantiomer composition. Used as chiral supporting materials are: heterogenous cellulose derivatives (cellulose esters, phenylcarbamates or arylalkylcarbamates), synthetic polymers such as polymethacrylates, polyamides, polyurethanes, or optical active natural macromolecules such as pepsin or serum albumin. In Fig. 4 are presented models for helical structures of various isotactic synthetic polymers, including cross sections.

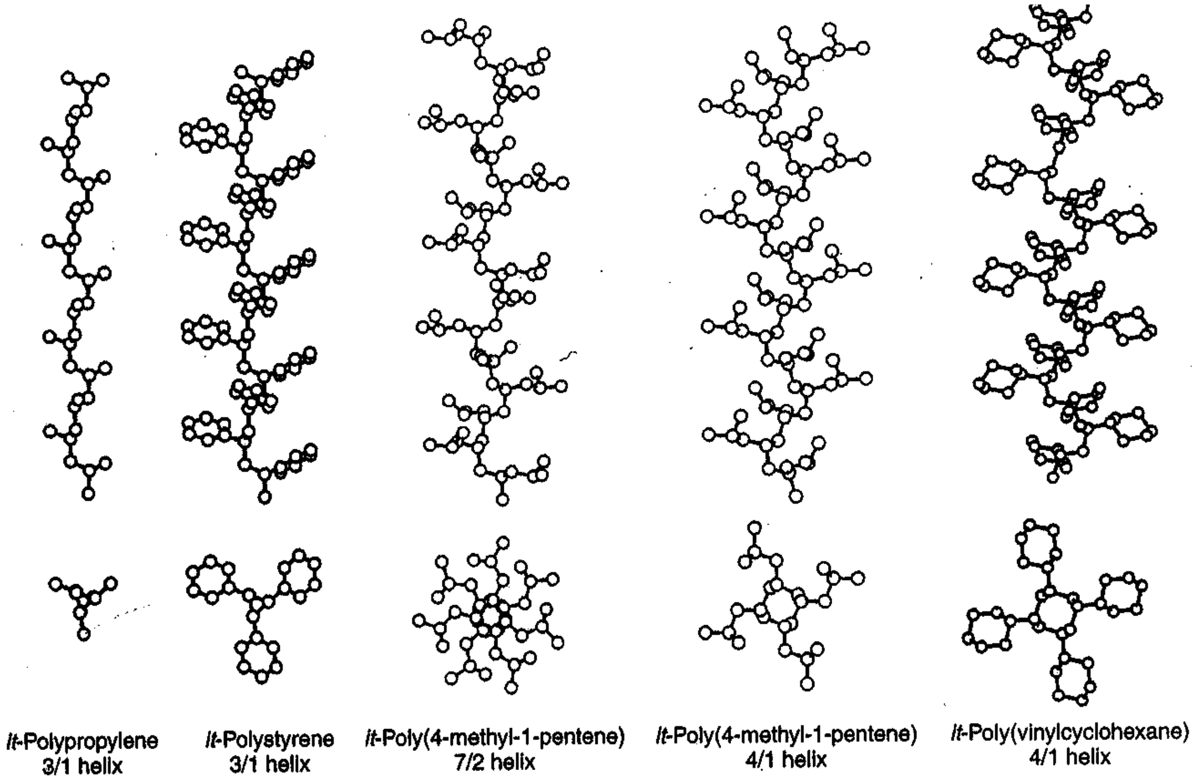


Fig. 4 *Models of helical structures of some isotactic polymers.*

Symmetry and asymmetry play an important role in our everyday life. Life is asymmetric, although visual forms of living organisms may be symmetric. Bilateral symmetry is imperative as a part for survival for birds, butterflies, insects, etc., but there are also many other symmetrical forms found in nature (pine cones, petals, etc.). Symmetry plays also an important role in chemistry. Orbital symmetry is involved in control of the stereochemical outcome of thermal or photochemical cycloadditions or rearrangements. Symmetry arguments are a powerful tool in teaching hybridization, molecular orbitals, selection rules in absorption spectroscopy, crystal structures, etc.

In contrast to external symmetry, the vertebrate inner body parts and the central nervous system are located asymmetrically. It is well known that the left and right hemisphere of the human brain have different processing functions. Already from ancient times plant extracts containing psychotropic compounds have been used, and modern drug abuse includes natural or synthetic mind altering compounds. In addition to men, animals can also be influenced by various organic compounds. For example, diadem spider (*Aranaeus diadematus*) when administered such compounds as those from marijuana (*Cannabis sativa* contains more than 420 different compounds) , benzedrine (amphetamine, a central nervous system stimulant), caffeine or chloral hydrate (a sedative and hypnotic compound) is disturbed in spinning his web and makes a distorted design. The spider silk is a wonder of nature. It is a helical protein polymer of about 300,000 Daltons, it is stronger than steel and more flexible than other polyamides. It can be streched to 30-40% before it breaks down. The fibroin consists of about

42% glycine and 25% alanine as the major amino acids. It is believed that the elasticity of spider silk is due to glycine-rich regions.

There is no complete accordance in body parts or behaviour asymmetry. For example, one in 10,000 people live with the heart at the right side (*situs inversus*), about 10% of people are left handed (some famous painters such as Leonardo da Vinci, Michelangelo, Raffael, Dürer, Picasso, etc. were also lefthanded). Some people write from left to right, some in the opposite direction, and a special case is the so called »boustrophedon« (»oxen plough«) writing. The Code of Gortyna (Gortis), dating to the early fifth century BC, is the oldest law code in Europe and is preserved on a wall (10 by 2 m in size) in Gortis on Crete. The script of about 17,000 letters runs from left to right and in the next row vice versa. The letters (for example E) are written then as mirror images, for example ∃.

For the first time in the history of mankind we have been now able to achieve chemical transformations in the manner as Nature does with the aid of enzymes to perform stereoselective or enantioselective syntheses. Catalysis has become the most important activity in chemical syntheses.

There are several ways to synthesize enantiopure chiral compounds:

- from natural chiral compounds (chiral pool) by synthesis and separation,
- from synthetic racemates by enzymatic or chemical separation,
- from prochiral compounds by stereoselective synthesis (chemocatalysis or biocatalysis).

In the year 2002, chiral products were generated 55% by traditional technologies (chiral pool and separation), 35% by chemocatalysis and 10% by biocatalysis.

Absolute stereoselective (enantioselective, sometimes called asymmetric) synthesis can be described as a synthesis which uses external physical influence to produce an enantiomeric excess in what would otherwise be a racemic product. The chiral specificity is the basis of a major industry producing chiral drugs. Today, a plethora of chiral catalysts have been developed and mainly chiral phosphines, complexed with transition-metals (Ru, Rh, etc) are used as chiral auxiliaries. Hundreds of enantioselective syntheses have been developed and some represent important industrial processes.

To illustrate the catalytic enantioselective synthesis, two examples will be presented. The first is a stereoselective (asymmetric) hydrogenation of didehydro amino acids. The preparation of chiral *L*-DOPA, used in treatment of Parkinson"s disease, involves homogeneous hydrogenation in the presence of a chiral diphosphine as chiral auxiliary to give the right stereoisomer with ee (enantiomeric excess) up to 94 % (Monsanto process) (Fig. 5).

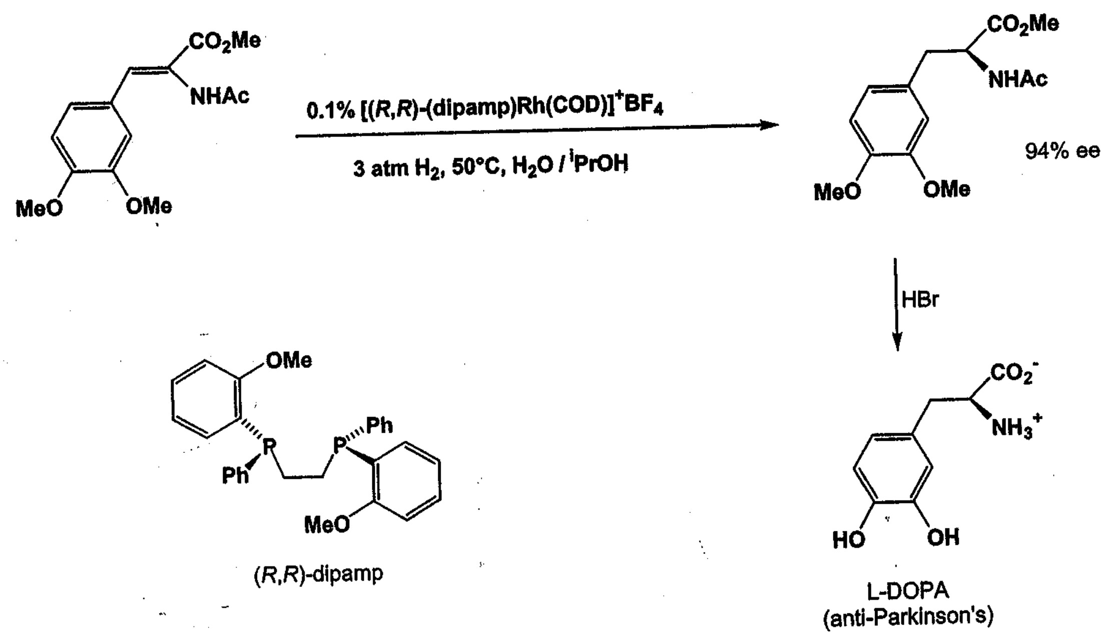


Fig. 5 *Synthesis of L-DOPA.*

The success of the reaction is dependent on the pressure and temperature applied. In a similar manner, the anti-inflammatory *S*-naproxen can be obtained with ee of 97 %. The synthesis of (*S*)-metolachlor, one of the important grass herbicides, proceeds by stereoselective imine hydrogenation and subsequent alkylation at the nitrogen atom. Ir-ferrocenyl diphosphine catalyst is used, capable of more than 1,000,000 turnovers. This is so far the largest-scale stereoselective catalytic process, the production is about 10,000 t/y with ee of 79%.

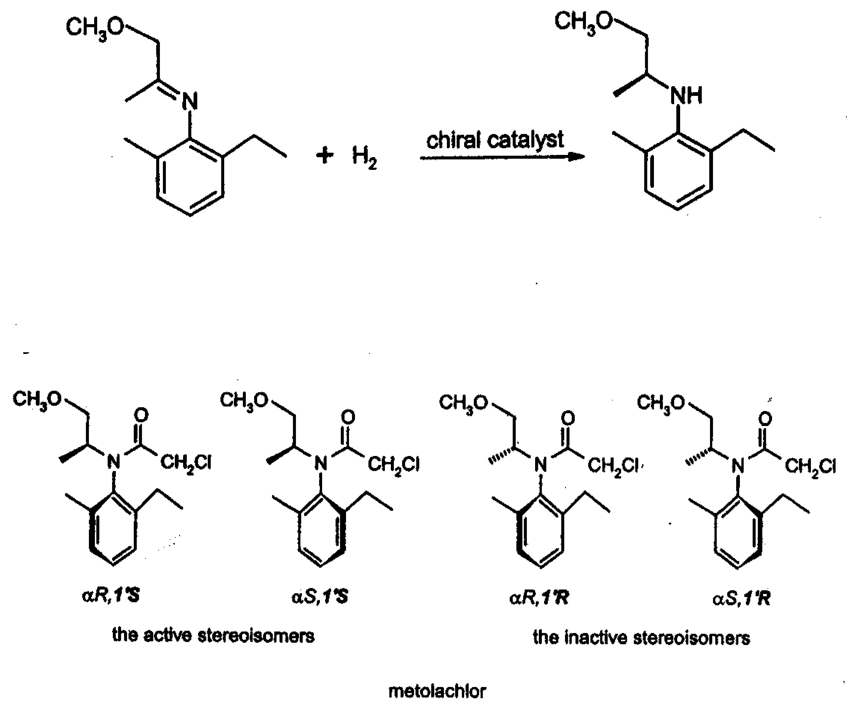


Fig. 6 *Synthesis of the herbicide metolachlor.*

As shown in Fig. 6, only two stereoisomers are active. The four stereoisomers exist as a consequence of one stereogenic center and hindered free rotation around the nitrogen and benzene carbon bond.

The following conclusion can be drawn on hand of the role of chirality in life processes.

As more and more biological and chemical phenomena are explained in terms of molecular interactions, the greater becomes the need for a detailed understanding of molecular asymmetry and stereochemistry. There is a close relationship between molecules of life and chirality.

Chirality offers protection and security to life processes and life as well, based on high selectivity in chemical molecular interactions. It represents the fundamental feature and is the warrant of accuracy in recognition and identification of a variety of molecules.

Since life is chemistry and chemical transformations, the teaching of chemistry – which is closely involved in life sciences – should in the future give greater emphasis to these interconnections.

References

Philip Ball: Stories of the Invisible. A Guided Tour of Molecules. Oxford University Press, Oxford 2001.

Vincenzo Balzani, Alberto Credi, Françisco M. Raymo, J. Fraser Stoddart: Artificial Molecular Machines. Angew. Chem., Int. Ed. **39**, 3348 (2000).

H. U. Blaser, E. Schmidt (Editors): Asymmetric Catalysis on Industrial Scale. Wiley-VCH Verlag, Weinheim, 2004.

Elisabetta Brenna, Claudio Fuganti, Stefano Serra: Enantioselective Perception of Chiral Odorants. Tetrahedron: Asymmetry, **14**, 1 (2003).

Doo Soo Chung, George B. Benedek, Fred M. Konikoff, Joanna M. Donovan: Elastic free energy of anisotropic helical ribbons as metastable intermediates in the crystallization of cholesterol. Proc. Natl. Acad. Sci. USA, **90**, 11341 (1993).

Fisher, L. Petrucelli, C.Gardner, C. Emory, W. H. Frey, L. Amadi, S. Sorbi, G. Sorrentino, M. Borghi, A. D" Aniello: Free *D*-amino acids in human cerebrospinal fluid of Alzheimer disease, multiple sclerosis, and healthy control subjects. Mol. Chem. Neuropathol., **23**, 115 (1994).

Jürgen-Hinrich Fuhrhop, Claus Endisch: Molecular and Supramolecular Chemistry of Natural Products and Their Model Compounds. Marcel Dekker, Inc. New York, 2000.

David S. Goodsell: Bionanotechnology. Lessons from Nature. Wiley-Liss, Inc. Hoboken, N.J., 2004.

Mark M. Green, R. J. M. Nolte, E. W. Meijer: Materials-Chirality. Vol. 24: Topics in Stereochemistry. Wiley-Interscience, Hoboken, New Jersey, 2003.

István Hargittai, Magdolna Hargittai: Symmetry through the Eyes of a Chemist. Second Ed., Plenum Press, New York, 1995.

P. Jollès (Editor): *D*-Amino Acids in Sequences of Secreted Peptides of Multicellular Organisms. Birkhäuser Verlag, Basel, 1998.

R. Noyori: Asymmetric Catalysis in Organic Synthesis. Wiley, New York, 1994.

John F, Robyt: Essentials of Carbohydrate Chemistry. Springer-Verlag, New York 1998.

Jonathan V. Selinger, Mark S. Spector, Joel M. Schnur: Theory of Self-Assembled Tubules and Helical Ribbons. J. Phys. Chem. B, **105**, 7157 (2001).

Solomon H. Snyder: Drugs and the Brain. Scientific American Library, New York, 1986.

Chi-Huey Wong, George M. Whitesides: Enzymes in Synthetic Organic Chemistry. Tetrahedron Organic Chemistry Series, vol. 12. Pergamon, 1994.

Tristram D. Wyatt: Pheromones and Animal Behaviour. Cambridge University Press, Cambridge UK, 2003

Chemical Literacy: An Approach Through Models and Modelling

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Abstract

The central roles played by the ideas of chemistry in human decision-taking are rehearsed. If chemical education is to prepare all citizens for competence in such decision-taking there will need to substantial change to the provision that is currently provided. Some broad approaches to such change are outlined. The dimensions to "chemical literacy", as such competence is usually called, are presented and discussed. It is suggested that models and modelling should make an important contribution to chemical literacy. The core ideas of models and modelling are presented with the aid of examples from chemistry. The demands that the attainment of different levels of chemical literacy will place on the treatment of models and modelling are outlined. Finally, some key questions for research and development are proposed.

Current challenges to chemical education

In a review of the current status of chemical education (J. K. Gilbert, De Jong,O.,Justi, R.,Treagust, D. F., Van Driel, J.H., 2002), on which this section draws very heavily, a self-evident truth was repeated: the ideas of chemistry play major roles in human decision-taking today. In personal decisions, for example the composition of a diet conducive to health, where the nature of the substances involved and the mechanisms for their metabolism underpin rational choices. In social decisions, for example on the location of a garbage incinerator, where public acceptance of the means of control of emissions used depends on an understanding of ideas of combustion, chemical adsorption, and catalytic conversion. In economic decisions, for example about whether to establish a biotechnology-based industry, where an understanding of the chemical basis of genetics and genetic modification, coupled to that of environmental risk, is needed. The emergence of chemistry as a science has been a great cultural achievement in recent centuries. The new substances to which it has given rise (paints, adhesives, plastics) permit an increased range of cultural expression. The ability to effectively discharge these roles, the recognition of the cultural achievement that is chemistry, and the full exploitation of the cultural tools made available, all suggest that an appropriate chemical education should be acquired by all.

It is therefore surprising that chemical education currently faces a range of strong challenges throughout the world. The ever-increasing range of knowledge competing for inclusion in the formal education provided by schools is leading to the separate major sciences being compressed into one smaller unit of the curriculum. Consequently, the amount of time devoted to chemical education is gradually being eroded, which has exacerbated the difficulty that many students find in understanding the ideas of on which it rests. Furthermore, what chemistry should be taught, and how, to the majority of students, is still very problematic. The paces at which chemical research and chemical technologies advance are making it difficult to decide what should be included in formal chemical education. It has also become evident that the ideas of chemistry are badly under-represented in the provision of opportunities for informal science education, through books, TV programmes, and in science and technology centres (Stocklmayer & Gilbert, 2002).

What, then, can be done to ensure that each of these justifications for chemical education is adequately addressed?

Constructive proposals for the reform of chemical education

A detailed critique of chemical education (Van Aalsvoort, 2000) can be turned into constructive suggestions, producing the following principles for general reform to achieve the conditions for the acquisition of "chemical literacy" (J. K. Gilbert, De Jong,O., Justi,R., Treagust,D,F.,Van Driel, J.H., 2002). For their health, social, and economic, wellbeing:

- all young people should finish their compulsory education familiar with the major chemical ideas that they are likely to meet outside school. The issue is then to decide what the "major ideas of chemistry" are and "where these ideas are likely to be met out-of-school";
- all young people would benefit from developing and sustaining a sense of wonder and curiosity about the chemical dimensions to the natural world. How can we do this and how can we assess their affective response to such an education?
- the chemical education of young people should place less emphasis on the knowledge of the outcomes of chemical enquiry and more emphasis on an appreciation of how that enquiry is conducted. The question is "how can this be done"?
- the provision of chemical education would be most effective if based on an agreed model of the development of young people"s chemical capabilities. Whilst some research in chemical education has been based on specific perspectives on learning (Johnstone, 1999) (Phillips, Pennington, & Hall, 1998), the implications of newer approaches (Case, 1996) have not yet been explored. We know little about the implications of social constructivist psychology for chemical education and are thus unable to talk about a coherent "psychology of the learning of chemistry". On what basis might such a psychology be developed?
- the assessment of the understanding of chemistry achieved should not be simply based on the recall of ideas as such, but rather be set in contexts where students are likely to meet chemical

ideas in the future. What are the specific conditions needed for the valid and reliable assessment of chemical education?;

- education in, for, and about, chemistry, should be interlocked with that in, for, and about, chemical technology. How can this be done?
- chemical education must systematically consider the implications of chemistry for everyday life. Again, how is this to be done?
- chemistry should be taught using a variety of methods. The subject is still taught using a narrow range of methods, mainly the lecture and the laboratory practical. Other approaches, e.g. computer-based simulations, project work, co-operative learning, need to be systematically developed, implemented, documented, and evaluated. What is needed to bring about what amounts to a revolution in pedagogy?;
- there should be freedom for young people to choose between general, vocational, and academic versions of the chemical curriculum as they near the end of their compulsory chemical education. On which principles should these alternatives be based?

This paper is concerned with the curricular aspects of the above questions: on what basis should the content of chemical education be decided? In short, what should constitute the intellectual substance of "chemical literacy"?

Dimensions of chemical literacy

The nature of "science literacy" has proved elusive and contentious (Laugksch, 2000). Perhaps inevitably, defining "chemical literacy", as a sub-set of "science literacy" has proved even more difficult. In one of the few attempts made, Holman and Hunt consider that it should consist of those:

> "essential chemical explanations which people need to make sense of their lives. (That):
>
> - everything is made of chemical substances;
> - everything is made up of building blocks;
> - (these building blocks consist of) chemical species;
> - (these building blocks undergo) chemical change;
> - explaining macroscopic properties (is done) in terms of the architecture of matter."
>
> (Holman & Hunt, 2002)

and furthermore that it should:

> "illustrate some of the impacts of chemistry on society by describing what chemists do (i.e.):
>
> - think creatively;
> - control (chemical) change;
> - (conduct chemical) analysis;

  - (undertake chemical) synthesis;
  - (produce chemical) formulations"

  (Holman & Hunt, 2002)

This suggests that chemical literacy would entail an understanding of:

- the nature of chemistry.

How it is conducted, how chemical knowledge comes to be agreed as such, how this knowledge is disseminated. At the heart of this must be a "philosophy of chemistry", which is far from being established (Erduran, 2001). However, this paper will suggest that modelling and models play central roles in such a philosophy;

- key chemical ideas.

This paper will suggest that this should be interpreted as "those models that have played / do play a central role in the advancement of chemical knowledge".

- how chemistry and chemical technologies relate to each other.

Layton has suggested, for the broader fields of science and of technology, that specific concepts are simplified and adapted for use in a specific technology (Layton, 1993)(p.58/9). This theme is badly underdeveloped in general and for chemistry and chemical technologies in particular.

- the impact of chemical technologies on society.

Such an impact would be at the personal, social, and economic levels. The American Chemical Society has produced an admirable textbook built around these themes (Stanitski, Eubanks, Middlecamp, & Pienta, 2003)

- how chemistry is communicated.

This is done through the channels of informal science and technology education, such as television, books, newspapers and books, science and technology centres, in which chemical ideas are currently both under-and badly- represented (Stocklmayer & Gilbert, 2002).

- how chemistry applies in everyday life.

This diffuse theme has received some imaginative treatments e.g.(Selinger, 1998) (Stanitski et al., 2003).

Before their potential contribution to "chemical literacy" can be consider further, the essential ideas of models and modelling, illustrated from the discipline of chemistry, must be rehearsed (for a detailed treatment , see: J. K. Gilbert & Boulter, 2000).

On models and modelling in chemistry and chemical education

Chemistry seeks to provide explanations for the properties and interactions of the substances of which matter is composed. However, "properties and interactions" are not ready – made: we impose our ideas of what might be important on the complexity of the natural world. Chemists then investigate these idealisations, what may be called "exemplar phenomena", at least at the outset of their enquiries in any given field. Early chemists preferred to work with solutions of pure substances, not with the mixtures found in nature. These exemplar phenomena have one thing in common: they are simplifications chosen to aid the formation of visual perceptions of what was happening at the macro level (J. K. Gilbert, forthcoming 2005). Such a descriptions and/or simplification of a complex phenomena is usually called a "model", this corresponding to the everyday meaning of that word (Rouse & Morris, 1986). As enquiry proceeds in any given field of chemistry, the complexity of the models of exemplar phenomena that are addressed increases progressively, and the aims of the enquiry become ever more ambitious.

This process of simplification and representation within the scope of human senses with the aid of models becomes of greater importance as, later in a sequence of enquiries, explanations for exemplar phenomenon are sought at the sub-micro level. Models then become vital if the visual imagery of entities, relationships, causes, and effects, within exemplar phenomena is to take place. The development of models and representations of them are crucial in the production of knowledge. A classic example is Kekule"s dream about the structure of the benzene molecule being like a snake biting its tail (Rothenberg, 1995). Models also play central roles in the dissemination and acceptance of that knowledge: for example, that of the double helix of DNA has now reached iconic status, such that an abbreviated version of it is instantly recognized (Giere, 1988) (S. W. Gilbert, 1991) (Tomasi, 1988). Models are used both to make abstractions visible (Francoeur, 1997), and, crucially, to provide the basis for predictions about, and hence scientific explanations of, phenomena (J. K. Gilbert, Boulter, & Rutherford, 2000).

This wide range of function is made possible because models can depict many different classes of entities, covering both the macro and sub-micro levels of representation. Many models are of material (or supposedly material) objects which are viewed as having either an independent existence (e.g. a drawing of a reaction flask, of an atom) or as being part of a system (e.g. a drawing of a reaction flask in an equipment train, of an atom in a molecule). A model can be smaller than the object that it represents (e.g. of an oil refinery) or larger than it (e.g. of a virus). Some models are representations of abstractions, entities created so that they can be treated as objects (e.g. flows of energy as lines, forces as vectors). Inevitably, a model can include representations both of abstractions and of the material objects on which they act e.g. of the forces thought to act within a structure. A model can be of a system itself, a series of entities in a fixed relation to each other (e.g. of carbon atoms in a crystal of diamond). It can be of an event, a time-limited segment of behaviour of a system (e.g. of the migration of an ion across a semi-permeable membrane). Lastly, it can be of a process, where one or more elements of a system are permanently changed (e.g. of the operations that take place in a catalytic converter of hydrocarbons).

The key role of models in the development of chemical knowledge was recognised by the mid-twentieth century (Bailer-Jones, 1999; Francoeur, 1997). Indeed, they have become "the dominant way of thinking" (Luisi & Thomas, 1990) in chemistry, something that chemists do "without having to analyse or even be aware of the mechanism of the process" (Suckling, Suckling, & Suckling, 1980). If models play important roles in chemistry, it therefore follows that they should play equally important roles in chemical education. Those students who may become research chemists must understand the nature and significance of the models that played key roles in the development of the subject. They must also develop the capacity to produce, test, and evaluate, both exemplar phenomena and explanatory models. Models are equally important in the education of the majority of any population who will need some understanding of chemical ideas for later life (Laugksch, 2000).

These roles for models in science education are not easy to discharge, for models can attain a wide diversity of epistemological status. A *mental model* is a private and personal representation formed by an individual either alone or in a group. All students of chemistry must have a mental model, of some kind, of an "atom". By its very nature, a mental model is inaccessible to others. However, in order to facilitate communication, a version of that model must be placed in the public domain and can therefore be called an *expressed model*. Any social group, for example a chemistry class, can agree on an (apparently!) common expressed model that therefore becomes a *consensus model*. Where that social group is of chemists and the consensus model is one in use at the cutting edge of science, it can be termed a *scientific model* e.g. the Watson - Crick model of DNA. A superseded scientific model can be called an *historical model* e.g. the Bohr model of the atom, the Pauling model of DNA (J. K. Gilbert, Boulter, & Elmer, 2000). Historical models remain in use where they can provide the basis of explanations that are adequate for a given purpose. Historical models also find their final resting place in the science curriculum: an example is the teaching of the "normality" approach to measuring solute concentration, a major 19th century idea in chemistry, that persisted in chemical education until after the mid-20th century.

On major aspect of "learning science" (Hodson, 1992) is the formation of mental models and the production of expressed models by individual students that are as close to scientific or historical models as is possible. To this end, simplified versions of scientific or historical models may be produced as *curricular models* (for example, the widely used dot-and-cross version of the Lewis-Kossel model of chemical bonding) that are then taught. Specially developed *teaching models* are created to support the learning of particular curricular models (for example, the analogy "the atom as the solar planetary system" used in the lower secondary / junior high school) (J. K. Gilbert, Boulter, & Rutherford, 2000). Sometimes teachers employ curricular models which can be called *hybrid models* because they merge the characteristics of several historical models, this having first been recorded in respect of chemical kinetics (Justi & Gilbert, 1999b). In respect of "the atom", the dominant model on which school chemistry is based is the Bohr model (an historical model) whilst the dominant model in higher education is based on the Schrödinger "probability envelope" model (the scientific model).

A further complication for science education is that any version of a model of a phenomenon in the public domain (i.e. an expressed, scientific, historical, curricular, or hybrid, model) is placed there by use of one or more of five *modes of representation*.

- The *concrete (or material) mode* is three-dimensional and made of resistant materials e.g. a plastic ball-and-stick model of an ion lattice.
- The *verbal mode* can consist of a description of the entities and the relationships between them in a representation e.g. of the natures of the balls and sticks in a ball-and-stick representation. It can also consist of an exploration of the metaphors and analogies on which the model is based, e.g. "covalent bonding involves the *sharing* of electrons" as differently represented by a stick in a ball-and-stick representation and in a space-filling representation. Both versions can be either spoken or written.
- The *symbolic mode* consists of chemical symbols and formula, chemical equations, and mathematical expressions, particularly mathematical equations e.g. the universal gas law, the reaction rate laws.
- The *visual mode* makes use of graphs, diagrams, and animations. Two-dimensional representations of chemical structures ("diagrams") are universal examples. Those pseudo three - dimensional representations produced by computers, which may be termed "virtual models, also fall into this category.
- Lastly, the *gestural mode* makes use movement by the body or its parts e.g. of ions during electrolysis by school pupils moving in counter - flows.

The next step in considering the contribution of models and modelling to chemical literacy is to discuss the principles on which a differentiated provision might be made to meet the needs of the whole (school) population.

Levels of chemical literacy

In his review of science literacy, Laugksch suggests that the population could be divided on the basis of three levels of need (Laugksch, 2000). Adapting these to the context of chemical literacy produces:

Level 1: chemically literate as being able to function normally in society. A person who has attained Level 1 will be able to use a restricted set of ideas derived from chemistry e.g. as a consumer or as a socially-active citizen;

Level 2: chemically literate as being competent with the ideas of chemistry. A person who has attained Level 2 will be able to draw on a restricted body of knowledge of chemical ideas in order to be able to communicate successfully with others about chemical problems that are set within a restricted range of contexts, activities, or problems;

Level 3: chemically literate as being learnéd. A person who has attained Level 3 will have acquired a substantial body of chemical knowledge without a specific reason for doing so and is able to use it in a large range of contexts.

It is not at all clear why a tripartite division is the most appropriate one. It is reminiscent of the division of medieval male European society into knights, villeins, and serfs. This is echoed today within the field of engineering, where status (and hence remuneration!) is of division into engineers, technologists, technicians. However, in the absence of a better scheme, I will explore the potential of this one. Three ideas seem to underlie a treatment of "levels": the range of chemical models that should be encountered; the range of "contexts" in which the student should experience these models; the depth of understanding of understanding to be achieved. Taking each of these in turn:

The range of chemical models to be encountered

Millar and Osborne have suggested that the following "explanatory stories" drawn from chemistry should form part of scientific literacy (Millar & Osborne, 2000)(p.2017-2018):

- that all matter is made up of tiny particles (i.e. particulate models of matter). A review of research into the teaching and learning of this topic has appeared (Harrison & Treagust, 2002);
- that a range of types of bonding is found between particles (i.e. models of bonding). For a review of the teaching and learning of bonding, see (Taber & Coll, 2002);
- that chemical reactions consist of a rearrangement of the particles of the reactant to form new substances (i.e. models of chemical reaction). Reviews of teaching and learning are available for

the component ideas of chemical reaction: chemical equilibrium (Van Driel & Graber, 2002), kinetics (Justi, 2002), and energetics (Goedhart & Kaper, 2002);

- that this range of types of bonding explains the range of behaviour found between different types of matter (i.e. models of explanation for the properties of substances). For a review of "explanation", see (J. K. Gilbert, Boulter, & Rutherford, 2000).

It would seem that models of these ideas are needed for the attainment of all three levels of literacy.

The range of "contexts" to be experienced

The notion of "context" is widely, variously, and loosely, used in chemical education. Stocklmayer and Gilbert have suggested that it would be safer to talk about "situations" (physical environments), "contexts" (the meaning that a person gives to a situation by mental activity on it), and "narratives" (the links made between contexts and on-going themes and concerns in the life of that person) (Stocklmayer & Gilbert, 2002). Thus the task for chemical education is to identify situations that are sufficiently engaging that students will create contexts out of them and of sufficient significance such that links can be made to important personal, social, and economic, narratives.

Using this terminology, Holman and Hunt suggest that suitable situations could be derived from:

- health and medicine;
- materials;
- cleaning, mending, preserving, decorating;
- agriculture;
- environments;
- alternative fuels.

(Holman & Hunt, 2002)

The themes addressed in the American Chemical Society course textbook "Chemistry in Context" (Stanitski et al., 2003) are, in summary:

- the atmosphere;
- global warming;
- energy;
- water and rain;
- nuclear fission;

- plastics and polymers;
- the molecular design of medicinal drugs;
- nutrition;
- genetic engineering.

These lists of themes have some overlaps both between them with the list produced by Altunata, who reviewed current trends in chemical research as being concerned with:

- environmental issues (e.g. the evaluation of atmospheric phenomena, the discovery of cleaner sources of energy, the development of waste management strategies)
- genetic engineering, with an emphasis on pre-emptive care and gene reprogramming, and on the production of genetically modified foodstuffs;
- neurochemistry, as the blood/brain and mind/matter barriers are better understood;
- the development of nanotechnological manufacturing systems;
- the creation of artificial life (Altunata, 2001)

It must be inferred that, because these situations of are of high saliency in chemistry per se, they may well eventually acquire an equivalently high profile in chemical education.

The depth of understanding to be attained

At the moment, the most widely used curricular approach to facilitating progression in the understanding of chemical ideas is by recapitulating the historical sequence – and hence the explanatory scope and adequacy –of the models that have been used in any given field e.g. for acidity (Oversby, 2000). However, the basic trouble with this approach is its lack of authentic historicity – little is ever said about why a particular model was developed, the intellectual circumstances of its development, and the reasons for its eventual abandonment as a research tool. One reason why this is done is that there is a dire shortage of accounts of how the models used in particular fields of chemistry succeeded each other. An exception is for the field of chemical kinetics (Justi & Gilbert, 1999a). Wandersee has made excellent use of the fragments of detailed knowledge that are available through the insertion of historical "vignettes" into otherwise orthodox chemistry lessons (Wandersee & Griffard, 2002).

Recently, the seeds of a very pragmatic approach to this problem have been sown in respect of the National Curriculum for Science of England and Wales. Initially it was established that basis of the curriculum in Science for 11-14 year olds was the use of four "key ideas" – particles, energy, force, cells. What was then done was to establish the nature of a "curriculum model" for each "key idea" that was "good enough" for the purposes of teaching and learning at this age group. The "place mat" for "particles" that has been made widely available to students in schools is given below in Figure 1.

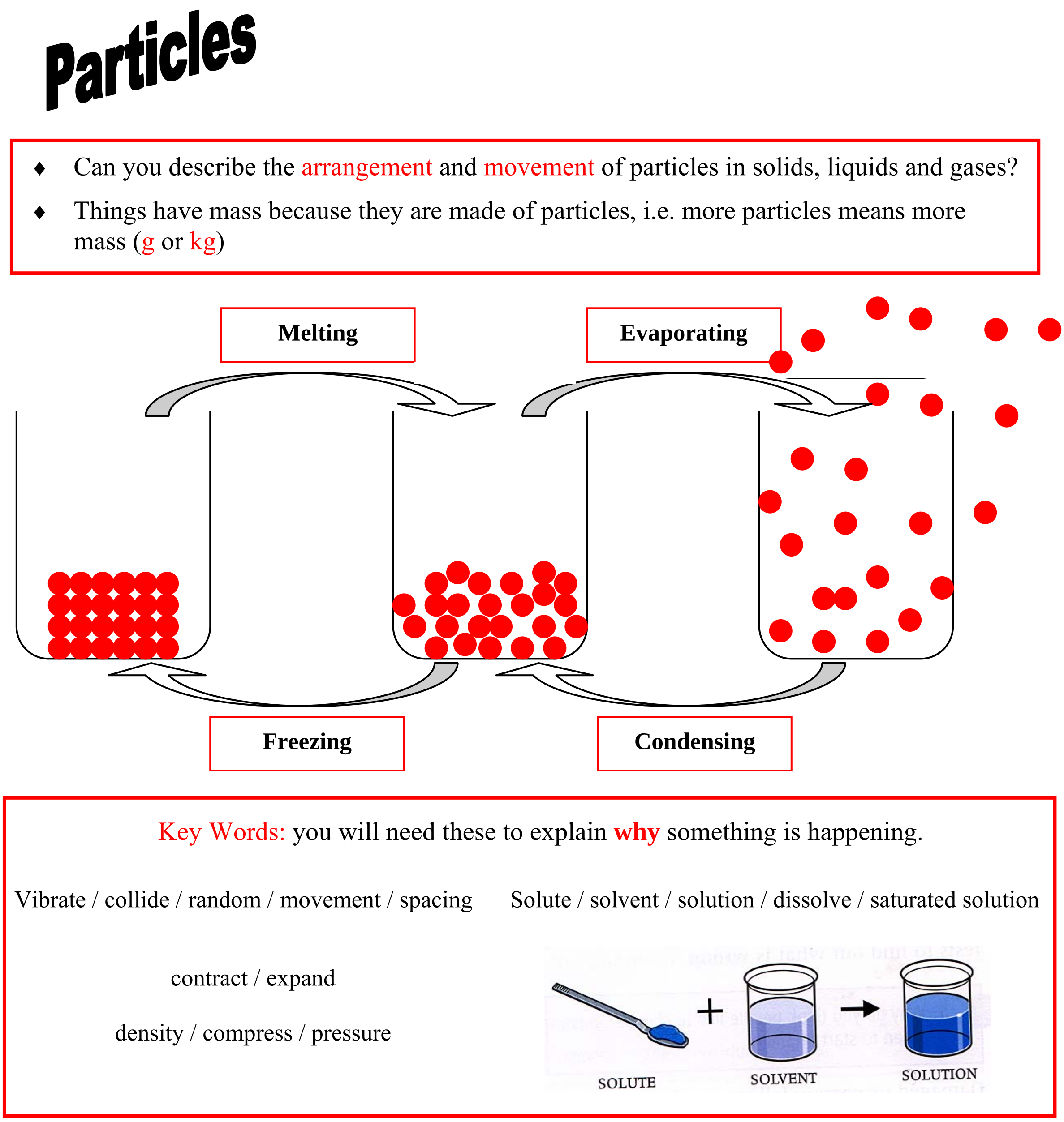

Figure 1: *The "good enough" teaching model for "particles"* (Newberry, Hardcastle, & Gilbert, in press).

A sequence of teaching each model was then established such that students could progressive reach the higher "levels of attainment" (from "3" up to "7") expected of them. This progression was called "The Levels" Mountain and is illustrated in Figure 2 (Newberry, Hardcastle, & Gilbert, in press).

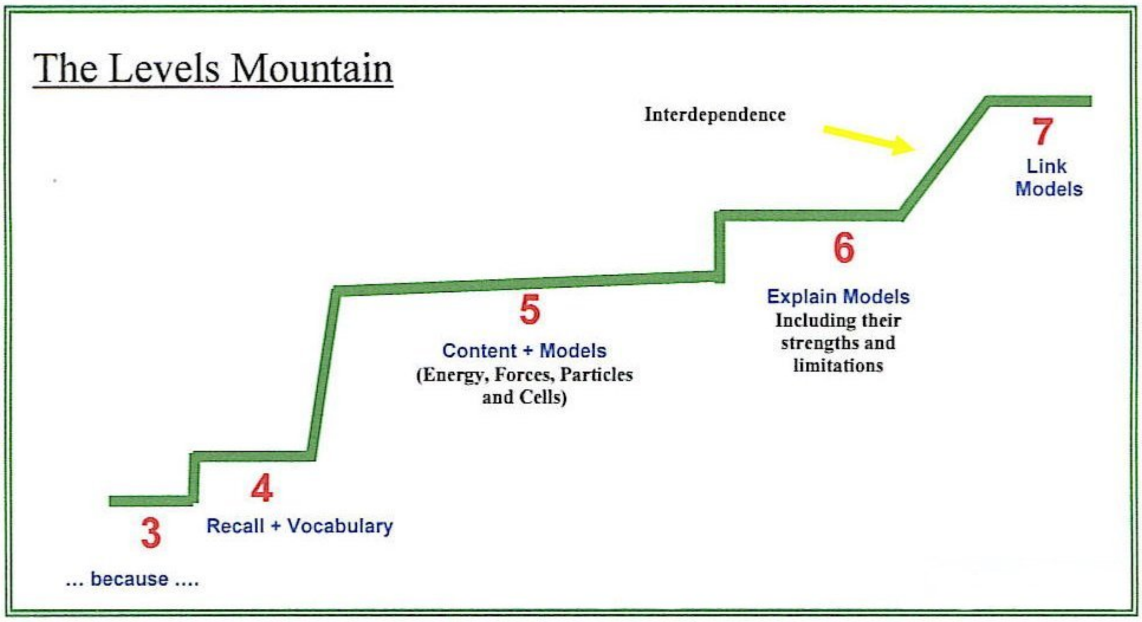

Figure 2: *The Levels Mountain*

This approach has proved so successful in teaching this age group, that it is being extended down the age range (i.e.5-11 years) and up the age range (i.e.13-18 years).

In this approach, the notion of "progression up the Levels Mountains" is being used as a surrogate for "progression up the levels of science (chemical) literacy". As this idea is worked out fully for "the particulate nature of matter" (interestingly, the only one of the key ideas to fall squarely in the field of chemistry), a secondary analysis will have to be done in terms of "levels of chemical understanding"(Gabel, 1999). Thus:

- The macro level. What range of "exemplary situations" should students aspiring to each of the three Levels of Understanding experience?
- The submicro level. What are "good enough" models for atoms, ions, bonding etc for each of the three Levels of Understanding?
- The symbolic level. What symbolic conventions i.e. forms of chemical equations are suitable for each Level of Understanding?

There is obviously much to be done if genuine differentiation and progression are to be facilitated.

Research

This paper is littered with themes that call for further research and development work. Five examples are:

1. what are the natures of the models of the major chemical ideas (see: (Millar & Osborne, 2000) and above) that are “good enough” for the various levels of chemical literacy?
2. how can a progression from Level 1 to Level 3 in chemical literacy be facilitated?
3. how can the informal provision of chemical education be harnessed to the ambitions of a differentiated provision of formal chemical education?
4. how can these ideas be implemented, so as to involve a diversity of teaching methods, the development of a positive affective response, and the use of suitable assessment methods?
5. how can modeling skills be taught in a chemical environment. For some general ideas, see: (Justi & Gilbert, 2002).

References

Altunata, S. (2001). Chemistry and humanity: challenges our profession faces as we advance towards the third millennium. Hyle, 7(1), 51-60.

Bailer-Jones, D. M. (1999). Tracing the development of models in the philosophy of science. In L. Magnani, N. J. Nersessian & P. Thagard (Eds.), Model-based reasoning in scientific discovery (pp. 23-40). New York: Kluwer Academic

Plenum Publishers.

Case, R. (1996). Changing views of knowledge and their impact on educational research and practice. In D. R. Olson & N. Torrance (Eds.), The Handbook of Education and Human Development (pp. 75-99). Oxford: Blackwell.

Erduran, S. (2001). Philosophy of chemistry: An emerging field with implications for chemistry education. Science and Education, 10, 581-593.

Francoeur, E. (1997). The forgotten tool: the design and use of molecular models. Social Studies of Science, 27, 7-40.

Gabel, D. (1999). Improving teaching and learning through chemical education research: a look to the future. Journal of Chemical Education, 76, 548-554.

Giere, R. (1988). Explaining Science. Chicago: University of Chicago Press.

Gilbert, J. K. (forthcoming 2005). Visualization: a metacognitive skill in science and science education. In J. K. Gilbert (Ed.), Visualization in science education. Dordrecht: Springer.

Gilbert, J. K., & Boulter, C. J. (Eds.). (2000). Developing Models in Science Education. Dordrecht: Kluwer.

Gilbert, J. K., Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert & C. J. Boulter (Eds.), Developing Models in Science Education (pp. 3-18). Dordrecht: Kluwer.

Gilbert, J. K., Boulter, C. J., & Rutherford, M. (2000). Explanations with Models in Science Education. In J. K. Gilbert & C. J. Boulter (Eds.), Developing Models in Science Education (pp. 193-208). Dordrecht: Kluwer.

Gilbert, J. K., De Jong,O., Justi,R., Treagust,D,F.,Van Driel, J.H. (2002). Research and development for the future of chemical education. In J. K. Gilbert, De Jong,O.,Justi,R.,Treagust,D.F.,Van Driel,J.H. (Ed.), Chemical education: Towards research-based practice (pp. 391-408). Dordrecht: Kluwer.

Gilbert, J. K., De Jong,O.,Justi, R.,Treagust, D. F., Van Driel, J.H. (2002). General Preface. In J. K. Gilbert, De Jong,O.,Justi,R.,Treagust,D.F., Van Driel, J.H. (Ed.), Chemical education: Towards research-based practice (pp. xi-xiv). Dordrecht: Kluwer.

Gilbert, S. W. (1991). Model building and a definition of science. Journal of Research in Science Teaching, 28(1), 73-79.

Goedhart, M. J., & Kaper, W. (2002). From chemical energetics to chemical thermodynamics. In J. K. Gilbert, De Jong,O., Justi,R., Treagust,D.F., Van Driel,J.H, (Ed.), Chemical education: Towards research-based practice (pp. 339-362). Dordrecht: Kluwer.

Harrison, A. G., & Treagust, D. F. (2002). The particulate nature of matter: Challenges in understanding the submicroscopic world. In J. K. Gilbert, De Jong,O., Justi,R., Treagust,D,F.,Van Driel, J.H. (Ed.), Chemical education:Towards research-based practice (pp. 189-212). Dordrecht: Kluwer.

Hodson, D. (1992). In search of a meaningful relationship: an exploration of some issues relating to integration in science and science education. International Journal of Science Education, 14(5), 541-562.

Holman, J., & Hunt, A. (2002). What does it mean to be chemically literate? Education in Chemistry, 39(1), 12-14.

Johnstone, A. (1999). The nature of chemistry. Education in Chemistry(March), 45-47.

Justi, R. (2002). Teaching and learning chemical kinetics. In J. K. Gilbert, De Jong,O., Justi,R.,Treagust,D.F.,Van Driel,J.H, (Ed.), Chemical education: Towards research-based practice (pp. 293-316). Dordrecht: Kluwer.

Justi, R., & Gilbert, J. K. (1999a). History and Philosophy of Science through Models: the case of chemical kinetics. Science and Education, 8(2), 287-307.

Justi, R., & Gilbert, J. K. (1999b). A cause of ahistorical science teaching: the use of hybrid models. Science Education, 83(2), 163-178.

Justi, R., & Gilbert, J. K. (2002). Modelling, teachers" views on the nature of modelling, and implications for the education of modellers. International Journal of Science Education, 24(4), 369-387.

Laugksch, R. C. (2000). Scientific literacy: a conceptual overview. Science Education, 84(1), 71-94.

Layton, D. (1993). Technology"s challenge to science education. Buckingham: Open University Press.

Luisi, P. L., & Thomas, R. M. (1990). The pictographic molecular paradigm: pictorial communication in the chemical and biological

sciences. Naturwissenschaften, 77(67-74).

Millar, R., & Osborne, J. (2000). Beyond 2000: science education for the future. London: School of Education, King"s College London.

Newberry, M., Hardcastle, D., & Gilbert, J. K. (in press). Progression in Key Stage 3 Science: climbing the levels mountain. School Science Review.

Oversby, J. (2000). Models and Explanations in Chemistry: the case of acidity. In J. K. Gilbert & C. J. Boulter (Eds.), Developing Models in Science Education (pp. 227-252). Dordrecht: Kluwer.

Phillips, P. S., Pennington, M., & Hall, R. (1998). Developing chemical intellect. Journal of Chemical Education(Sept.), 130-133.

Rothenberg, A. (1995). Creative cognitive processes in Kekule"s discovery of the structure of the benzene molecule. American Journal of Psychology, 108(3), 419-438.

Rouse, W. B., & Morris, N. M. (1986). On looking into the black box: prospects and limits in the search for mental models. Psychological Bulletin, 100(3), 349-363.

Selinger, B. (1998). Chemistry in the marketplace (5th ed.). St.Leonards,NSW: Allen and Unwin.

Stanitski, C. L., Eubanks, L. P., Middlecamp, C. H., & Pienta, N. J. (2003). Chemistry in context:Applying chemistry to society. Boston: McGraw Hill.

Stocklmayer, S. M., & Gilbert, J. K. (2002). Informal chemical education. In J. K. Gilbert, De Jong,O., Justi,R.,Treagust,D.F.,Van Driel, J.H. (Ed.), Chemical education: towards research-based practice (pp. 143-164). Dordrecht: Klwer.

Suckling, C. J., Suckling, K. E., & Suckling, C. W. (1980). Chemistry through Models. Cambridge: Cambridge University Press.

Taber, K. S., & Coll, R. K. (2002). Bonding. In J. K. Gilbert, De Jong,O., Justi,R., Treagust,D.F., Van Driel,J.H. (Ed.), Chemical education: Towards research-based practice (pp. 213-234). Dordrecht: Kluwer.

Tomasi, J. (1988). Models and modelling in theoretical chemistry. Journal of Molecular Structure, 179, 273-292.

Van Aalsvoort, J. (2000). Chemistry in Products: a cultural-historical approach to initial chemical education. Unpublished Ph.D., Universiteit Utrecht, Utrecht.

Van Driel, J. H., & Graber, W. (2002). The teaching and learning of chemical equilibrium. In J. K. Gilbert, De Jong,O.,Justi,R., Treagust,D.F.,Van Driel,J.H. (Ed.), Chemical education:Towards research-based practice (pp. 271-292). Dordrecht: Kluwer.

Wandersee, J. H., & Griffard, P. B. (2002). The history of chemistry: Potential and actual contributions to chemical education. In J. K. Gilbert, De Jong,O., Justi,R., Treagust,D.F.,Van Driel,J.H. (Ed.), Chemical education: Towards research-based practice (pp. 29-46). Dordrecht: Kluwer.

Chemistry/Science Literacy for Sustainability: What should it Take?

(In Teaching, Learning and Assessment Strategies)

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In view of the unrealistic and/or unfulfillable expectations of people in our world of conflicting/competing values, interests and *finite* unevenly distributed resources, the environmental imperatives and the limited economical feasibility of several of even the most innovative/advanced technologies, the merging battle cry of all to "think globally and act locally," targeting at a sustainable world, is obvious. Yet, although science and technology may be useful in establishing what can be done in these contexts, neither of them can tell us what *should* be done, particularly with respect to sustainable development which is conceptualized differently by different people, groups and societies.

Given the current world state of affairs and the consequent evolving *paradigm shifts* – growth-to-sustainable development, correction-to-prevention, wants-to-needs, gaps increase-to-gaps decrease, passive overconsumption-to-active participation and options selection-to-options generation, the corresponding paradigm shifts, particularly as far as development, growth, rational consumption and management of resources as well as the science/technology/environment/society (STES) and chemistry/science education are concerned, is unavoidable (Zoller, 2000, 2001, 2004; Zoller & Scholz, 2004).

The essence of these paradigm shifts is presented in Table 1 (Zoller, 2004; Zoller & Scholz, 2004).

Table 1. *Selected paradigm shifts in science, technology, environmental research and STES-oriented education*

From:	*To:*
• Technological, economical, and social growth at all cost …	Sustainable development
• Corrective	Preventive
• Reductionism; i.e., dealing with *in-vitro isolated*, highly controlled decontextualized components	Uncontrolled, *in vivo complex systems*
• Disciplinarity	Problem-solving oriented, systemic, inter-/cross-/transdisciplinarity
• Technological feasibility	Economical-social feasibility
• Scientific inquiry (*per se*)	Socially accountable and responsible and environmentally sound
• Algorithmic lower-order cognitive skills (LOCS) teaching	"HOCS Learning"
• "Reductionist" thinking	System/lateral thinking
• Dealing with topics in isolation or closed systems	Dealing with complex, open systems
• Disciplinary teaching (physics, chemistry, biology, etc.)	Interdisciplinary teaching
• Knowing/recognizing/applying facts and algorithms for solving exercises/tasks	Conceptual learning for problem solving and transfer
• Science and technology *per se* (in dealing with environmental/sustainable development)	Integrative science-social science education in the STES interfaces context
• Teacher-centered, authoritative, frontal instruction	Student-centered, real world, project/research-oriented team learning

A sound, meaningful chemistry/science education, which will be responsive to, and have the chance of playing a leading role in the above processes, requires a revolutionized change in the guiding philosophy, rationale and models of our thinking, behavior and action. In this respect chemistry/science literacy for sustainability means the capability of *evaluative system thinking* in the STES context. Therefore, the development of our student's higher-order cognitive skills (HOCS) – system (lateral) critical thinking, question-asking, decision-making and problem solving – in the context of the sciences, environmental sciences research and education – should become the priority goal of contemporary and future sound chemical education. Accordingly, a meaningful chemistry/science education for sustainability is envisioned as an interdisciplinary, critical system thinking-problem solving/decision-making – oriented teaching, targeted at *HOCS learning,* leading, hopefully, to the capacity of *evaluative system thinking* and *transfer* beyond the science and/or disciplines specificity in the complex interwoven STES systems context (Zoller, 1993, 1999, 2001, 2004a,b; Zoller & Scholz, 2004). Chemistry/science for sustainability is, thus, conceptualized as *the* *capacity of evaluative, critical thinking for decision making, problem solving and transfer in the interdisciplinary S-T-E-S interfaces context*.

It appears that the essence of the current reform in science/chemical education worldwide is, indeed, a gradual shift from algorithmic/imparting knowledge-type teaching to higher-order cognitive skills (HOCS) learning. In the context of chemical education for sustainability, the ultimate target is the science-technology-environment-society (STES)-literate graduate, capable of evaluative thinking, decision making, problem solving and taking a responsible action accordingly. A major issue of concern is, clearly, how to translate this goal into effective, implementable courses, teaching strategies and assessment methodologies, which are consonant with this goal of 'HOCS learning'.

Accordingly, a sound response to the questions – (a) What should it include in the context of contemporary science/chemical education reform, worldwide? and (b) What type of chemical *education* can lead to changes in behavior of individuals, industries, institutions, organizations and governments, that will allow *development* and *growth* to take place within the limits set by *ecological imperatives*?, would be:

A shift –

- *from* algorithmic lower-order cognitive skills (LOCS) teaching to HOCS *learning* (Zoller, 1993, 1999) *as having the capacity of evaluative, critical system thinking for decision making, problem solving and transfer in the interdisciplinary S-T-E-S interface context.*
- *from* doing justice to the chemistry discipline (disciplinarity) to doing justice to the learner and the public at large (interdisciplinary/cross-disciplinarity) (Zoller, 2004b; Zoller & Scholz, 2004).
- *from* imparting of knowledge/"covering material" to conceptual learning/development of transferable HOCS
- *from* assessment of passive knowledge to assessment of HOCS (Zoller, 1993, 2001; Tsaparlis & Zoller, 2003); and
- *from* focusing on "what should our graduates *know*" *to* "what should our graduates *be able to do?*

The crucial issue within the educational setting is the translation of the 'evaluative system learning' goal into implementable effective transdisciplinary, HOCS-oriented chemistry courses, teaching, learning and assessment strategies.

The following are a few selected, illustrative implemented research-based examples:

A full description of an elective lecture-lab course for college juniors/seniors – "The Chemistry of Man's (People's) Environment" – is given elsewhere (Zoller & Scholz, 2004).

Selected HOCS-promoting teaching strategies follow:

(1) Self-study of pre-class lecture material. Students have the course outline, scheduling, objectives, requirements and assignments in their hands, and they study the relevant material *before* it is 'covered' in the class, to which they bring *their* questions to be discussed.
(2) No specific assigned course textbook(s). Students are provided, at the beginning of the course, with a list from which they can choose text- and reference books, to use for the study of any relevant topic as they find appropriate for their needs during the course.
(3) Homework assignments—mainly problems (not exercises)—that require HOCS for their solution. These problems are to be worked out by the students (preferably in groups) and submitted, *individually*, for feedback and grading by teaching assistants, former "graduates" of these courses.
(4) Students' self-assessment. Students self-assess their home assignments, pre-guided by the course professor (Zoller et al., 1997).

The following environment-related five questions (Q_1: 1.1-1.5 and Q_2: 2.1-2.5) were interwoven in mid-term (E_1) and term (E_2) 'Chem One' exams and thus served for assessment and grading, as pre-test and post-test, respectively, within a related research design (Lubezki et al., 2004).

Q_1: ***In a battery factory workers are exposed to ZnS and $CdCl_2$ (in the manufacturing of electrodes), HCl (in the preparation of the electrolytic bridge); oily grease (from oily metal parts, CH_2Cl_2 (a solvent for cleaning the grease), and H_2S. A suggestion was made to replace the water by petroleum for washing the workers' working clothes.***

1.1 *Do you think that the idea of replacing the water with petroleum is good from the point of view of cleaning the clothes?* Explain (Question level: HOCS).

1.2 *What is the possible source of the (poisonous) H_2S in the battery factory? Explain and write the relevant chemical equation* (Question level: LOCS).

1.3 *Based on the chemistry that you know, propose a simple practical method to overcome the H_2S problem in the factory* (Question level: LOCS+).

1.4 *Do you think that the idea of replacing the water with petroleum is good from the point of view of the environment outside the factory?* Explain (Question level: HOCS).

1.5 *Do the terms 'chemical bond', 'electronegativity', 'polarity' and 'hydrogen bond' have any relevance to your reply to the previous question (1.4)?* Explain (Question level: HOCS).

Q_2: ***Groundwater pollution by chromium (Cr), the origin of which is industrial disposal, constitutes a real health risk to the public who is using this water. The chromium-containing anions are CrO_4^{2-} which are mostly found in neutral water and $HCrO_4$, mostly found in more acidic water. Both are water soluble. Usually, Cr concentrations in groundwater are less than***

50 mg/liter. However, in concentrations higher than 500 mg/liter the dominant ion is $Cr_2O_7^{2-}$. In basic water $Cr(OH)_3$ is mainly found. It is less water soluble compared with the previous three and, apparently, less problematic than the other three with respect to its toxicity.

2.1 Try to hypothesize a possible reason for the difference, in the extent of risk to the public, between the chromium in $Cr(OH)_3$ compared with that in the first three anionic species (Question level: HOCS).

2.2 Suggest a simple experimental lab method via which you may determine the concentration of chromium in basic groundwater samples. Briefly explain how you would do that (Qustion level: HOCS).

2.3 What, in your opinion, will be the effect of acid rain on the relative abundance of the ions CrO_4^{2-}, $HCrO_4$, $Cr_2O_7^{2}$ and $Cr(OH)_3$ in chromium-contaminated ground water? Explain (Question level: HOCS).

2.4 In your opinion, what will be the effects of a particularly rainy year on the chromium toxicity risk in drinking of chromium-contaminated groundwater. Explain your answer (Question level: LOCS).

2.5 In your opinion, are the concepts: Oxidation-Valence, Chemical Bond, Acidity, Basicity, and Electronegativity relevant, and do they have a connection to your previous answers (1.1-1.4)? Explain (Question level: HOCS).

[for operational definitions of LOCS- and HOCS-type questions, see: Zoller & Tsaparlis, 1997; Tsaparlis & Zoller, 2003)].

The essence of our research-based consequent recommendations are:

1. Environmental chemistry literacy should be an imperative for *all*.
2. Attaining environmental literacy requires an interdisciplinary conceptual approach in teaching and *'HOCS evaluative learning'* for transfer.
3. Goals and expected outcomes of any STES-oriented chemistry/science course/program should be pre-defined/determined, to be followed by an appropriate, in accord, HOCS-promoting assessment process.
4. Chemical/education for sustainability should become an imperative within science education at all levels.

Summary, conclusions and implications: What should it take?

- Restructuring of education at all levels and science teacher training programs as well;
- Teaching of how to deal with interconnected complex systems and situations;
- A much greater emphasis on inter/cross disciplinarity in teaching and learning;
- A switch from the contemporary dominant algorithmic teaching, to conceptual HOCS-learning;
- The development and implementation of instruments and methodology for contextually-bound HOCS assessment;

Meaning, a *should* shift –

- *from* algorithmic lower-order cognitive skills (LOCS) teaching *to* HOCS learning; which would require the implementation of the following
- *Higher-Order Cognitive Skills*-oriented teaching strategies;
- *Active participation* of the students in the learning process;
- Fostering of “Question-Asking” and critical (Evaluative) thinking;
- Encouraging *group work* on *homework assignments* (and mini-projects);
- Extensive and effective student-teacher feedback mechanisms;
- *No specific course textbook* to be assigned;
- Providing *in-class opportunities* to defend and/or ‘test’ concepts;
- *Students cover/learn material before it is ‘covered’ by the instructor in class;*
- Lecture, recitation and lab sessions are integrated within the course;
- Administration *of specially designed HOCS- and ‘Conceptual’ change-oriented exams.*

References

Lubezki, A., Dori, J.Y., & Zoller, U. (2004). HOCS-promoting assessment of students' performance on environment-related undergraduate chemistry. *Chemistry Education: Research and Practice, 5*(2), 175-184.

Tsaparlis, G., & Zoller, U. (2003). Evaluation of higher- vs. lower-order cognitive skills-type examinations in chemistry: Implications for university in-class assessment and examinations. *University Chemistry Education, 7*(2), 50-57.

Zoller, U. (2000). Environmental chemistry: The disciplinary/correction-transdisciplinary/prevention paradigm shift. *Environmental Sciences & Pollution Research, 7*(2), 63-65.

Zoller, U. (2001). The challenge for environmental chemistry educators. *Environmental Sciences & Pollution Research, 8*(1), 1-4.

Zoller, U. (2001). Alternative assessment as (critical) means of facilitating HOCS-promoting teaching and learning in chemistry education. *Chemical Education Research and Practice in Europe 2*(1), 9-17 (an electronic publication: http://www.uoi.gr/conf_sem/cerapie).

Zoller, U. (2004). Editorial: Chemistry and environmental education. *Chemistry Education: Research and Practice, 5*(2), 95-97 [http:///www.uoi.gr/cerp].

Zoller, U. (2004a). From algorithmic LOCS teaching to HOCS learning – A paradigm shift: What does/should it take in practice-oriented research in STES education? In Ralle, B. & Eilks, I. (Eds.), *Quality in Practice-oriented Research in Science Education*. Proceedings of the 17th Symposium on Chemical Education, Dortmund, June 3-5, pp. 125-135.

Zoller, U. (2004c). Promoting "HOCS learning" via students' self-study and assessment in freshman chemistry courses. In Druger, M., Siebert, E.D. and Crow, L.W., *Teaching Tips*, Innovations in Undergraduate Science Instruction, Society of College Science Teaching, NSTA, Washington.

Connecting Chemical Education with the Real World

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1 Introduction

During the last century a fast increase in scientific knowledge and its application for technology development have changed the lives of most people on earth. Science based, new technologies have created numerous opportunities for increased production, efficient environmental practices, fast global communication, better health and longer lives, and improved access to information. Insight into and ability to make efficient use of science and technology have become the key to economic wealth, both among nations and within individual countries. The appearance of new, educated middle classes in many developing countries (of immense importance for their political development) is to a large extent due to the ability of individuals to take advantage of opportunities offered by science based technologies for economic gain. Today, the educational standards of a country's workforce determine its potential for economic success, much more than conditions that earlier were the most important, such as the natural resources of a country.

In recent years, science and technology (S&T) based opportunities have benefited industrialized countries and a select group of developing countries, e.g. in East Asia, the most, while many other Third World countries have been unable to take sufficient advantage of such opportunities. Typically, the latter have been unable to develop or sustain a workforce which can take advantage of the technological opportunities of today. It seems clear that performance in this area is related to the cultural base in developing countries: Countries and cultures which traditionally have valued and respected (scientific and technological) knowledge highly, have been able to create the needed workforce and have made fast economic progress, while other countries have remained behind.

Higher education, research and research training have become increasingly important ingredients in this picture (World Bank, 2002). Today, most key technologies are research based and they change much more often than before. Therefore, it is essential that the workforce is able to keep track with this development and this is only possible if it includes manpower with research training in the relevant science and technology fields. Only then will it be possible to continuously evaluate technologies considered for import and to modify or develop new technologies for local use (Thulstrup, 1999a).

It must be added that we are not only dealing with research based technology in the workplace; our spare time is also increasingly based on the use of such technologies. In other words: Most citizens must be able to apply both science and science based technologies (Caillods, Gottelmann-Duret, and Lewin, 1996) and many must also know how to evaluate and modify foreign technologies, as well as how to create new technological and scientific knowledge.

In order to be competitive in today's markets, to ensure efficient solutions to science based societal problems, and to help the populations take advantage of scientific knowledge in their daily lives, nations must provide an increasing amount and quality of science and technology education to all citizens and must produce a sufficient number of scientists and engineers, trained at an up-to-date level in their respective field. Some of them must be able to produce new knowledge in their field.

Thus countries need to provide (Thulstrup, 1999b):

- Efficient science and technology education "for the citizen" at the primary and secondary levels, that efficiently relates academic science to real life applications,
- a strong motivation for a sufficient number of young, talented people to enter science and technology based careers at different levels, together with a satisfactory preparation for such further studies,
- undergraduate study opportunities in engineering and other science based fields, at an internationally competitive quality level, providing a comprehensive preparation for real life jobs, and
- opportunities for postgraduate studies in relevant fields, designed so that they support national development and do not lead to excessive "brain drain" (see below).

Only few countries, industrialized or developing, are able to satisfy all the demands listed above, in spite of the fact that many are well aware of the obvious opportunities for national economic development through a buildup of a qualified S&T labor force. The implications are many, for example: Insufficient S&T training "for the citizen" may lead to inefficient S&T practices, both among individuals and in society as a whole (e.g. with respect to environmental practices and regulations). An even more severe problem, with global implications, is the inability of many industrialized countries to recruit a sufficient number of talents for S&T careers. This problem has intensified, especially during the early 1990s, when many countries experienced a "swing away from science".

2 Recruiting Talent for the S&T Labor Market in Industrialized Countries.

Denmark is an example of a country that has suffered (and will suffer even more in the future) because of the swing away from science (Table 1). A shortage in the pipeline of talented S&T labor in

Denmark has since the mid-1990s caused leading industries to move attractive research and development (R&D) activities abroad, e.g. to China. As in other countries, the swing away from science in Denmark took place in the first half of the 1990s (Danish Ministry of Education, 1997; Sarpebakken, 1997) and the pendulum still has not returned. The huge production of Danish graduates in humanities (most at the Master level) has led to high levels of unemployment in this group.

Table 1. *New Enrollments in Danish Universities 1990-96*

	Humanities	Science	Engineering
1990	2,800	2,800	5,000
1993	3,600	2,800	4,100
1996	5,500	2,100	3,100

(Danish Ministry of Education, 1997)

The decline in the number of engineering enrollments has continued since 1996, although less drastically. The most recent number, for 2004, is about 2450. The share of Danes in their 20s working on degree programs in science and engineering is today 5 per 10,000, compared with 24 in Sweden (Børsen, 2004). Even a popular belief that Danes are much smarter than Swedes will not solve the problems caused by this huge difference in numbers! To make matters worse, since most Danish programs in S&T subjects accept all applicants without any selection, the interface problems between high schools and universities are often serious, and drop-out rates are high throughout the studies.

The decline in numbers of S&T students may partly be accounted for by a decline in the birth rates in Denmark around 1970 (due to the introduction of the pill in the early 1970s?). However, these demographic changes can only explain part of the decline during the 1990s. Between 1988 and 1995 the number of applicants for engineering education programs fell 40% in Denmark, but also other countries experienced large declines - 35% in Switzerland, and 10% in the Netherlands, Norway, and the German region closest to Denmark, Schleswig-Holstein (Danish Ministry of Education, 1997). On the other hand, between 1988 and 1995 enrollment in engineering programs increased by around 50% in South Korea and by 35% in Sweden (the latter, however, from a low level).

Another part of the reason for the low interest in science and engineering, observed in many countries, is clearly the competition from other study programs, many of which seem to appeal more to our present-day students. In Denmark, humanities have drawn huge student numbers during the 1990s and following years (Table 1). Another reason is the inefficient Danish market mechanisms: Denmark has generous unemployment benefits that reduce the importance of job availability, generous retraining programs, and relatively uniform salaries among different academic fields with no special economic rewards for training in S&T fields.

It is striking that a significant part of the "swing" in Denmark was caused by a change in preferences among girls. In Denmark, before 1990, pharmacy had a solid majority of female students and the student intakes in chemistry and chemical engineering were close to a gender balance (Danish Ministry of Education, 1989). Today, most of these programs are again male dominated.

Finally, many industrialized country students are not attracted to S&T fields because they consider these difficult and boring, and they may have a point! The huge benefits to mankind of science based technologies are not clear to many - the creation of efficient infrastructures, eradication of diseases, medication that improves and prolongs life for those who are ill, food safety, convenient new materials, consumer electronics, communication technologies, and many other improvements of the material quality of life are taken for granted in many industrialized countries and not considered outcomes of efficient application of S&T. From an economic perspective, one may say that, in many rich countries, efforts to create new wealth through applications of S&T often seem less important than the struggle about how to distribute the existing wealth.

Many universities do not even try to emphasize the relations between their programs and real life needs, although this may be the most cost effective way of increasing a low student intake in selected programs. For example, at a Danish university a program in "Medicinal Chemistry" was able to attract students much better than a program in "Chemistry", in spite of the fact that the latter in reality could provide the same specialization. Clearly the word "Chemistry" alone does not create the proper associations among young Danes.

A frequent discouragement for first year students, particularly in engineering and hard science programs, is caused by interface problems, i.e. the differences between the realities of learning in upper secondary schools and the expectations of university teachers. These problems should not be neglected by the latter, nor should high drop-out rates. In the long term, interface problems may be reduced, partly through a strengthening of upper secondary school mathematics and science, but also through a more realistic attitude at universities, combined with an adaptation of new and more efficient learning strategies (Thulstrup, 2001). Most of all, a closer cooperation between education at the secondary and tertiary level could reduce the problems considerably.

During their education, most science and engineering students are rarely given a chance to feel excitement over the great accomplishments of S&T – such accomplishments often seem hidden in the curricula behind a wall of mathematics, basic sciences, and purely technical skills. Lih (2002) has compared traditional engineering education programs to a baseball (here football) training camp in which the participants hardly get a chance to play ball (Table 2).

3 Recruiting Talent for the S&T Labor Market: Who Pays the Price?

The fact that rich countries, in particular, have failed to motivate a sufficient number of their young talents for careers in science based fields does not mean that they have to suffer the most. Rich countries increasingly solve these problems by attracting the lacking S&T talent from poor countries through brain drain. These years, reliance on brain drain is becoming part of the national S&T policies of an increasing number of rich countries. Unfortunately, it often leaves the poor countries that provide the brains in a very difficult situation. Although they usually still have plenty of talents, they lack the ability to develop enough of them to compensate for the loss. In particular, Africa, that can afford it the least, is badly hurt by this practice. About 23,000 well educated professionals from Africa are lost annually to richer countries; replacing them with expatriates would costs about USD 4 billion (Solomon, Åkerblom, and Thulstrup, 2003).

The fact that science and engineering education in developing countries often refers to Western conditions and problems makes it even more tempting for developing country graduates to pursue careers in rich countries. Clearly, students must be exposed to (and can actually often find solutions to) domestic problems. However, with the increasing globalization and improved communication facilities it has become tempting for developing country universities to rely on curricula and course activities that may be obtained at leading Western universities, even recorded lectures or lectures provided by satellite or Internet are used. This is likely to remove university education even further from local, real life needs and opportunities in the home country, and may further promote brain drain[1]. For a discussion of the risks involved in the import of curricula, see Jones and Oberst (2001).

Denmark is a relative newcomer in the group of countries relying on import of science talent, but the benefits of introducing such practices have in recent years increasingly been discussed in Danish industry and among politicians. The fact that other rich countries, with which Danish industry is competing, are doing it, is usually mentioned as a justification for the theft or loan of intellectual capital.

[1] As an example, look at Table 2. It was originally produced by Lih with reference to baseball, a seemingly boring ball game that is unknown in many countries. However, the translation from baseball to football (soccer) made the wonderful illustration of what is missing in engineering education understandable globally.

Table 2. *Soccer Training Schedule, Modeled after the Traditional Engineering Curriculum*

Week 1 Sports Fundamentals + Electronic Sports Lab Soccer Rules 1 Running Calisthenics Physics	***Week 2*** Sports Psychology Soccer Rules 2 + Electronic Soccer Lab Jumping and Running Economics Bio-mechanics
Week 3 Kicking the ball Heading Tackling Psychology Business Practices Aerodynamics	***Week 4*** Controlling the Ball Free Kicks Corner Kicks Sportsmanship Management History of Soccer
Week 5 Offense Strategies + Electronic Lab Simulation (E) Goal Keeping Off-side Rules 1 Soccer Business Teamwork (E) indicates elective	***Week 6*** Defense Strategies + Adv. Lab Simulation (E) Soccer Ball Technology (E) Soccer Shoe Technology Classical Games (E) Coaching
Week 7 (E) Inter-player Coordination Business/Sports Ethics Substance Abuse (E) Off-side Rules 2 (E) Refereeing Games 1	***Week 8*** Sports Laws Contracts & Negotiation (E) Verbal Abuse (E) Soccer Management Soccer Greats Games 2

Lih, 2002, translated from baseball to soccer by E.W. Thulstrup

How can the present, unsatisfactory situation be improved? In principle the answer is simple: On the one hand, developing countries must make a much stronger effort to motivate S&T students for work on domestic problems and in domestic industries, thereby promoting local development. Furthermore, they must provide young talented S&T staff with acceptable working conditions - it has been demonstrated that this reduces brain drain significantly (IFS, 2001). On the other hand, industrialized countries must also get their act together and develop the needed number of their own talents. However, in the real world this does not have high priority and is not done to any great extent; many industrialized countries seem to consider the present reliance on brain drain a fairly convenient solution, although an extensive reliance on this “free lunch” may turn out to be risky.

4 Preparing Students for the S&T Labor Market

Insufficient exposure in science and engineering education to real life problems and S&T accomplishments does not only result in a lack of excitement in S&T education. It also may produce graduates, in both industrialized and developing countries, that are poorly prepared for the actual job demands in life after university (Kornhauser, 2001). Study programs, for example, still tend to be defined according to traditional subjects (e.g. chemistry, biology, physics, civil engineering, etc.). When chemistry curricula try to deal with real life applications, they sometimes end up reflecting the kind of chemistry that was important in industry 20 or 30 years ago, and interdisciplinary aspects of real life applications are often only vaguely reflected in curricula that are defined in terms of traditional subjects. Even today, engineering students in many countries hardly learn about patent laws and marketing.

The gap between university education and real life is not only a problem in developing countries. Some of the general (process) skills that are given very high priority in industry are usually not systematically developed in traditional S&T curricula, even in the most technologically advanced countries. A study by Taylor and Lee (1996; Table 3) of priorities among industrial employers in Texas shows the high priority given to general skills, especially skills related to communication and teamwork and to hands-on knowledge about real life industry.

Table 3. *Importance of University Chemistry Graduates' Skills and Experiences - a Survey of Industrial Employers (3.0 = extremely important, 0.0 = not important)*

Ability to speak and write clearly	3.0
Demonstrated willingness to be a team player	2.8
A 3 months internship in an industrial lab	2.3
Completion of Ph.D. or M.Sc. research program	2.1
Publication of research in peer-reviewed journal	1.8
Leadership in extracurricular activity	1.5

(Taylor and Lee, 1996).

Why has learning at universities often been so insensitive to the needs of the graduates? Why has it so often been defined in terms of the actions of teachers, rather than those of the students, and why do many curricula still only reflect research specializations of teachers, not real life job demands? Part of the explanation may be the political climate at many Western universities a few decades ago, when education and research were separated and industry was considered by many to be an improper partner (Fig. 1). Today, the situation is completely changed – it is considered appropriate not only to integrate education and research, but also to include real life applications in the process (Fig. 2). Note the "triangle" of overlapping education, research, and applications in the center of the figure. This is likely to define a field that, in particular, promotes useful learning (Kornhauser, 2001). Still, reforms along these lines come very slowly at many universities.

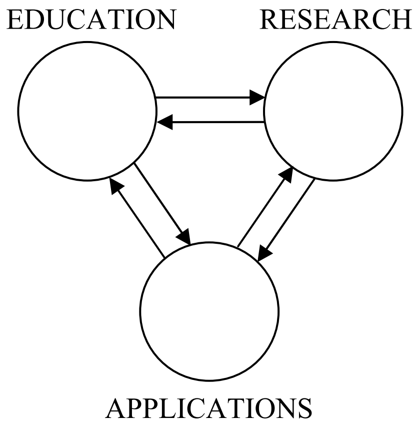

Figure 1: Relations between Education, Research and Applications in the 1970s (Thulstrup, 1999a)

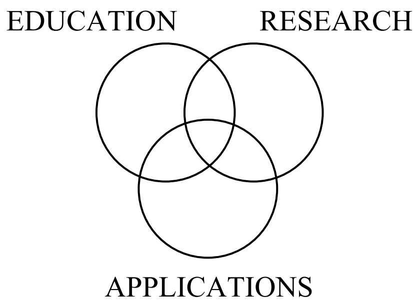

Figure 2: Relations between Education, Research and Applications in the 2000s (Thulstrup, 1999a)

Another important reason for the slow pace of change is that the traditional format for education, lectures, still dominates higher education around the World. Lectures are by nature teacher centered, and university teachers tend to be researchers in fairly narrow specializations. This is generally good; the resulting deep scientific insight and enthusiasm are likely to have a positive effect on student motivation and learning. However, as guiding lights for curriculum design, the individual backgrounds and interests of teachers are often not well suited. Even at good universities, curricula frequently end up being strongly influenced by special interests. Another problem with the lecture format is that many of today's students find lectures boring; the oral traditions of earlier times have disappeared, and concentrating on a single speaker for long periods seems hard for many young students.

Lectures are often supplemented by problem solving activities. Most introductory chemistry textbooks today provide a wealth of such problems, often with solutions. However, these problems often serve primarily as illustrations of (chemical) theory and not of real life chemistry. There is also the frequent risk with problem solving that bright students may decide to learn efficient “problem solving techniques” that allow them to do the job without having fully understood the concepts behind the theories.

Often examinations are also inefficient; testing the students’ understanding of concepts is often considered too complicated, and, although they may know better, many teachers are able to live a fantasy in which most students have acquired a long-lasting knowledge corresponding to the carefully specified pages in the textbook. Often examinations encourage memorization (for the immediate future) rather than long-lasting understanding of concepts and practical applications. Similarly, laboratory activities are often dominated by “verifying activities”, with few challenges to the students’ creative and innovative (“thinking”) skills, e.g. through design activities.

5 Educational Reforms in China

The country with the most successful industrial expansion during the last decades, China, has tried to move away from a higher education system dominated by traditions. These traditions reflected in many ways the problems discussed above, and were poorly suited for satisfying the manpower needs of modern industry. Encouraged by a young and reform-minded Ministry of Education, that has carried out a string of pedagogical experiments, and supported by a World Bank loan, a group of 28 leading Chinese universities (university mergers have since then reduced the number to 26) have undertaken substantial reforms of their undergraduate science and engineering education (Thulstrup, 1999c). The reforms were partly initiated by Chinese industry that found the S&T graduates insufficiently practical and innovative as well as poor team players (which may not be surprising, since they come from a generation of single children).

One of the many pedagogical experiments, on which the Chinese reforms were based, tried to measure the learning that is believed to take place during lectures: At Beijing Medical University (now merged with Peking University) students in a first year physiology course were divided into two groups. One group was “taught” in the traditional way, with a large number of lectures and a standard (verification type) laboratory course. The other group of students was only given half as many lectures, but was asked to use the time, that had become available, to study on their own, especially in the lab, performing open-ended design experiments, instead of the traditional experiments (Beijing Medical University, 1998).

At the end of the course the two groups were given the same examination, designed for the traditional “teaching” format, i.e. the first group. In spite of this bias there was no significant difference in the scores of the students from the two groups (actually the second group seemed to do slightly better). Some students from the second group noted that the demands on them had been remarkably high – instead of the many quiet and peaceful hours of passive listening to lecturers they were now supposed to perform tiring, independent thinking. This is an indication that efficient learning takes place – few would doubt that the combined amount of learning for the second group of students, especially outside the textbook content, was much higher than that for the first, although this was not tested in the examination.

In response to complaints by employers and based on the outcome of such pedagogical experiments, the group of Chinese universities has made extensive reforms of their undergraduate science and engineering programs. One of the main reforms is an increase in the emphasis on practical aspects of the subjects. The reformed curricula have, among other, reduced the number of lectures drastically, have upgraded and expanded laboratory activities. Redesigned laboratories were used for independent student activities, especially design activities and activities related to real life applications. Also examinations were changed considerably. Just a single, simple reform, introduction of open-book exams, has reduced the traditional excessive memorization considerably and has made time available for more constructive learning.

Today, essentially all universities involved consider the reforms a success and they are engaging in new reforms. Internationalization of higher education programs is, for example, given high priority. But also improved use of staff time and skills has come into focus, e.g. in connection with the traditional separation of the academic staff in theoretical and laboratory teachers. This separation is about to disappear, partly due to a shortage of the latter, but to considerable benefit for the students.

6 Problem Based Learning

Clearly reforms in chemical education and in S&T education in general are badly needed. Common problems include boring educational activities, lack of excitement about S&T accomplishments, real life inputs and relevance to local problems, insufficient preparation for later careers, demands of excessive memorization and short-sighted, shallow learning. One solution may be to replace lectures, which in many programs take up a vast amount of the students' valuable time, with other activities that reduce these problems and target relevant learning more effectively. Increasingly students and educators have found that replacing lectures by active work on real life problems, for example in cooperation with industry, produces a higher degree of motivation and thus also learning at a higher level (Fig. 2).

Curriculum reforms are rarely easy; they do not succeed by themselves, but often require hard work, including a large amount of diplomacy, to become successful (Ware, 1992). They must often build on, and thus be adapted to, the foundations of the existing curricula and systems. Experiences from China have shown that substantial reforms in higher education may become successful after only 5-6 years, but the conditions at the Chinese project universities were particularly conducive and a sudden introduction of drastic reforms may not work everywhere.

One educational strategy that may help reduce some of the most serious weaknesses in today's higher education is Problem Based Learning (PBL), sometimes called project education. The outcomes of PBL may be harder to define than those of traditional lecture based learning, which are often specified as a number of chapters in a book that the students are supposed to have read and possibly understood. In spite of these more diffuse outcomes most students and educators involved in PBL agree that the resulting learning is more applicable and at least as extensive as that resulting from lecture based learning. Many students also feel that PBL is more motivating, so that they work (and think) harder than they would otherwise have done. Work within PBL is often done in small groups; this provides important training in team work.

In addition to the traditional subject specific learning that result~~s~~ from PBL, it often also provides the students with a number of important skills outside the traditional subject fields (Thulstrup, 2001), for example:

- the ability to think independently,
- flexibility, which makes it possible to adjust to and work effectively under new conditions,
- experience in the analysis and solution of specific problems within a given time-frame,
- inquiry skills and attitudes,
- ability to work in teams,
- communication skills, in connection with both written and oral presentations,
- experience with strict deadlines,
- interdisciplinary knowledge,
- insight and interest in applied aspects of academic knowledge, and
- knowledge about what potential employers want and how they work.

Some of these skills (communication, team work, knowledge about industry) are by employers considered more important than academic degrees, scientific publications, and, especially, extracurricular activities (Taylor and Lee, 1996; see Table 3). Nevertheless, communication skills, skills as team players, and insight into industrial work practices are often given low priority in traditional, lecture based study programs. PBL may also increase student excitement about S&T accomplishments and may help soften interface problems in the first year of university studies.

Experience within the use of PBL is presently increasing fast. Among other, two Danish universities, Aalborg University (Kolmos, 2002; see also Kolmos *et al*, 2001) and Roskilde University (Thulstrup, 2001) have used PBL as their main educational tool for more than two decades. A considerable research effort related to PBL in engineering programs has been carried out at Aalborg University, and a Master program in PBL based science and engineering education has recently been established there (Aalborg University, 2004).

7 Conclusions and Recommendations

Today, many rich countries are unable to recruit a sufficient number of talents for studies in engineering and other science based fields. Part of the price for this inability is paid by some of the poorest countries in the world, which cannot afford such generosity. This is hardly acceptable from any point of view; obviously rich countries must do more to solve recruitment problems themselves. They might, for example, strengthen school science at all levels, mobilize the media, industry, and others more efficiently in the promotion of career choices in science based fields, and provide improved counseling of students and their parents in upper secondary schools. Universities should get involved in these efforts and help increase enrollment by making science based programs more attractive, e.g. by emphasizing the relations between the programs offered and real life needs.

Interface problems between secondary schools and universities - differences between what students actually learn in secondary schools and the optimistic expectations of university teachers - should not be neglected, but dealt with through cooperation between the two educational levels and by the introduction of more flexible educational strategies, such as PBL, at the first and second year university levels.

Old fashioned focus on what the teachers do and disregard for what students learn should be replaced by an active interest in what and how the students learn; it is, for example, particularly important that they feel fully responsible for their own learning. Similarly, the goals for the educational processes should be defined in terms of what the graduates can do, not in terms of what the students have learned or been taught (Jones, 2002).

The lack of excitement for science based accomplishments, both among secondary school students and S&T university students may be improved by targeting real life uses of S&T knowledge more directly and visibly in the programs offered. This is also likely to provide the students with more relevant skills for life after graduation. But such reforms are difficult to accomplish in university and curriculum structures that are completely dominated by lecture based learning in traditional, theoretical subjects; such structures must be changed.

In today’s job market the graduates need not only purely scientific subject matter skills, although these are still very important. Other skills, for example interdisciplinary and process skills have become increasingly important in today’s job market. Clearly, universities should not neglect these changing needs, but must adapt their programs to include the relevant training.

Curriculum reforms usually require a lot of hard work. In spite of examples of successful implementation in China only 5-6 years after the introduction of new strategies, radical curriculum change is likely to require years of gradual improvements, e.g. through a “trial and error” process. Many relevant reforms, especially those that integrate education, research, and real life applications, may be facilitated through replacement of traditional lecture based learning by PBL. The use of this educational strategy is presently growing fast.

Where are the friends and allies of S&T education today? The traditional partners have been the research establishments in each subject, but these partnerships have not always worked well. At times there has even been lack of trust between science educators and scientific researchers. A stronger integration of education and research, using the students as a glue, may improve the situation, but even then, these partnerships rarely extend much beyond the ivory towers. A “real life” input is required and this can only come from other players in society, especially industry. There is little doubt that in the coming decades, cooperation with industry will become an increasingly important activity in science education at any level.

Table 4 summarizes a set of recommended directions of reforms. The emphasis given to each of them, as well as the velocity with which they are introduced, must be carefully decided in each individual case. Careful studies and evaluations, and possibly targeted educational experiments, will also be required. Based on the results of these activities, adjustments of curricula and strategies must be performed regularly.

Table 4. Recommended Directions of Change for Education Strategies

Work only within Ivory Towers	→	Work in Society, Attracting Students
Dissatisfaction with High Schools	→	Cooperation with High Schools
Focus on Teaching	→	Focus on Learning
Teachers are Responsible	→	Students are Responsible
Focus on what the Students are Taught	→	Focus on what the Graduates can Do
Passive Listening to Lectures	→	Active Work on (Real Life) Problems
Reproduction of Known Results	→	Design, Creation of New Knowledge
Boring	→	Exciting
Ivory Tower, Traditional Subjects	→	Real Life, Interdisciplinary Subjects
Emphasis on Theory Alone	→	Emphasis on Real Life Use of Theory
Narrow, Subject Specific Skills	→	Wider Skills Needed after Graduation
Partnerships within Ivory Towers	→	Partnerships with Industry, Society

8 References

Aalborg University, 2004. http://www.mpbl.aau.dk

Beijing Medical University, 1998. Private communication.

Børsen, 2004. http://www.borsen.dk/dagens-nyheder/index?ids[]=63857&offset=0&specList (in Danish).

F. Caillods, G. Gottelmann-Duret, and K. Lewin, 1996. "Science Education and Development". UNESCO/IIEP, Paris.

Danish Ministry of Education, 1997. "White Paper on Engineering Studies in Denmark" (original report in Danish, 1996). Copenhagen.

Danish Ministry of Education, 1989. "Evaluation of Higher Education in Chemistry" (in Danish). Copenhagen.

IFS, 2001. "Mobilising Scientists for Development", pp 1-63. International Foundation for Science, Stockholm.

R. Jones, 2002. "Curriculum Development Ideas". In B. Mwamila and E.W. Thulstrup, Eds., "Engineering and Technology for Sustainable Development", Sida/SAREC, Stockholm.

R. Jones and B. Oberst, 2002. "Foreign Adaptation of US Engineering Education Models". In B. Mwamila and E.W. Thulstrup, Eds., "Engineering and Technology for Sustainable Development", Sida/SAREC, Stockholm.

A. Kolmos, 2002. "Facilitating change to a problem based model", Int. J. for Academic Development 7, 63.

A. Kolmos, C. Rump, I. Ingemarsson, A. Laloux, and O. Vinther, 2001. "Organization of staff development – strategies and experiences", European J. Engineering Education 26, 329.

A. Kornhauser, Ed., 2001. "University, Industry, Government Cooperation: How to make it Work?", and papers therein. ICCS, University of Ljubljana.

M. Lih, 2002. "Faculty Development: Recapturing and Conveying the Excitement of Engineering". In B. Mwamila and E.W. Thulstrup, Eds., "Engineering and Technology for Sustainable Development", Sida/SAREC, Stockholm.

B. Sarpebakken, 1997. "Swing Away from Science in Denmark" (in Norwegian). Danish Ministry of Education, Copenhagen.

T. Solomon, M. Åkerblom, and E.W. Thulstrup, 2003. "Analytical Chemistry in the Developing World", Analytical Chemistry 75, 106A.

G.L. Taylor and T.R. Lee, 1996. "Does Chemical Education Fulfill Its Customers' Needs?". In "Education for Industry", American Chemical Society, Washington, DC.

E.W. Thulstrup, 1999a. "How can Research Capacity be Created *and Used* in Developing Countries? A Strategy for the Next Decade". In "North South University Co-operation in Higher Education and Research", J.G. Simonsen, J.P. Myklebust, and H. Karlsen, Eds. NUAS, Univ. of Bergen, Norway.

E.W. Thulstrup, 1999b. "Secondary School-University Interface: Science and Engineering". Global Journal of Engineering Education 3, p. 9.

E.W. Thulstrup, 1999c. Paper presented at the International Forum on "Higher Education and Research in China in the 21st Century". Univ. of Stockholm, November, 1999.

E.W. Thulstrup, 2001. "University-Industry Cooperation within Project Based Learning: Near Infrared Spectroscopy for Undergraduate Students". In A. Kornhauser *et al*, Eds. "University, Industry, Government Cooperation: How to Make it Work?". ICCS, University of Ljubljana.

S. Ware, 1992. "Secondary School Science in Developing Countries: Status and Issues". PHREE Document 92/53. The World Bank, Washington, DC.

World Bank, 2002. "Constructing Knowledge Societies: New Challenges for Tertiary Education" The World Bank, Washington, DC.

Science Education Research: Beyond Classic Treatment vs. Control Research Designs

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Abstract

People outside the field of science education often expect to see numbers that "prove" one teaching method is "better" than another. They typically look for a treatment and control group, t – test and significance level that "absolutely" answer the question of a teaching method's effectiveness. However, people, unlike molecules, do not always behave in simple predictable ways. The teaching process is intertwined with the learning process and both processes are multi-variable systems. Not all of these variables have been identified and thus a simplistic treatment vs. control experimental design often is inappropriate and as a result, shows no significant differences between groups.

There are ways to deal with the multifaceted processes of teaching and learning. They involve using a mixed methods design to include both quantitative and qualitative methods of analysis. Data collected on several variables in the teaching and learning process can be triangulated to provide a more realistic picture of the interaction among variables. Within a quantitative methods approach, instruments such as surveys and achievement measures should be tested for reliability and validity before use in an experiment. When true treatment and control groups cannot be constructed, then one-classroom designs that subdivide the class into different groups based upon a variable(s) of interest can be used. Other research may forego the use of statistics and concentrate on identifying the pertinent variables in the teaching/learning process.

This paper will review these alternatives to the classic treatment vs. control research design and offer examples from current research that uses the alternatives.

Introduction

The classic scientific research design involves the use of treatment and control groups. Applying this design to educational research usually involves having two classes. One class (treatment group) is taught using a new approach or curricula materials. The other class (control group) is taught using traditional approaches or materials. Achievement measures are used to determine which group scores significantly higher on tests.

Although this design might work well when dealing with molecules, it does not necessarily work for educational studies. Learning and teaching are multi-faceted processes. It is not feasible to control all the variables except the one of interest. For instance, variables that could affect the achievement outcome of two different groups could include the teaching style and personality of the teacher, the physical environment of the classroom, and the background of the students on key points such as mathematical aptitude, previous science experiences, logical reasoning ability, preferred learning style and mental maturity. Other sociological variables such as parental support for learning, time to study either due to either family or work responsibilities, age of the student, and traditional vs. returning student status may also affect student achievement on the measures used in the study.

Even with the long lists of variables that previous research has identified, there are many more variables and interactions in the learning and teaching process that we are not yet aware of. These intervening variables (both mentioned here and as yet unknown) can obstruct differences in achievement between the treatment and control groups. Unlike molecules, students are not identical in all things except the treatment and its effect on their learning. When dealing with students in educational research, the rights of the student must also be protected throughout the experiment. This means that all students enrolled in a course, regardless of whether the students are the subjects of a treatment or control group, must be guaranteed a fair chance of success in the course. This results in a treatment vs. control design that really measures the "value added" as a result of the treatment. Such a design handicap can result in no significant differences between treatment and control groups when either the treatment effect is small or the control experience is good in and of itself.

The discussion thus far has dealt with the unique situations that can arise in educational research based upon differences in students or teachers in both treatment and control groups. However, the most obvious reason why a treatment vs. control experimental design may not be appropriate in some educational settings is that such a design requires *random* assignment of subjects to treatment and control groups. Although this may be possible in some situations, most classes used in educational studies are intact classes and as such, have their composition determined by someone other than the researcher. From a statistical point of view, this situation can result in a dramatic decrease in the sample size. Two classes of 500 students each, where the students are not randomly assigned to one class vs. the other, results in a sample size of 2, not 1000. A sample size of 2 is too small to analyze statistically.

Although the use of classic experimental designs in educational studies seems difficult, there are ways around some of the problems mentioned here. These solutions involve the use of other experimental designs that may not be as well known as the treatment vs. control design used in scientific studies. One important consideration in selecting an experimental design is to match the design to the question being asked. This issue is the first one that the researcher must address when planning an experiment in science education.

Research Questions

Although the most popular question asked in educational research studies is "Does this approach or curriculum work better than traditional approach or curriculum?" it is not the only question or even the most interesting or valid question to ask. We might want to ask *how* a seemingly innovative approach works or even *why* it works. Also of interest is the effect of a particular teaching approach or curriculum on specified groups of students in the class such as male vs. female, traditional vs. returning students, students with high math ability vs. low math ability, confident students vs. non-confident students, etc. In addition, it might be necessary to identify what the important variables are in certain learning situations. This could be the case if we wanted to understand *why* students have a difficult time solving stoichiometry problems. We might also be interested in identifying the critical parts of a new teaching approach or curriculum vs. those that could be eliminated or modified without sacrificing student learning gains.

These questions cannot all be answered through the use of a treatment vs. control design experiment. Some of them might not be well served by a quantitative experimental design at all. In these cases, the question asked may be best investigated using a qualitative experimental design.

Matching the Research Design to the Research Question

There are some basic differences between the two major categories of quantitative and qualitative research designs. The differences start with the types of questions asked by the researcher. Quantitative research designs generally are used to compare and contrast. It is expected that the outcome of such research will result in a “winner” and a “loser” for a particular population in a particular situation. Qualitative research, on the other hand, is used to investigate *what, how*, or *why* something happens in the learning and teaching experience. Qualitative research helps to identify the pertinent variables and their interactions in a particular situation. Quantitative research assumes that the variables and their interactions are known and can be controlled either through the design of the experiment or statistically in the analysis.

Qualitative research starts with the assumption that the variables are interwoven and difficult to understand. Quantitative research assumes that the variables can be identified and the interactions measured. The purpose of quantitative research is generalizability and prediction. The purpose of qualitative research is interpretation of the reality of the situation at hand. Qualitative research does not start with a hypothesis the way quantitative research does. Qualitative research develops a hypothesis on the basis of the analysis of the data collected from the situation. In qualitative research, the researcher is the basic tool for collecting and analyzing data. Quantitative research, on the other hand, starts with a hypothesis and manipulates formal instruments to test it. The researcher manipulates the tools while remaining as objective as possible. Qualitative studies are intense studies of a few individuals while quantitative studies rely on the aggregate scores of many individuals to point to a trend.

Both of these research traditions, qualitative and quantitative, have “rules of engagement”, assumptions and standards that must be adhered to for the purpose of conducting quality research. A discussion of some of these “rules” follows.

Qualitative Research

Although qualitative research is often not well understood by physical scientists, it does have a long history in the research of psychology, history, sociology, nursing, anthropology and education. Each discipline has contributed to one of several qualitative research designs. Five of the more common designs (Creswell 1998) are biography, phenomenology, grounded theory, ethnography and case studies. Of these designs, the three that would most likely be of interest to the science educator are phenomenology, grounded theory and case studies.

Phenomenological studies focus on a specific concept or phenomenon. This type of study seeks to understand the phenomenon through the experiences of the individuals involved. Grounded Theory studies attempt to generate a theory or model about a situation by analyzing the responses of individuals to a particular situation. This qualitative approach is the most rigorous and closest to scientific experimental designs in its analysis (Creswell 1998). The Case Study is an in-depth study of a “bounded system”. A bounded system is one that is defined by time, place, situation or individuals involved. Multiple sources of data are collected to present an in-depth picture of a situation or individual.

Qualitative Research Tools

The main research tool of qualitative research is the researcher himself. The researcher through background investigation, observation and interview, collects data for analysis. The discussion of qualitative research tools in this paper will be limited to two – interviews and surveys.

Although most people understand what an interview is, interviews for qualitative research range from structured to unstructured (Jaeger 1988). Structured interviews consist of a predetermined set of questions that each interviewee is asked in the same way. Interviewers are trained not to deviate from the printed script. Interviewee answers can be videotaped, audio-taped or the interviewer can write notes during and after the interview. Semi-structured *interviews* can also follow a script but here the interviewer is free to ask spontaneous questions of the interviewee. Semi-structured interviews often include a demonstration or problem that the interviewee is asked to solve aloud. Once again, the interviews can be video, audio-taped or the interviewer can write notes. In an unstructured interview, the interviewer asks the interviewee questions as they arise in the conversation. Not all subjects are asked the same questions in this situation.

Surveys can be either qualitative or quantitative tools depending on how they are constructed and analyzed. If a survey is used qualitatively, then it probably includes open-ended questions, which permit students to respond in their own words without being forced to explain something by choosing someone else’s words. These free responses can be used by the researcher to develop a valid Likert scale (quantitative) survey. Likert Scale surveys can be distributed to many students and then analyzed statistically.

Qualitative researchers amass a great deal of data in their studies thus creating the need for systematic data reduction. One way to reduce the data is to analyze it for trends or categories(Creswell 1998). It is the data itself that suggest the trends or categories. The researcher uses the data to develop a complete rubric that contains the trends and categories suggested by the data. This rubric is then used to “code” all the data collected. The results of the analysis are used to support the interpretation that the qualitative researcher builds in the discussion of the research. Frequency tables of trends/categories and/or typical student comments can be used in the discussion of the research to support the researcher’s conclusions.

Quantitative Research

One of the main differences between quantitative and qualitative research is that quantitative research reports on the aggregate (average of students in the study) while qualitative research reports on a limited number of specific cases. There are two general categories of quantitative research designs -- pure experimental and quasi-experimental designs.

(Abraham and Cracolice 1993-94) identify several pure experimental research designs including pretest-post test design, post only, and Solomon’s four-group design. The pretest-post test design is familiar to many. Here students are *randomly* assigned to either treatment or control groups. A pretest is used to measure variables of interest followed by the implementation of a new teaching approach or use of curriculum materials with the treatment group. A posttest, which is either identical or equivalent to the pretest, is administered and significant change from pre to post tests is analyzed. One problem with this design is the potential interaction between pre and posttests. The pretest can act as an advance organizer and help structure student learning during the treatment phase. Another possible interaction involves students remembering the posttest questions from the pretest and answering them as they did before.

The posttest only design also *randomly* assigns students to treatment and control groups. It then includes treatment and the administration of a posttest. Possible problems with this design include the fact that the treatment and control groups may not be equivalent on variables of interest even though they were randomly assigned to groups. Second, if there is a differential dropout rate of students from either the treatment or control groups, a biased sample could result and unduly influence the analysis. Without a pretest on some variables of interest, an analysis of the differential effect of the treatment on a specific subgroup is impossible.

Solomon’s Four Group design can be thought of as a combination of both the pretest-post test and posttest only designs. It, too, *randomly* assigns students but in this case, the assignment is to one of four groups, namely, pretest-treatment, pretest-control, posttest only-treatment, and posttest only-control. Analysis of the data permits several different comparisons including treatment vs. control, pretest treatment vs. pretest control, pretest-treatment vs. post test only treatment, etc. In order to conduct this experimental design, a large number of students is needed so that there is a reasonable number of students assigned to each of the four groups. This design also requires a more sophisticated statistical procedure to analyze the data.

It should be noted that all the quantitative designs discussed here required *random* assignment of students to treatment and control groups. As has already been discussed, random assignment is not always possible in a real learning/teaching situation. There are quantitative designs that do not require random assignment. They are known as quasi-experimental designs. Two examples of quasi-experimental designs are discussed here.

Quasi-experimental Designs

In quasi-experimental designs, students do not need to be randomly assigned to groups (Jaeger 1988). To compensate for the error that this might introduce into the analysis, pertinent variables are identified, measured, and compared between the groups to assure equality on the variables of interest. Such variables might include gender, age, math aptitude, and science vs. nonscience majors, logical reasoning ability, College Admission Test scores, and grade point average among others. Two types of quasi-experimental designs discussed here are interrupted time series and the one-classroom design.

(Jaeger 1988) describes the interrupted time series design as the collection of data for many consecutive points in time both before and after a treatment is introduced. These data are then plotted and the shape of the graph studied. If there is a an abrupt shift in level or direction of the graph at a point in time corresponding to the application of the treatment, the treatment is then interpreted as having been the cause for this effect. This design is appropriate for use with a small number of students but it can be difficult ruling out other possible causes for the shift in the graph.

One-classroom designs include the identification and measurement of a small number of variables of interest such as logical reasoning ability, math aptitude, gender, etc. The treatment is then administered and the data analyzed for possible differential effects of the treatment on one group vs. another. One-classroom designs can be used when a treatment is applied for some topics and not others during the experiment. Achievement on the topics without the treatment is then compared to that with the treatment. Combination of these two types of one-classroom designs can also be used. Such combinations require sophisticated statistical methods of analysis.

Mixed Methods Evaluation

Obviously, there are advantages and disadvantages of using either qualitative or quantitative research designs. One solution is to design an experiment that incorporates both qualitative and quantitative methods into one study. The advantages of such a design (NSF 1997) include improved instrumentation and triangulation. Instrumentation in studies of learning and teaching often include the use of surveys constructed for the specific project at hand. By using qualitative methods to analyze the responses to open ended survey questions, a more valid Likert scale survey can be constructed. The valid Likert scale survey can then be distributed widely and analyzed quantitatively.

A second advantage to using mixed methods evaluation is triangulation (NSF 1997; NSF 2002). Triangulation is defined as measuring different aspects of the same variables to provide a more realistic interpretation of the data. Triangulation strengthens the validity of the interpretation of the data. An example of this is the occurrence of a low achievement score for a student on a multiple-choice test. This data point does not tell the researcher if the student really understood the principle being tested and just made a small error somewhere in the solution or really didn't understand the principle at all. By combining the quantitative measure of an achievement score of right or wrong with a qualitative open-ended "explain" portion of the answer, the researcher would have a better understanding of the student's knowledge. This is a small example of how a mixed methods approach can utilize triangulation.

Examples of Research Designs Used in Recent Studies at Catholic University

(Daubenmire 2004)conducted a study of *how* the Guided Inquiry (GI) approach to learning used at Franklin and Marshall College was experienced by students. GI involves students working in cooperative learning groups on worksheets that introduce a topic through the use of a model or analysis of data, provide practice and opportunities for advanced application of the topic. Lecture is not used in the course except for a limited number of 10-minute lectures to guide students who have been stymied by a particular principle. As a result of using GI in their general and physical chemistry classes for 10 years, Franklin and Marshall College has experienced a dramatic decrease in the number of students who earned either a D/F or dropped the course. The faculty at Franklin and Marshall College wanted to know *how* GI was working for students.

The experimental design used to investigate this research question was a qualitative design that involved filming the interaction within two cooperative groups in two GI classes once a week for 10 weeks. Analysis of the tapes included viewing the tapes to identify strategies and procedures used by groups to complete worksheets. A subset of students who were filmed were asked to view portions of the tape with the researcher and verify and/or comment on what was happening in their learning process at key points on the tape. Based upon verification by students, a rubric was developed to code all tapes. Tapes were coded by the researcher and one other investigator. An inter-observer reliability of .856 was calculated for this procedure.

The results show the identification of four phases and two bridges of learning that students experience during the GI process. The phases are as follows: Phase I: Compare and Contrast; Phase II: Group Interaction; Phase III: Confirmation or Rehearsal; and Phase IV: Missionary. Phase I: Compare and Contrast involves students checking responses with each other in the group. Phase II: Group Interaction takes place when students discuss their thoughts and ideas about chemical concepts. This phase involves two or more students as equal contributors to the discussion. Phase III: Confirmation or

Rehearsal includes the process of students retracing their thought processes to an answer to make sure they understand the concept. Phase IV Missionary takes place when a student, confident in his understanding, offers to help another student who is unsure of his answers.

The two learning bridges used both between and within phases are the Tutoring Bridge and the Mentor Bridge. The Tutor Bridge is characterized by one student seeking help from another student who understands the concept. This typically occurs from Phase I to Phase II or to facilitate movement through Phase II. The Mentor Bridge involves the teacher who offers help when a group reaches an impasse or moves in the wrong direction. This bridge is typically used to move from Phase II to III or within Phase II.

The use of a qualitative approach matched the question of *how* learning occurred in the GI approach. A quantitative assessment of achievement would not have been appropriate to answer the question.

A second research experiment by (VandenPlas, Havanki et al. 2004) looked at the comparative effectiveness of a student response system (SRS) for in-class web-based questions vs. online quizzes on student achievement. This study used a mixed methods approach with a quasi-experimental, one-class design and open-ended surveys. This design was used to investigate which of these two technological innovations was effective in improving student achievement, if there was an advantage to using both of them, and how students used the innovations to prepare for tests.

The experimental design included the use of a pretest called the Group Assessment of Logical Thinking (GALT) Test (Roadrangka, Yeany et al. 1982) to differentiate the class into low, medium, and high GALT groups. Online quizzes were used during the interval following each lecture and prior to the next lecture. In class, students used laptop computers with a wireless router to answer web-based questions posed by the teacher during lecture. Student achievement was measured on monthly teacher-written exams for questions that had a parallel question on prior online quizzes and others that had a parallel on the in-class web-based questions. A national American Chemical Society exam was used as a delayed achievement measure for questions that had parallels on the online quizzes and/or in-class web-based questions.

Open-ended surveys were administered at the end of the semester. Students were asked to comment on their use of the online quizzes to prepare for exams. The in-class web-based questions were not available to students for use after class. The graded online quizzes were available to students throughout the semester.

The use of online quizzes resulted in higher achievement on teacher written exams but offered no advantage on the American Chemical Society Exam. The use of in-class web-based questions offered no advantage on either teacher written exams or the American Chemical Exam. Students of different GALT groups did not score significantly differently on either the teacher-written or the American Chemical Society Exam. On the survey, students reported using the graded online quizzes to prepare for the teacher written exams. The conclusion is that having access to the result of technologically assisted questioning throughout the semester enables students to practice, reflect and review the topic more effectively then simply presenting the questions during a class or in a testing situation.

Summary

A simple treatment vs. control experimental design may not be appropriate for many science education research studies largely due to the complexity of the intervening variables in the teaching/learning process and the inability of most researchers to guarantee true randomization of subjects to treatment and control groups. Other research designs are available. The design chosen for a particular study should match the type of question asked in the research. Depending on the type of question asked, a qualitative, quantitative, or mixed methods design can be selected. A secondary question in deciding which research design to choose is the number of subjects available for the study. Quantitative studies require larger numbers of students. Qualitative studies can be conducted with a few students. Within quantitative studies, the question of whether randomization can be accomplished will determine whether the study uses a pure experimental or quasi-experimental design. The presence or absence of a control group will further determine whether the study is a single-classroom or multiple –classroom design. Identification and control of intervening variables is of vital importance in designing quantitative experiments. Use of a mixed methods design or covariables/pretests on variables of interest can be used to address this issue. The important point to consider when designing science education research is whether the experimental design chosen and/or developed matches the question and conditions of the study.

References

Abraham, M. R. and M. S. Cracolice (1993-94). "Doing Research on College Science Instruction: Realistic Research Designs." Journal of College Science Teaching **Dec 93/Jan 94**: 159-153.

Creswell, J. W. (1998). Qualitative Inquiry and Research Design: Choosing Among Five Traditions. Thousand Oaks, Sage Publishers.

Daubenmire, P. (2004). A Longitudinal Investigation of Student Learning in General Chemistry with the Guided Inquiry Approach. Chemistry. Washington, DC, The Catholic University of America.

Jaeger, R. M., Ed. (1988). Complementary Methods for Research in Education. Washington, DC, AERA American Educational Research Association.

NSF (1997). User-Friendly Handbook for Mixed Method Evaluations. Washington, DC, National Science Foundation.

NSF (2002). The 2002 User-Friendly Handbook for Project Evaluation. Washington, DC, National Science Foundation2.

Roadrangka, V., R. H. Yeany, et al. (1982). Group Assessment of Logical Thinking. Science Education, University of Georgia.

VandenPlas, J., K. Havanki, et al. (2004). Effectiveness of a Web-based Student Response System (SRS) in Nursing Chemistry. Poster Presentation at BCCE Conference, Iowa, The Catholic University of America.

Keynote Lectures

Comparative Analysis of Problems in Chemistry and Science Teachers Training in Europe and America

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Introduction

The quality of teacher training is the main point in the analysis of factors that influence the quality of science education. This analysis can help educational authorities look for ways to improve different stages in science teaching and learning. The author of this work has a long experience of teaching chemistry and science subjects in European and South America (SA) countries, and this experience allows him to propose different observations and conclusions about this topic.

Methodology and results

It is known that the quality of pre-service and in-service teacher preparation in many European countries is rather high. That is what we can conclude based on data from different international evaluations of school students, medals and prizes in International chemistry and science Olympiads (Orlik 2002). There are many factors that have a positive influence on that situation and many of them can be observed now in the educational systems of the EU countries. The most important of these factors are: 1. The high level of development of science and technology in the society; 2. The existence of an effective system of pre-service preparation of science and chemistry teachers, that combines the high level of teaching of science subjects with different good quality courses on methodology and pedagogy of teaching science and chemistry; 3. The existence of a special system of continuing professional development for in-service teachers who can periodically and systematically attend the special courses of modern methodology and pedagogy of science and chemistry education for achieving a higher qualification level. Generally this system is organized by the Ministries of Education and this important measure allows teachers to take special time to prepare themselves on modern methodologies for improving teaching and the student learning process. A good example of organization of such systems was in the former Soviet Union and current Russia, and it's clear that this system is a strong foundation for getting good results in science education; 4. The science teacher and generally the secondary and high school teacher in many countries holds a rather high level and position in the society. This absolutely normal situation is one of the main reasons for obtainig rather good results in science education.

There are, of course, a lot of other factors that have an important influence on the quality of the science and chemistry education in the developed countries. For example, the system of science education of many countries has two essential subsystems: formal and non-formal science education. Teachers of science and chemistry are the main educational potential of both sub-systems. The first subsystem is the formal science education at primary, secondary school and in higher education as well. The other one, the non-formal part, is connected with the popularization of science at museums, associations, science organizations and so on; and it is also linked with the many efforts for improving science education generally in the non-class activities and joined forces with Ministries of Education and other parts of the formal educational subsystem. There is rather strong cooperation between both parts of the science educational system and usually they share the same goals in the countries with relatively good and satisfactory results in Science education (in North America, Europe, Russia).

In many American countries we can find another situation with respect to this topic (Orlik 2004). Obviously the level of development of science and technology in SA society is not as high and in some cases there are special government programs for improving this situation. In many SA and other developing countries, we can not find strong examples of the special system for achieving a higher qualification level for in-service teachers to raise the level of their educational qualification. In some countries, many science and other teachers never have opportunities for such work or for updating their qualification after graduation from the special pedagogical university major, and this becomes one of the main causes of the serious problems we face with respect to the low quality of science education in these countries. Unfortunately, in many of these countries, the current situation of the science teacher in society is far from the good and necessary standards, and a school teacher is not considered a central figure in society. This low status can become one of the main sources of problems in the quality of science education.

Another important requirement for training science teachers is the need for designing the system of National Science Educational Standards (Moore 2003). A good example of a modern approach in this direction is the development of not only national but also international standards of science and chemical education in Europe. But in some SA countries, we don't have these standards at all, or this process is only in its initial stage for establishing this significant part of teacher preparation. Another problem is to teach teachers how to use these standards in their daily class work. That could only be done if a good system of preparation and perfection of pre- and in-service teacher exists, as stated above. The modern science teacher should do this difficult work, too, on the basis of integral methodology of teaching and learning (Orlik 2002). This means that the educational activities should be carried out with a variety of instructional methods and means that allow students to gain good knowledge and develop high level skills.

There are a lot of problems with the formal and non-formal science education in SA countries, and this situation suggests that both sub-systems are strongly divided and there is not the necessary cooperation and coordination between them. We can also notice the little coordination in planning activities between the science and education authorities in the topics of science education and popularization. For example, sometimes activities in schools and science museums are separated. In many cases the small amount of funds that have been provided for the science education and popularization in these countries is not handled properly and with the necessary effectiveness either.

Conclusions

Some urgent measures should be taken to encourage the improvement of the quality of science and chemistry teacher's development programs. Some effective ways for that are:1. Organization of strong cooperation and coordination between science and education authorities in programs, plans and activities toward improving the quality of the pre-service preparation of science teachers; 2. Working on strategies to improve the social role and status of the science school teacher and of other subjects; 3. Organization of a special system to improve the level of educational qualification in science, mathematics and other subjects for in-service primary, secondary and high school teachers; 4. A modern system of Science Educational Standards should be developed to allow the teacher to do this difficult work on the basis of integral teaching methodology.

Bibliography

J. Moore. Preparation of chemistry teachers. J. Chemical Education, N 7, vol. 80, 719, 2003.

Y. Orlik. Chemistry: active methods of teaching and learning (in Spanish), Iberoamérica Publ., México, 2002,

Y. Orlik. Editorial. Preparation of science teachers. J. Science Education, vol. 5, N 1, p.4, 2004.

Endocrine Disrupting Chemicals

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Abstract

Internally secreting glands (endocrine glands) such as pituitary, thyroid, parathyroid glands, breast, kidneys, suprarenal glands, pancreas, and gonads secrete hormones which are essential for the normal functioning of living organisms. Disruption of their functions may have untoward effects on several other organs and life processes. Unbalanced functioning of the endocrine glands may be, besides several disease processes, caused by external factors such as radiation (particularly ionised), medicines and certain chemicals used in daily life. There is proof beyond doubt that a few chemicals can cause disturbance of endocrine function in man and wildlife in large doses. Some of these chemicals are no longer used, but their effects are still actual because of their persistence and tendency to accumulate, e.g. polychlorinated biphenyls (PCB) and dichlorodiphenyl trichloroethane (DDT). There are experimental data about the endocrine effects of several other chemicals. However these data were mainly acquired *in vitro,* therefore they ought to be extrapolated very carefully to *in vivo* situations as it is virtually impossible to simulate the complex vertical and horizontal links among endocrine and other organs of an intact organism in cell cultures. For a couple of hundred chemicals there is a suspicion that they might disrupt hormonal balance purely as a consequence of their structural similarity to known endocrine disrupting chemicals.

Our presentation will include details on some confirmed endocrine disrupting chemicals, their properties, presence in the environment, potential sources of exposure and their effects on humans and wildlife.

Keywords: chemicals, endocrine disruption, literature review

1 Introduction

Several reports concerning disruption of endocrine (hormonal) balance in man and wildlife have appeared in professional literature and lay media in the last twenty years. Based on these reports, many organisations including the World Health Organisation, the European Commission, and the US Environmental Protection Agency, initiated activities to elucidate several unclear and controversial aspects of endocrine disruption. (Groshart & Okkerman, 2000; IPCS, 2000; Reiter *et al.*, 1998; Safe, 2000). We present a literature review of professional reports in this field.

1.1 Definition

An endocrine disrupting chemical (EDC) is an exogenous substance or mixture that alters the function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub)populations. A potential endocrine disrupting chemical is an exogenous substance or mixture that may alter function(s) of the endocrine system and consequently cause adverse health effects in an intact organism, or its progeny, or (sub)populations (Damstra *et al.*, 2002).

1.2 Physiology of endocrine organs

The internally secreting (endocrine) organs include: hypothalamus, pituitary, thyroid and parathyroid glands, breast, kidney, suprarenal glands, pancreas, gonads (ovaries in women and testes in men) and bone. Many peripheral hormone systems are controlled by the hypothalamus and pituitary. The hypothalamus is sited at the base of the brain and is connected to the pituitary via special blood supply. Hypothalamic cells secrete hormone- releasing and –inhibiting substances which cause specific response in the pituitary followed by release of stimulatory or inhibitory hormones which cause or prevent secretion of hormones by other endocrine glands. The hormones secreted by other glands exert their effects on the target organs, but also on the hypothalamus and/or pituitary. In an intact organism hormonal balance is constantly being maintained predominantly via a negative vertical feedback mechanism. Beside the vertical communication along the hypothalamic-pituitary-other endocrine gland axis, there are multiple horizontal connections among endocrine and non endocrine organs. In view of the complex relationships among various components of the endocrine system, and other organs, distinction between primary and secondary effects of EDC proves difficult. The effects of age and the developmental stage of the exposed organism further complicate the evaluation (Damstra *et al.*, 2002; Kumar & Clark, 2002).

2 Effects of EDC, Mechanisms of Action, Dose/Response Relationship, Exposure

The fact that certain medicines can affect the functioning of the endocrine system has been well established (Kumar & Clark, 2002). Besides it has been confirmed that persistent organic pollutants (POPs), such as dichlorobiphenyl trichloroethane (DDT) and polychlorinated biphenyls (PCB) may in large doses can cause malfunctioning of the endocrine system. There is suspicion that certain effects of serious concern have occurred secondary to EDCs exposure of humans and wildlife Damstra *et al.*, 2002; Holoubek *et al.*, 2000).

From over 500 substances which appear on the list of suspected EDCs around 50 have been shown to cause hormone disruption while the majority are on this list due to their structural resemblance to the known EDCs (Groshart & Okkerman, 2000).

2.1 Suspected effects of EDCs in humans

A decline in quantity and quality of human sperm has been reported by various researchers since 1930's (Jouannet *et al.*, 2001). In Slovenia, scientists at the *In Vitro Fertilisation Clinic* in Ljubljana carried out a study between 1983 and 1996 in which 2343 healthy partners of women with tubal disease were examined. A 0.67% decline per year of birth decline in sperm concentration has been noted in men born from 1940 to 1960, but an increase in those born after 1960. No changes in sperm quality apart from progressive mobility have been established. Possible causes such as socio-economic state, psychological stress and environmental factors have been suggested, but none of these have been studied further (Zorn et al., 1999). Sperm characteristics are influenced by multiple population and methodological factors such as origin of man, occupation, age, diseases, medication, diet, smoking, clothing, psychological stress, mode of sperm collection, methods of analysis, sexual abstinence, seasonal inter- and intra- technician variability, and statistics (Jouannet *et al.*, 2001). A decrease in male/female ratio is another cause for concern. Decreased sex ratio has been associated with exposure to ethanol, anaesthetics, dibromodichloropropane, dioxins and vinclosin. Epidemiological studies showed reduced fertility in people exposed to tobacco, high dietary PCBs or mercury, and in farm workers exposed to high doses of pesticides. In individuals exposed to 2, 4 dichlorophenoxyacetic acid (2, 4 D), DDT and hexachlorobenzene (HCB) an increased incidence of spontaneous abortions has been noted. Increasing occurrence of male sexual organ developmental abnormalities, precocious puberty, endometriosis, disturbed neurobehavioural development which present further causes of concern has also been observed.. Whether these changes are due to hormone disruption or not, remains to be elucidated (Damstra *et al.*, 2002).

Last but not least, the increasing incidence of cancer in hormonally responsive tissues including breast, uterus, testes, prostate and thyroid gland is worrying. A particularly pronounced increase in breast cancer incidence has been noted worldwide (Sasco, 2001; Pompe Kirn *et al.*, 2002). Known risk factors for development of breast cancer include genetic factors and life long exposure to female sexual hormones (oestrogens). Exposure to oestrogens is increased in women with early first menstruation, late menopause, in those who never delivered or breastfed, in those with postmenopausal obesity, and in women on contraceptive pill or hormone replacement therapy. Some authors associate an increase in breast cancer with exposure to POPs, i.e. DDT its metabolite DDE (dichlorobiphenyl dichloroethylene, PCB, HCB. The current data, however, do not indicate a direct causal link. At this instance it is important to stress that exposure in early life might be critical, but is presently poorly determined. A protective effect ascribed to phytoestrogens (female hormones present in certain vegetables e.g. soya beans) presents another controversial point in the association between xenoestrogens and breast cancer, namely rising a question as to why should man-made oestrogens be more hazardous than natural ones (Damstra *et al.*, 2002; Holoubek *et al.*, 2000).

Comparison of human studies in order to establish a causal relationship between exposure to EDC and untoward effects is difficult on account of the following: the data is often gathered in different age groups or in variable exposure conditions; there is a substantial lack of data on exposure in critical life stages; studies are performed with variable methodology. Data interpretation is further complicated by the fact that the concentration and potency of EDCs or potential EDCs are usually lower than those of endogenous hormones. (Damstra *et al.*, 2002).

2.3 Suspected effects in wildlife

In seals exposed to PCB in DDE unwanted effects on reproduction and function of the immune system have been seen (Bergman, 1999). Birds exposed to DDT developed thinning of egg shell and altered function of gonads leading to a decrease in bird populations. Suggested mechanisms include disturbed calcium supply, inhibition of carbon anhydrase and changes in steroid receptors.(Damstra *et al.*, 2002). According to some authors the spill of organochlorine pesticides in Lake Apopka in Florida is responsible for changes in gonads and developmental anomalies in alligators (Guillette *et al.*, 1999). Decreasing populations of amphibians have been noted worldwide, but the data is insufficient for establishing a causal link with the EDCs. In fish untoward effects on reproductive capacity and developmental malformations have been linked to sewage waters and paper industry waste waters. The mechanism has not been elucidated. A decline in marine gastropode populations secondary to their masculinisation through increase in male hormones is a rare example of a reliably established role of EDCs, namely antifouling agents containing tributyltin compounds
(Damstra *et al.*, 2002).

2.4 Mechanisms of action

The link between effects of EDCs and their mechanisms is not sufficiently clarified. But numerous data on molecular level help to explain various mechanisms of action of EDCs such as effect on hormone synthesis, transport and metabolism. EDCs may mimic or antagonise the endogenous hormones. Due to the complexity of the endocrine system the prediction of effects proves difficult. Further exposure to the same dose at various developmental stages may cause different effects. Simulation of multiple vertical and horizontal links of an intact organism is virtually impossible on a molecular level. Therefore much caution is required when extrapolating from *in vitro* to *in vivo* situation. (Damstra *et al.*, 2002).

2.5 Dose/Response Relationship

The golden rule of toxicology established by Paracelsus, all substances are toxic; the right dose distinguishes the medicine and the poison, has in the context of EDCs acquired a new contradictory dimension. Some authors believe that the presence of endogenous hormones in physiological concentrations results in EDC's capacity to cause effects at lower concentrations than those required to affect other target organs. In some studies of EDCs a biphasic curve in dose/response relationship has been identified, namely that a more pronounced response was seen at lower doses. It is not clear whether this finding is of any clinical relevance. As already mentioned the same dose may also cause different effects, depending on the age of the organism (Cross, 2001; Damstra *et al.*, 2002).

In view of the above specific dose/response relationship the adequacy of classical toxicity testing has become questionable. However, it must be stressed that the results of studies which showed higher effects at lower doses were not repeatable and present the most contradictory area in the study of EDCs (Ashby, 2000).

2.6 Exposure to EDCs

In evaluating EDCs the lack of exposure levels and trends currently presents a susbstantial problem. The exposure data are mainly limited to groups accidentally exposed to high doses of POPs in Europe and North America. Potential sources of exposure include food, drinking water, air, consumer products. While the content of EDCs in the environment is relatively well characterised, this is not the case concerning biological tissues with the exception of mother's milk and adipose tissue. Exposure in critical developmental stages remains widely undetermined (Damstra *et al.*, 2002). The quantification of exposure as well the determination of biologically effective dose is being extensively investigated.

3 Conclusions

The numerous allusions and suspicions concerning the effects of EDCs in humans and wildlife are biologically plausible. The concerns raised are justified in view of the known effects of endogenous hormones, adverse effects of certain medicines, the results of *in vitro* and *in vivo* studies , and the established effects of POPs at high dose levels. However there is no hard proof for effects at low dose levels in real life settings. The area of EDCs is a subject of intensive research worldwide. Beside the importance of choosing the right dose and age of organism, the influence of genetic variability, sex, nutrition, coexistent diseases and concurrent exposure to other agents are important factors which need to be considered carefully during planning of research studies. While the results of current research are being awaited, toxicovigilance and application of the precautionary principle in order to reduce the exposure to (potential) EDCs as much as reasonably possible are essential.

4 Literature

1. Ashby, J. 2000. Getting the problem of endocrine disruption into focus: The need for a pause for thought. APMIS 108: 805-13.
2. Bergman, A. 1999. Health condition of the Baltic grey seal (*Halichoreus grypus*) during two decades. Gynaecological health improvement but increased prevalence of colonic ulcers. APMIS, 107:270-282.
3. Cross, F.B. 2001. Legal implications of hormesis. Hum Exper Toxicol, 20: 122-128.
4. Damstra, T. *et al.* 2002. G. Global Assessment of the State-of-the-Science of Endocrine Disruptors. Geneva, WHO: 180 str.
5. Groshart, Ch. & Okkerman, P.C. 2000. Towards the establishment of a priority list of substances for further evaluation of their role in endocrine disruption. Final Report. Delft. European Commission DG ENV: 53 str.
6. Guillette, L.J.Jr., *et al.* 1999. Serum concentrations of various environmental contaminants and their relationship to sex steroid concentrations and phallus size in juvenile american alligators. Arch Environ Contam Toxicol, 36, 4:447-455.
7. Holoubek, I. *et al.* 2000. Persistent, Bioaccumulative and Toxic Chemicals in Central and Eastern European Countries- State-of- the- Art-Report. RECETOX_TOCOEN, Brno, 2000 (www.recetox.muni.cz/).
8. IPCS. Endocrine disruptors. IPCS News: 12: 4-5.
9. Jouannet, P. *et al.* 2001. Semen quality and male reproductive health: the controversy about human sperm decline. APMIS 109: 333-344.
10. Kumar, P. & Clark, M. (ur) 2002. Clinical Medicine, Edinburgh, W.B. Saunders: 1446 str.
11. Pompe Kirn *et al.* 2002 (ur). Register raka za Slovenijo. Incidenca raka v Sloveniji 1999. Poročilo št. 41. Ljubljana, Onkološki Inštitut: 75 str.
12. Reiter, M.W. *et al.* 1998. The US federal framework for research on endocine disruptors and an analysis of research programs supported during fiscal year 1996. Environ Health Perspec, 106: 105-113.
13. Safe, S.H. 2000. Endocrine disruptors and human health-Is there a problem? An update. Environ Health Perspec,108: 487- 493.
14. Sasco, A.J. 2001. Epidemiology of breast cancer : an environmental disease? APMIS, 109: 321-332.
15. Zorn, B. *et al.*, 1999. Semen quality changes among 2343 healthy Slovenian men included in an IVF-ET programme from 1983 to 1996. Int J Androl, 22: 178-183.

Oral Presentations

Is it Possible to Learn Chemical Equilibrium at High School?

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Introduction

It is well known that from the constructivism viewpoint, each individual builds up his/her own knowledge. In the process there often arise previous ideas, or alternative conceptions, that frequently become an obstacle in learning scientific concepts, but taking them into account might be one of the main resources for succeeding in the teaching-learning process and, therefore, in the literacy of the future citizens.

During the last decades science education research has focused on how students learn and has made evident that pupils possess ideas regarding the world's nature. Often these ideas do not agree with scientific concepts and have received several names through the years. Among these names, which arise from different ideological conceptions of education, are misconceptions, alternative conceptions, naive science, child's science, and etceteras. In this paper they are called previous ideas.

Alternative conceptions are personal constructions, in many cases a product of a non formal or implicit learning, whose aim is to establish regularities in the world, making it more predictable and controllable.

Students' previous ideas have an enormous impact in learning. Following Giordan, it can be said that previous ideas are not a reservoir to be consulted when needed, but they act as a conceptual filter that allows pupils to understand somehow the world surrounding them. Therefore, these ideas or conceptions become a key factor in learning and must be taken into account when planning courses and curricula.

In the beginning, previous ideas were treated as if they were isolated, but there has been a lot of work regarding their structure; most authors take them as involved in conceptual nets or conceptual niches. Often authors talk about conceptual ecology (Campanario, 1999; Strike & Posner, 1985), but others (Mortimer, 1995) believe that they might be forming frames or, some of them, could be isolated as well.

Most educators visualise the aim of education as the transformation of previous ideas into conceptions as close as possible to scientific knowledge. This process is called conceptual change.

Conceptual change has been the subject matter of many investigations for over 20 years and it has changed from a rather simple idea – previous ideas can be radically substituted by scientific concepts once and forever – to a much more complex conception of learning. Nowadays, most authors conceive conceptual change as a tough process, which might last many years, even a life long term.

Many researchers (Chi, 2003; Caravita, 1994; Vosniadou, 1994; Carey, 1985) believe that there are two kinds of conceptual change: the weak one, which can be easily achieved and the tough one, which is often very difficult to accomplish. Different authors assign various names to each type of change. So, the weak one is also known as knowledge restructuring, assimilation or conceptual capture; whereas the strong or radical change is called accommodation, conceptual exchange or conceptual change. Some authors separate knowledge accretion from conceptual change while others include it as a third level (Duit, 2003). Mortimer (1995) prefers to talk about conceptual profile change, rather than conceptual change itself. Because his proposal assumes that previous ideas coexist with scientific conceptions in the same domain and the learner (or scientist) chooses them for specific contexts.

On the other hand, some authors classify models of conceptual change as cold or hot, depending on whether they are mainly centred in cognitive aspects (cold ones) or else they take into account affective and social aspects (hot models) as well.

The authors of this paper share the view point of many researchers (Campanario, 1999; Strike and Posner, 1985) and believe that previous ideas should be taken as a starting point in planning education, in defining objectives of courses, themes and lectures, as well as in the design of teaching strategies. Doing this, students can be guided towards conceptual change or, at least, towards a conceptual profile change.

Chemical Equilibrium is a tough subject, because it involves understanding the particulate nature of matter, chemical reaction and difficult concepts like concentration and rate of reaction. Some Mexican teachers even wonder if chemical equilibrium is a subject that can be learned and understood in high school. And yet many high school curricula include Chemical Equilibrium as a subject to be taught in General Chemistry courses.

The authors of this paper have been involved in a research project (Flores et al., 2002) that included an inventory of previous ideas, their categorisation and the proposal of some teaching strategies that seek students' conceptual change.

This paper presents some schemes of students' thought regarding chemical equilibrium and points out some recommendations for teaching this theme, at high school level, which seem to have been successful.

Objectives

The aim of this paper is:

– to present and discuss a classification of Mexican high school students' previous ideas related to chemical equilibrium, that shows some schemes of thought,
– to share and discuss the above mentioned schemes of thought, and
– to present some recommendations for teaching chemical equilibrium at high school.

Methodology

The authors compared Mexican high school students' previous ideas, related to chemical equilibrium, with those reported in the literature and found out that they are very similar.

In the search, the authors found so many previous ideas that they felt that it was imperative to classify them. To classify previous ideas the authors were bound to analyse and interpret them. This allowed the authors to recognise some schemes or frameworks of students' thought. So, a categorization of previous ideas was made. We took into account other classifications found in international journals and books, and made our own.

The frameworks of students' thought related to chemical equilibrium revealed that the conceptual change sought was not a weak one; quite on the contrary, these schemes of thought required a deep conceptual change; affective aspects and the social environment of students should also be taken into account. Some teaching strategies were designed and probed with a pilot group of high school students. Since the population involved in this research was within 15-18 years of age, the teaching strategies designed included lecture demonstrations and a game played by students. Both seem to have been successful; but especially the game helped students to understand the concept of reversible reactions.

There are many lecture demonstrations related to chemical equilibrium in the literature, so we will not describe them in this paper.

The game was originally designed by Raul Valdes to help his high school students to understand reversible reactions, as the bases to grasp chemical equilibrium. It is an analogy of Haber's synthesis of ammonia.

$$N_2 + 3H_2 \rightleftarrows 2NH_3$$

The materials needed are some plastic straws, cut in pieces of about 3 cm of length and pieces of cardboard; we then made them into equilateral triangles, with three holes in each triangle. The holes should be big enough to hold the pieces of straw inserted in them. Two pieces of straw were stuck together with a little piece of masking tape or other adhesive tape, to represent dihydrogen molecules (H_2). Two triangles were also stuck together, to represent dinitrogen molecules (N_2). Both kinds of "molecules" were put in small boxes.

Pupils were organised in teams of two or three. One team was supposed to compete with another team. The whole group (about 30 students) was involved in the game. One team's task was to split the couples of straw and cardboard pieces, to represent the dissociation of molecules; and then, insert three pieces of straw in the holes of each cardboard, to represent the formation of ammonia molecules (NH_3). Once an ammonia "molecule" was made, the team put it immediately on the table. The opponent team's task, instead, was to split the newly formed "molecules" of ammonia to give back "molecules" of the elements hydrogen and nitrogen. The teacher was encharged with giving the start and finish signals, taking several fixed periods of time, unknown for the students, since the teacher took them randomly. At the end of each period, the students counted how many "molecules" of reactants and products were on the table for each couple of teams. The teacher counted how many "molecules" of reactants and products were produced by the whole group and then helped the students to analyze the results.

Results

Table 1 shows the authors' classification of students' previous ideas in terms of schemes of thought, called associated conceptions.

About three weeks after the teaching strategies were applied to the pilot group, a term test was applied to a larger number of pupils (ca. 300). The students' sample performed quite well compared to other pupils of the same study level who had not had these teaching strategies. Since it was a pilot group the comparison was only qualitative.

Table 1. Categorisation of previous ideas related to chemical equilibrium

TOPIC	ASSOCIATED CONCEPTIONS Examples	PREVIOUS IDEAS Examples
Symbolism	There is a physical separation between reactants and products.	Each side of the chemical equation can be manipulated independently
Dynamic character of equilibrium	Somehow all reactions come to an end.	Once the same quantity of reactants and products is obtained (equilibrium) no reaction takes place.
Concentrations at equilibrium	Concentrations of reactants and products may or may not change at equilibrium.	At equilibrium reactants and products concentrations vary constantly as the reaction oscillates between reactants and products.
The equilibrium constant	K, the equilibrium constant, is not really a constant, since it changes with equilibrium conditions.	K changes when the concentration of one of the components in an equilibrium system is altered.
Changes at equilibrium conditions	Changing initial reaction conditions raise changes at equilibrium.	Changes in a system in equilibrium increase the rate of the favorable reaction and decrease the rate of the opposite reaction.
Role of catalysts at equilibrium	Catalysts might affect the opposite reaction, forward reaction or both.	When a catalyst is added to the system at equilibrium, the rates of the forward and reverse reactions are either unchanged or increased depending on whether the catalyst favors the forward or reverse reaction.
Chemical kinetics	Rates of forward and backward reactions change as the whole reaction proceeds.	The rate of the forward reaction increases with time from the mixing of reactants until equilibrium is established.

Impact on learning

The game is very simple and can be played with very simple and cheap materials. The students had a lot of fun playing the game and, together with lecture demonstrations, leading pupils to get good grades in a term test related to chemical equilibrium. We may infer that the applied teaching strategies were successful and helped students to understand reversible reactions and the dynamics of chemical equilibrium. Of course, they have to be accompanied by lectures and other teaching strategies (Kind, 2004) to approach completely the complex theme of chemical equilibrium.

Recommendations for teaching

Since previous ideas are often very tough to change, to be able to lead high school pupils towards conceptual change, first of all, it is necessary to know them and take them as a starting point of the teaching-learning process. It is also needed to apply different teaching strategies to explore students' previous ideas and to search conceptual change as well. Lecture demonstrations have proved their value in both senses. Games are also a very good resource since they arouse students' interest and help to avoid boredom during lectures; but, they have to be followed by reflection and analysis. It is also important to point out similarities and differences between the analogy used and the phenomenon under study.

Conclusions

It is the belief of the authors that previous ideas should be the starting point of any strategy to succeed in teaching any subject at high school, and it becomes particularly important if we are attempting to teach chemical equilibrium.

The authors' answer to the title question is yes, it is possible to learn chemical equilibrium at high school if the proper teaching strategies are chosen. This implies focusing on students' alternative conceptions, to use lecture demonstrations and allow students to play games like the one included in this paper.

Bibliography

Campanario, J. M. & Moya, A. (1999). ¿Cómo enseñar ciencias? Principales tendencias y propuestas. Enseñanza de las Ciencias, 17(2), 179-192.

Caravita, S. y Halldén, O. (1994). Reframing the problem of conceptual change. Learning and instruction, 4, 89 – 111.

Carey, S. (1985). Conceptual change in childhood. Cambridge, MA: A. Bradford Book. The MIT Press.

Chi, M.T.H. & Roscoe, R.D. (2003). The process and challenges of conceptual change. En Limón, M. & Mason, L. (2003). Reconsidering conceptual change: Issues in theory and practice. Kluwer Academic Publishers, London, p. 3 – 27.

Flores, F., et al, (2002). http://ideasprevias.cinstrum.unam.mx:2048

Garnett P. J., Garnett, P. J., & Hackling M. W. (1995). Students' alternative conceptions in chemistry: A review of research and implications for teaching and learning. Studies in Science Education, 25, 69-95.

Hackling, M. W. & Garnett, P. J. (1985). Misconceptions of chemical equilibrium. European Journal of Science Education, 7(2), 205-214.

Hameed, H., Hackling, M. W. & Garnett, P. J. (1993). Facilitating conceptual change in chemical equilibrium using a CAI strategy. International Journal of Science Education, 15(2), 221-230.

Kind, V. (2004). Más allá de las apariencias. Ideas previas de los estudiantes sobre conceptos básicos de química. Facultad de Química, UNAM– Santillana, México.

Maskill, R. & Cachapuz, A. F. (1989). Learning about the chemistry topic of equilibrium: the use of word association tests to detect developing conceptualizations. International Journal of Science Education, 11(1), 57-69.

Mortimer, E. F. (1995). Conceptual change or conceptual profile change? Science & Education, 4, 267-285

Quílez-Pardo, J. & Solaz-Portolés, J.J. (1995). Students and teachers' misapplication of Le Chatelier's principle: implications for the teaching of chemical equilibrium. Journal of Research in Science Teaching, 32(9), 939-957.

Van Driel, J. H., De Vos, W., Verloop, N. & Dekkers, H. (1998). Developing secondary students conception of chemical reactions; the introduction of chemical equilibrium. *International Journal of Science Education, 20(4), 379-392.

Vosniadou,S.(1994) Capturing and modeling the process of conceptual change. Learning and Instruction, 4, 45-69.

The Importance of Patent Informatics in Education of Students of Chemistry and Related Fields

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Introduction

Patents play an important role in scientific research and development and have two main functions: they provide legal protection of inventions (Figure 1), and are a unique source of scientific information. From the viewpoint of intellectual property rights, a patent is a legal document, granting its holder the exclusive right to make use of an invention for a defined period of time and for a limited geographic area, and the right to stop others from making, using or selling the claimed invention without authorisation. In addition to their legal functions, patents are valuable sources of scientific literature, bringing newest information on innovative developments in various areas of science and technology. Patents can therefore be used as indicators of applied scientific research and development (R&D). Patent bibliometrics and other information methods can be used to detect shifts in the innovation system, point to dynamic innovation areas, and investigate prosperous R&D fields. If monitored consistently, patents become effective means of avoiding parallel developments and duplication of research [1]. Because of their innovative nature and the "no prior disclosure" conditions, patents bring information on new scientific and technological achievements before scientific articles, conference proceedings and monographs are published. Moreover, statistics show that over 70% of information in patents is never published elsewhere [2]. For this reason, comprehensive information studies should include both, analyses of non-patent scientific literature (indicating trends in basic research), and analyses of patent documents (illustrating applied research and development).

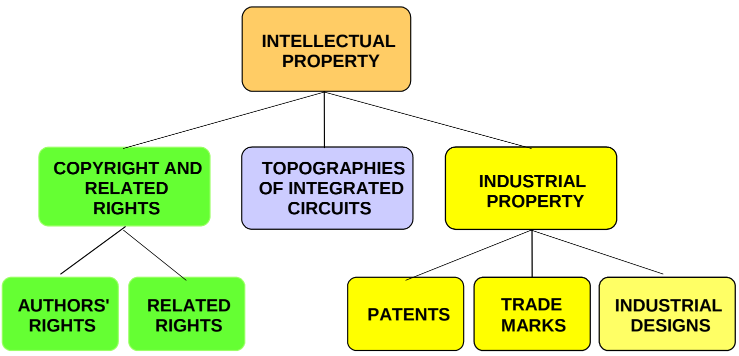

Figure 1. *Main groups of the intellectual property*

Patent bibliometrics and value-added bibliographic database processing can be applied to detect shifts in the innovation system, to point out dynamic innovation areas, and to investigate prosperous fields. Learning about patents has to become an essential part of university S&T curricula, especially in studies related to chemistry, pharmacy, and biotechnology. Students need to acquire skills to be able to efficiently monitor innovations and generate new R&D ideas. In addition, students need to know about and learn how to test the novelties (results of their own research) to avoid infringing existing patents.

This article provides examples of introducing patent informatics into university undergraduate and postgraduate courses of chemistry and related scientific and technological studies. Examples are taken from the microencapsulation technology field, which can be regarded as a typical knowledge intensive dynamic research field, with a wide spectrum of industrial applications and a rapid growth of publications, which calls for the introduction of information methods and patent informatics for both, industrial information studies and education of students.

Materials and methods

STN International (The Scientific and Technical Information Network) was used as a commercial host for online database processing. In addition to online searching with full-featured service designed for professional information searchers through special telecommunication links (STN Classic), STN can be accessed on the Web (http://stnweb.fiz-karlsruhe.de/html/english/). A Search Preview Tool enables testing of search profiles in different databases, giving as a result the number of hits per database. This search possibility was used in combination with the methodology of value-added database processing [3] for processing bibliographic/patent databases to predict and recognise trends in specific research and development domains. The method includes four essential steps: (I) definition of a research field by a combination of key words (to define the specific research field), a time series (publication year), and other searchable parameters, such as document type, corporate source/patent assignee, location, language, etc.; (II) selection and processing of most appropriate databases for a given research problem, preparation of detailed search profiles; (III) statistical analysis of search results, which can be performed manually or automatically by specific commands, (IV) graphic presentation of results for the recognition and interpretation of trends.

In addition to commercial databases, Espacenet, a patent database offered by the European Patent Office (http://ep.espacenet.com/), and the US patent fulltext database (http://www.uspto.gov/patft/), were used as freely available sources of primary patent documents that can be accessed through the Internet.

Heuristic information methods, such as data structuring and recognition of patterns were applied for the analysis and synthesis of data from similar patent documents with diverse, scattered and fragmented information [4]. These methods enabled the recognition of research areas, application fields, families of products, and facilitated the recognition of potential new products within the unoccupied/non-patented market niches, or the development/improvement of technological process backbones. Patent processing algorithm-H [5] was applied for the recognition of the-state-of-the-art in specific research and development fields.

Results

The results of using these methodological approaches are illustrated with some examples from joint university-industry research projects and educational courses where students were exposed to real-life situations, taught how to effectively process international databases, coping with large amounts of information, using strategies of information-based problem solving, structuring scientific and technological data into systems, recognising the key parameters and their hierarchy, designing patterns of knowledge, and using the information density for the prediction of trends (Figures 2 - 9).

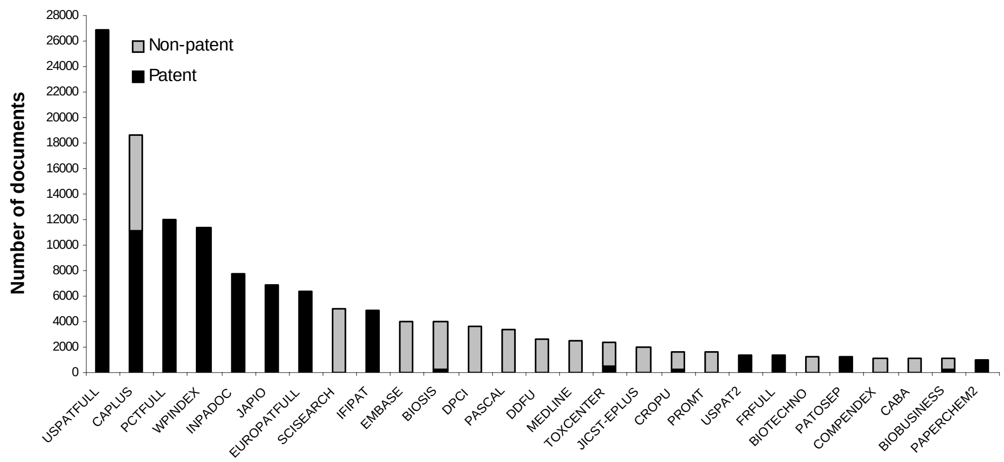

Figure 2. An example of bibliometric analysis: bibliographic databases containing more than 1,000 records on microencapsulation (STN International, database clusters: Chemistry, Bioscience, Patents; search profile *microcapsul? or microencapsul?*

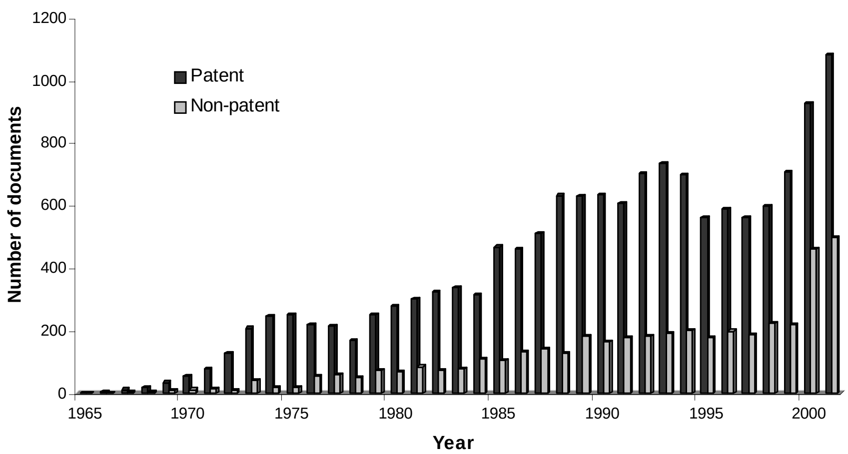

Figure 3. An example of value-added database processing: rapid growth of new publications on microencapsulation in CAPlus database, indicating the ratio of applied (patent) and basic research (non-patent); search profile *microcapsul? or microencapsul?*

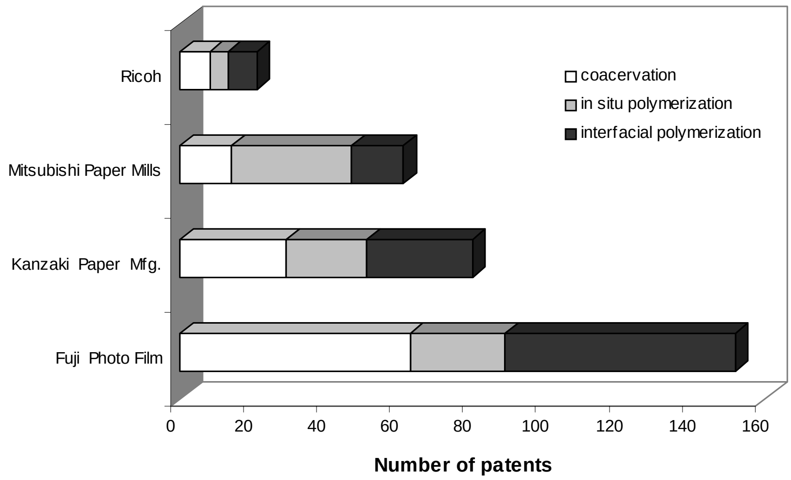

Figure 4. An example of value-added database processing, based on functional information density: patent assignees with largest number of patents on micoencapsulation of leuco dyes for graphics and printing, and the recognition of three main microencapsulation technologies (CA Plus database).

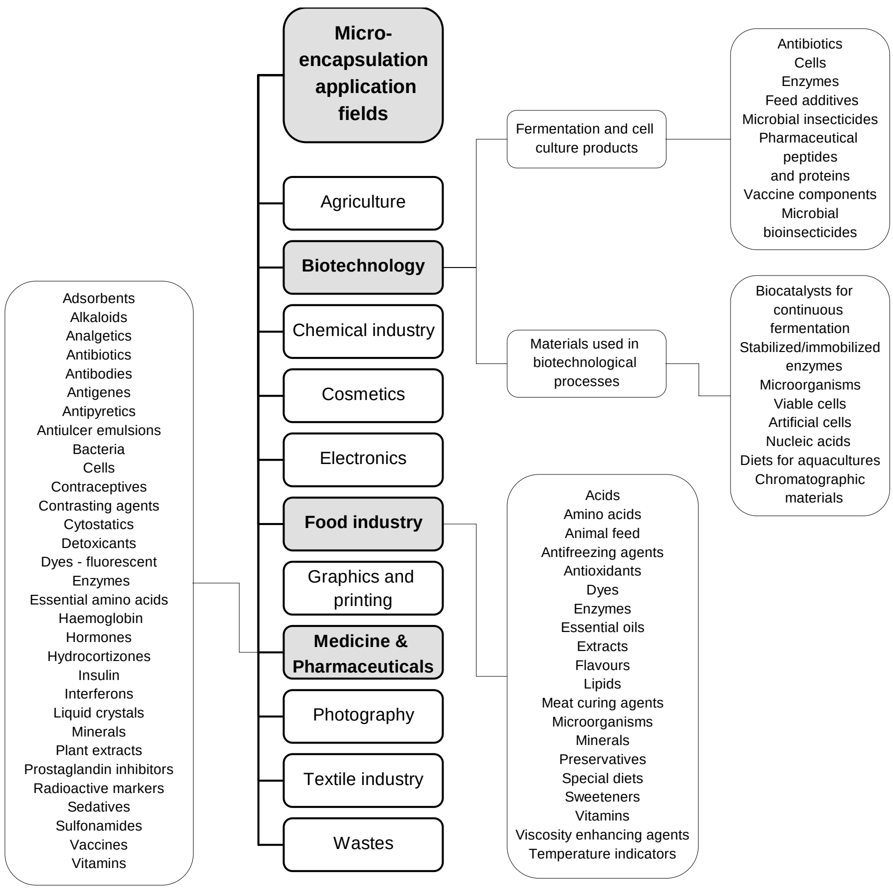

Figure 5. An example of data structuring: bio-microencapsulation applications in biotechnology, pharmaceuticals and food industries.

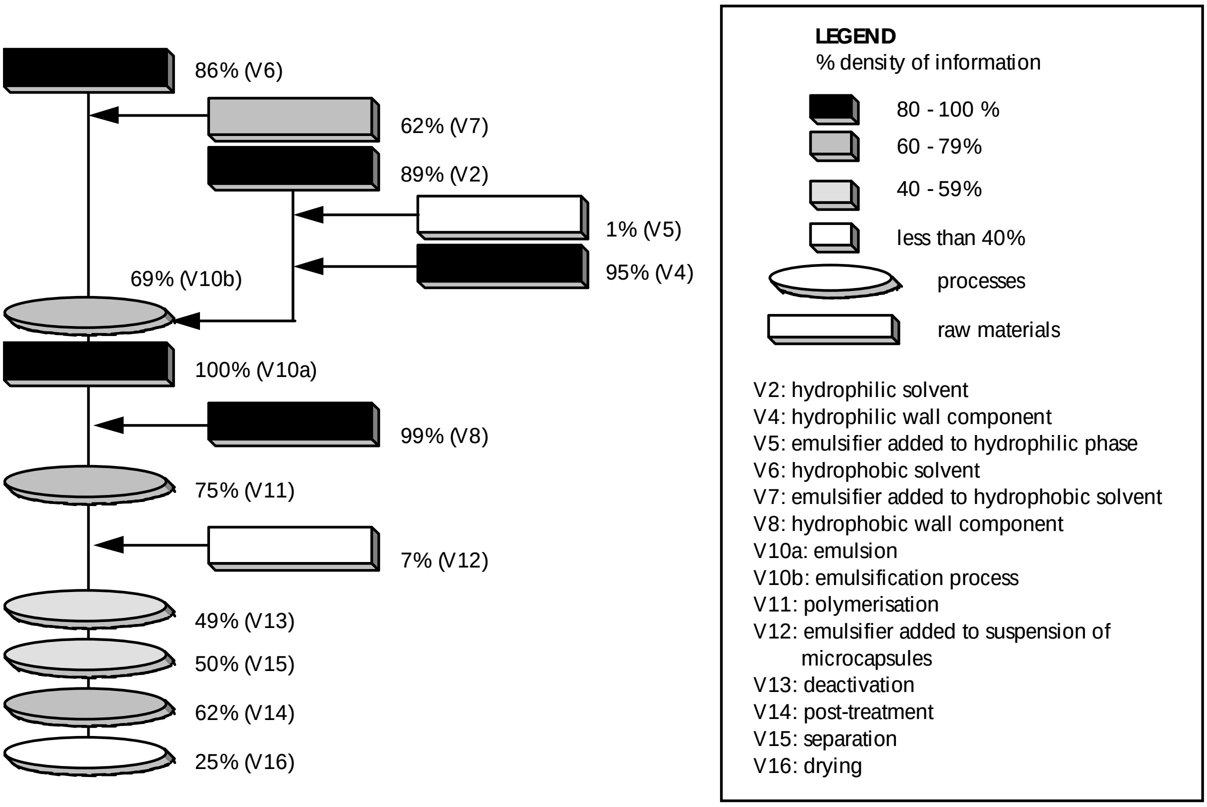

Figure 6. An example of using the concept of information density: graphic representation of a process backbone scheme for a microencapsulation procedure, illustrating the information density of individual entering raw materials and main technological phases. The backbone was prepared with data analysis, comparisons, overlapping of numerous partial process descriptions, and with a computer-supported calculation of information density. Such schemes are particularly useful in the design of laboratory experiments.

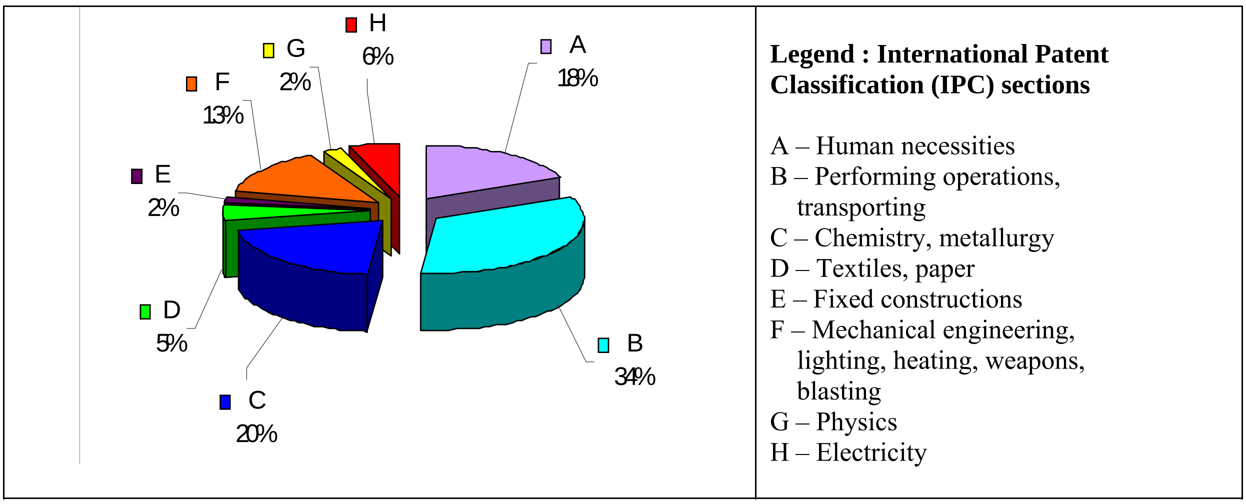

Figure 7. An example of patent analyses: the distribution of patent documents on microencapsulated phase change materials by the International Patent Classification (IPC)

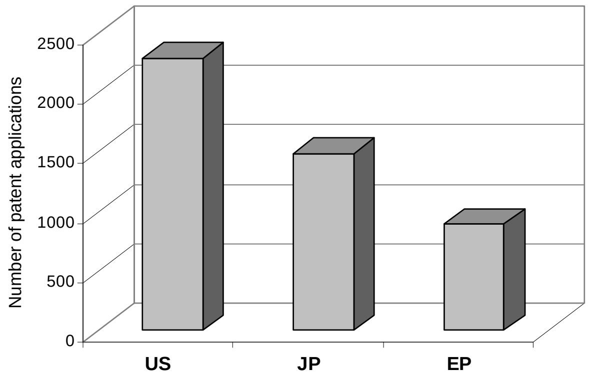

Figure 8. An example of value-added database processing: ratio of US, Japanese and European patent applications on microencapsulation in the Espacenet patent database; Advanced Search - search profile: Keyword(s) in title or abstract: *microcapsule or microcapsules or microencapsulation or microencapsulated,* Application number: *US* (or JP, EP)

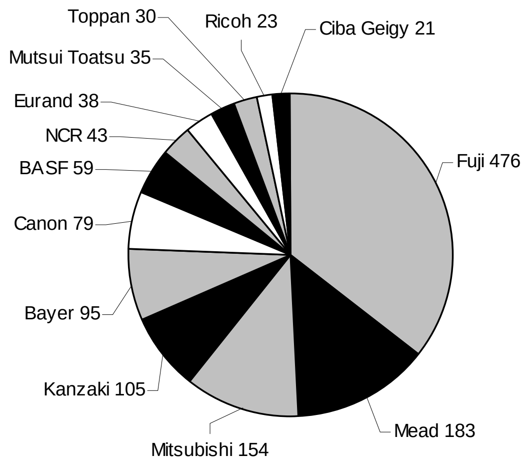

Figure 9. An example of value-added database processing: patent applicants with more than 20 patents on microencapsulation in the Espacenet patent database; Advanced Search - search profile: Keyword(s) in title or abstract: *microcapsule or microcapsules or microencapsulation or microencapsulated,* Applicant: *Fuji* (applicant names)

Conclusions and implications for education

The skill of efficiently analysing and using patent literature has become one of the prerequisites for the employability of graduates of chemistry and related scientific and technological fields, especially in research and development departments of chemical, pharmaceutical, biotechnological and similar companies, where industrial intellectual property rights play a crucial role in competitiveness and in early identification of prosperous market niches. The basic knowledge, infused into university curricula for science and technology students, should enable cost-efficient value-added processing of patent databases, simple analyses of patent documents, drafting patent applications, and understanding confidentiality issues, including patent ownership and licensing. These aspects related to patent informatics need a deeper consideration in university curricula.

As emphasised by the Delors Commission on Education for the Twenty-First Century in the four pillars of education, learning is not enough to know; students have to learn to do, learn to live together and with others, and learn to be, which includes a balanced all-round development of each individual, including the ability for critical thinking and accepting the responsibility for independent decision-making. By exposure of students to real-life research fields of future employers, students can better learn how to solve research problems, how to communicate in basic research, industrial and market environments, and how to manage research and development projects.

References

[1] Arshady R., Boh B., 2003: Microcapsule Patents and Products - The Art and Science of Microcapsules, Patents and Patent databases. Microcapsule Patents and Products, The MML Series Vol.6, Citus Books, London, pp. 1 - 46.

[2] Devon T. K., Kardoš D.: Educational Aspects of the Role of Intellectual Property. In: Kornhauser A. (ed.), University-Industry-Government Cooperation: How to Make it Work? Teaching / Learning Manual. UNESCO-ICCS, Ljubljana, 2001, pp. 185 - 207.

[3] Kardoš D., Boh B., 2000: An information method for achieving value-added processing of bibliographic databases in science and technology, Online Information Review, Vol. 24, pp. 294 - 301.

[4] Kornhauser A., Boh B., 1992: Information Support for Research and Development in Biotechnological Applications. In: DaSilva E.J., Ratledge C., Sasson, A. (eds.), Biotechnology: Economic and Social Aspects. Cambridge University Press, Cambridge, pp. 309 - 353.

[5] Starešinič M., 2001: Methodological Approaches in Patent Analysis. Example: Microencapsulation Technology. Masters Thesis, University of Ljubljana.

DIDAC: A Worldwide Teaching and Learning Tool for Chemistry

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Abstract

DIDAC was set up in 1994 at the occasion of the 75th anniversary of IUPAC. It consists of specially prepared viewgraphs for teaching chemistry. Originally developed in Flanders by an editorial team of the **Agfa - Gevaert industries** and assisted by the **Royal Flemish Chemical Society** with an inter-university group of chemistry educators, the DIDAC project has proven extremely successful, as it is now already translated from the original Dutch into French, English, Arabic, Korean, Russian, Japanese, Chinese and other languages in progress. Presently more than 100 countries have been involved in the DIDAC program, evolved and coordinated through **IUPAC** (COCI: Committee on Chemistry and Industry, and CCE: Committee on Chemistry Education), with strong financial and technical support by **UNESCO** (Division of Basic and Engineering Sciences, A. Prokovsky).

DIDAC is a didactic communication tool that assists in making chemistry lessons more interesting and more understandable for students. The DIDAC transparencies are produced using four-color printing techniques. The sheets do not contain written comments and are therefore language-independent. DIDAC is also independent from local educational programs and based on internationaly accepted concepts in teaching modern chemistry. Black-and-white versions of the viewgraphs, of which copies can be made are available for students. DIDAC consists of five sets each of approximately sixty coloured transparencies, covering a number of chemical concepts as well as applications from everyday life: the periodical system of elements, water, air, colloids, thermodynamics, chemical equilibrium, petroleum chemistry, electrochemistry, photography, structure of atoms, polymers, bio polymers, chemical bonding, separation techniques, chemistry and health. DIDAC is one of the ways to build the much talked-of bridge between chemical education and industry in an easily understood way. It supports the visualization of chemical principles at the interface between phenomenological, corpuscular, symbolic and contextual patterns in the teaching and learning of chemistry.

Since March 2004, DIDAC materials are also available in an electronic version on cd-rom (English, French, Dutch), as a book (English, French) and as thematic booklets (air and water) (English, French). Presently, thanks to the enormous promotional support of UNESCO, by means of the field officers and the UNESCO National Commissions, DIDAC-viewgraphs are introduced in at least 120 UNESCO member states. DIDAC cd-roms and books are sent to universities, teacher training institutions and well-equipped secondary schools in about 200 countries. About 2000 rural area schools in 50 developing countries have received booklets and the poster series about the subject “air and water. In the near future the DIDAC materials will be installed for free use on the worldwide internet.

In view of this unexpected success “DIDAC” may really be characterized as a basic modern worldwide teaching and learning tool for chemistry!

DIDAC is a educational project that started in Flanders, the Dutch part of Belgium, already in 1994. The main aim of the project was to produce a useful package of illustrative schemes and figures about basic chemistry that should enable chemistry teachers to improve their teaching methods by improvement of their visualization tools .

In his paper we like to deal with successively

- The educational philosophy behind DIDAC
- What is DIDAC?
- Origins and evolution of DIDAC
- DIDAC materials at present

In summary we could say that the editorial board that started the DIDAC-project was fully convinced of an educational philosophy based upon scientifically correct and attractive visualization of basic chemistry.

- DIDAC originated from the need for visualization and functional visualization techniques in chemistry teaching
- That need for improved visualization results from specific educational demands for chemistry
- Well- designed viewgraphs *seem to be preferable* as an essential tool to improve visualization in chemistry

Let us fill up this aspect of chemical didactics a little bit more.

We all are fully alive to chemistry as

- a basic fundamental science,
- as a key for a whole spectrum of applied sciences,
- as an important driving power in mankind's historical and philosophical evolution, and
- as an essential part of one's cultural background and education.

However, to achieve that, not only should scientists be convinced of its multiple role in society, but amongst also the youth and the man in the street, chemistry has to be stimulated as an essential part of basic education. That means that in chemistry teaching a broad variety of chemical knowledge should be involved such as e.g:

- Conceptual chemistry and the scientific models behind it
- Contextual chemistry in relation with technological and daily life uses
- Chemistry as a contribution to cultural education

In order to spread the value of chemistry through the educational systems scientists and chemistry teachers, all over the world, published over the last decennia a lot of exciting books covering these three aspects of chemistry to a very broad extent.

But nevertheless, the daily learning of chemistry at secondary school level seems to be rather problematical. Enquiries all over the world, in different countries often reveal a mixture of positive and negative attitudes.

Chemistry is at the same time:

- fun, attractive, interesting, and important, **as well as**
- boring, very difficult, not relevant for daily life and society, and it has a low job profile.

Also about these kinds of interactions, namely the pedagogy and the teaching needs and didactics for chemistry, a whole range of good books and periodicals are available for teachers.

Chemistry teachers try their best to develop a good educational format to educate their pupils both about the scientific content of chemistry and about the uses and the role of chemistry in the past and present society.

Good chemistry teaching demands a constant interaction between the phenomenological, conceptual and contextual levels within the chemical world.

A good infrastructure and pedagogical comfort, well adapted to the local school types, are the starting keys to develop an attractive and well visualized way of chemistry teaching.

Visualization of chemical concepts, principles and phenomena, in a very broad sense is indeed essential to make chemistry understandable for the youth and the broad public.

In addition tu understanding chemistry, the public is practically getting more and more familiar with the network of chemical concepts, and chemistry as a whole is indeed a concept map of high complexity that needs on top of that a high level of visualization for the learners.

Indeed understanding the conceptual network in chemistry needs special attention to visualization of concepts and their interrelationships from different viewpoints and at different levels of abstraction. Therefore visualization in chemistry teaching needs awareness and techniques on at least three visualization levels

- the phenomenological level: what learners can perceive and become curious about
- the conceptual level: what learners can imagine and try to understand with the help of the formal-symbolic language of chemistry
- the contextual level: what learners can experience in their environment and life style

At present chemistry teachers may use a very broad spectrum of visualization techniques, dependent on their real daily teaching environment. Practically there are hardly any limits to visualizing any aspect of chemistry in classroom teaching

But of course that does not mean that all chemistry teachers all over the world have all of these tools at their disposal.

Teachers also have to be very creative with the available teaching tools in their given situation, so as to be aware of new technical possibilities to improve their visualization of chemistry.

The improvement of visualization of chemistry in a school is surely often a financial problem. However, continuous attention in a creative way to the needs and realisations of new visualization techniques is equally important.

Classrooms can vary from rather primitive, but learner oriented rooms, up to highly sophisticated but often asocial technical rooms.

Attentive teachers mostly have a large choice in books, wall charts, posters, show-boxes, molecular models as illustrative materials.

They may perform chemical experiments in simple but adequate environments or in real school laboratories with high technical standards.

These days teachers may even teach and show in a classroom or for individualised teaching almost the whole of chemistry by searching and selecting chemical phenomena on the world wide web. So it becomes possible to teach chemistry in a complete virtual way, without visualizing it by any real experimental work. However the pedagogical value of this kind of extremely virtual visualization can be seriously doubted.

They may choose, in addition to the ordinary blackboard, between a variety of very adequate projection techniques either for showing pictures and figures during group instructions or for visualising micro-chemical phenomena occurring in small test tubes or reaction cells.

Actually teachers may even teach and show in a classroom or for individualized teaching almost the whole of chemistry by searching and selecting chemical phenomena on the world wide web. So it becomes possible to teach chemistry in a complete virtual way, without visualising it by any real experimental work. However the pedagogical value of this kind of extremely virtual visualisation can seriously be doubted.

Since quite some time, and surely since the seventies, viewgraphs have become an important and essential tool for the improvement of visualisation for chemistry teaching, because in principle they can:

- offer the basic illustrative schemes and images for a variety of teaching patterns and teaching methods.
- visualize chemistry at different levels of imaginative and concrete thinking
- be used as well by teachers as by learners, for individual and group instructions
- be easily transformed in black and white or coloured paper sheets, introduced in work sheets and books, enlarged to poster formats, scanned for electronic presentations and for informative and interactive teaching packages on the internet
- be used by every teacher, in every country, in every educational system.

These are indeed also the basic principles that underlie the “DIDAC “ project.

The DIDAC – philosophy has resulted from a well considered view and objective for improved visualization of chemistry in worldwide teaching situations. It is based on the strong conviction that :

Imaginative corpuscular thinking needs support by concrete images that stick in one's memory. These images have to be composed as well from the formal symbolic language of scientific chemistry as from the phenomenological world of real chemistry.

The elaboration of the DIDAC-philosophy resulted in a series of **320 viewgraphs …….**

Chemistry teaching with DIDAC

DIDAC offers **320 viewgraphs**

- Language and curriculum independent
- Wide–spread at low cost
- Easy and flexible use by teachers and learners
- Limited to basic principles and examples of
  - **Chemical perception in the area of**
    - **conceptual and experimental chemistry**
    - **industry and technology**

Chemistry teaching with DIDAC

DIDAC offers **320 viewgraphs**

- Created by a professional team of chemists : teacher trainers, teachers, researchers
- Digital printed at low cost in full colour on verso-side on strong transparencies
- Writable on recto-side
- Compliant with IUPAC conventions
- Supplied in strong boxes with additional materials for teachers and learners
  - Explanatory texts for teachers
  - Black and white copies for the learners

Spread over five boxes, the following subjects can be distinguished from the conceptual viewpoint:

Chemistry teaching with DIDAC

Conceptual approach :

- The periodic table of chemical elements
- Atomic model
- The chemical bond
- Chemical equilibria
- Watery solutions and pH
- Thermodynamics
- Electrochemistry
- Polymers and biopolymers

As I do not have the opportunity nor the time during this presentation to go through the whole series in detail, I will only show you some examples from each conceptual subject.

The subject "**the periodic table**" consists of a rather extensive series of overlay-viewgraphs, that allow teachers to built up the system and to illustrate periodic relationships along his or her preferred teaching pattern.

The subject "**atomic model**" offers the classical experiments of Rutherford and Bohr, completed with a small introduction towards the wave mechanical model.

The subject "**chemical bond**" focuses on the relationships between the concept of polarity and diverse types of bonding in molecules and also offers an introduction to stereochemistry based on the valence shell electron pair repulsion model.

The subject "**chemical equilibrium**" is often characterized as a very difficult topic to teach, especially when it has to be treated also in a quantitative way. Therefore it is one of the most elaborated parts of the whole Didac-series, with changes in equilibrium well correlated with colour changes and with study of applied chemical equilibrium in nature and the human body.

Similar to its importance in secondary school chemistry, major attention is given to chemical reactions in watery solutions and their relationship with acid-base reactions and pH.

There is only a small contribution to elementary thermodynamics, because it is a controversial subject to teach in secondary school chemistry.

On the contrary the basics of **electrochemistry** are well illustrated in a series of viewgraphs on oxidation – reduction reactions, electrochemical cells, batteries and corrosion.

Synthetic as well as natural **polymers** are treated in a beautiful series with special attention given to the visualisation of three-dimensional structures of polymers.

Although in all the treated conceptual subjects viewgraphs with attention to applied chemistry are provided some more contextual oriented series **are included with special attention given to the role of chemistry in a daily life environment**.

Chemistry teaching with DIDAC

Applied and contextual approach :

- The role of chemistry in our daily lives
- Air and water
- Petrochemistry
- Silverhalide chemistry
- Colloidal systems
- Separation techniques
- Chemistry and health

A survey is given by a series of rather playful drawings from a caricaturists' view. Physical-chemical aspects of air and water are visualised in a separate series.

Both the basic chemical industry and the more high-tech applied chemistry are illustrated by viewgraph series about the **petrochemistry, the silverhalide chemistry and the use and applications of separation techniques**. And finally, a special series about "**chemistry and health**" illustrates very nicely the correlation between chemical knowledge and a healthy and safe daily life.

Origins and evolution of DIDAC

DIDAC - Milestones

- **1994** : DIDAC-1 launched in Belgium on the occasion of the **100th anniversary** of the founding of the **N.V.Gevaert - photoproducts** **(actually Agfa-Gevaert Group),** coinciding with the **75th anniversary of IUPAC**
- **1995** : DIDAC-2 and following volumes : reinforcement of editorial team with teachers and experts in the teaching of chemistry from the Teachers Training Centres of Flemish Universities and Polytechnics
- **1999** : DIDAC 1-2-3-4-5 available in Dutch
- **2000** : complete DIDAC series available in Dutch - French - English

DIDAC and Belgian Chemical Organisations

Fruitful cooperation between the Agfa –Gevaert Group with :

- **Fedichem –** ***Federation of Chemical Industries*** **in Belgium**
  1999 Project with substantional sponsoring resulting in additional distribution of ca 1900 sets in Belgium
- **NCS / CNC –** ***Belgian National Committee for Chemistry***
  contacts with IUPAC-COCI-CCE :
  presentation at several IUPAC-meetings
  (***1997, Geneva;****1998, Johannesburg;1999, Berlin;2003, Ottawa)*
- **KVCV -** ***Royal Flemish Chemical Society***
  1994 - 2000 :active participation and support of the editorial team and making DIDAC 'known' in Flanders

  2000 …… consultancy for further improvement and surveillance of the content and didactics of DIDAC

DIDAC and IUPAC

Fruitful cooperation between the Agfa-Gevaert Group with IUPAC :

1998 : project established with the Committees of Chemical Industries (COCI) and Teaching of Chemistry (CTC) as IUPAC project nr. #022/17/98

1999 : COCI sponsored distribution of the system by its members in many parts of the world to ascertain its international relevance

via a collaboration with UNESCO and after the IUPAC Congress in Berlin DIDAC material was presented in advanced teacher training courses and to educational officials, mainly outside Western – Europe

2003 : renewed attention at the IUPAC congress in Ottawa

DIDAC en IUPAC

2003 : IUPAC Congress in Ottawa

- CCE (chair Peter Atkins)
  Three main projects to promote worldwide
  Microchemistry
  DIDAC
  The Periodic Table Revised
- DIDAC - symposium (chair Paul de Bièvre , COCI)
- IUPAC - Council : DIDAC mentioned in the presidents'« State of the Union »

DIDAC and UNESCO

Fruithful cooperation and active support from the

UNESCO-Division of Basic and Engineering Sciences (Dir.Dr.Alexander Pokrovsky)

By the end of 2002:
the project was presented and 200 complete sets of DIDAC-viewgraphs were distributed in at least 120 UNESCO Member States. With support of local industries or chemical societies, several translations of the DIDAC – texts are made of are going on in many languages , e.g. Russian, Japanese, Chinese, Arabic, Korean …..

By the end of 2004 :
5000 cd-roms and DIDAC-books will be distributed in more than 190countries for use in the universities , teacher-training institutions and those secondary schools with good facilities.
Colour posters with the teaching booklet "Air and Water" will be distributed through 2000 rural area schools in 50 developing countries

By the end of 2005 :
DIDAC will be available on the worldwide UNESCO – website, for free download by every chemistry teacher in the world !

Future plans for DIDAC

- Agfa-Gevaerts' present policy (1):
  - **hand over the DIDAC-project to UNESCO/IUPAC and allow these organisations to further develop the project in additional areas in the world and allow the achievement of the effective 'usage in the field' in countries addressed**
  - **therefore Agfa is willing to grant to UNESCO and IUPAC a world-wide, non-exclusive, non-transferable and royalty free license without the right to grant sub-license, as long as the use thereof is without seeking any commercial benefit and as long as the preparation of different language versions consists in translating the texts without modifying the content**

Future plans for DIDAC

- Agfa – Gevaerts' present policy (2):
  - **Agfa is not interested in any cooperation to commercialise DIDAC, e.g. cooperation with publishers**
  - **in case Agfa would be sollicited by organisations (other than IUPAC/UNESCO) seeking to make use of the DIDAC-materials in order to achieve the effective 'usage in the field' thereby observing the same principles of not seeking any commercial benefit, we would take a decision depending upon the case.**

DIDAC materials at present

Although the DIDAC-series were originally published in five separate boxes, due to chronological and technical limitations within the editorial and production process, it has always been the aim of the authors and editors to allow teachers themselves **to select and to link together** the necessary viewgraphs for support of their visualisation procedures within a given chemistry course in their specific class environment.

Looking at, examining and discussing the pictures and schemes on the viewgraphs, together with the learners, should be the didactical key to stimulate curiosity, interest for and explanation of chemical phenomena to the learners.

Teachers, and certainly those who are not so familiar with chemistry as trained chemists are, also find in the DIDAC-boxes the essential background explanation they need to understand the content and aims of the pictures and schemes on the viewgraphs.

For the learners the use of DIDAC-viewgraphs might not result in some quickly and cursory viewing during group instructions. They should be trained to explore and to think about the pictures and schemes and to question the chemical concepts and phenomena behind them. Therefore the original DIDAC-boxes also contain the basic black- and white material for cheap copying and distributing among the learners, for use in work sessions, home work, evaluation and exercises.

Recently the package of DIDAC viewgraphs has been extended with new materials as the **DIDAC-CD-ROM**, the **DIDAC-BOOK**, the **DIDAC- THEMATIC-BOOKLETS with POSTERS**, and in the near future the **DIDAC-WEBSITE**.

The original DIDAC boards of authors and editors have finished their work and are extremely grateful for the unexpected but very effective support from IUPAC and UNESCO to spread the DIDAC materials and the DIDAC-philosophy all over the world.

In the near future the DIDAC materials will be available for every chemistry teacher on the world wide internet. Perhaps that evolution can be a new starting point to complete the series with other topics and additional visualisation materials.

To finish, let me express my hope and belief in the continuation of the support for IUPAC and UNESCO initiatives to improve world-wide chemistry teaching as they have already been doing for many years, e.g. with the low-cost material project, the micro-chemistry project and, last but not least, the DIDAC-project.

From the chemical didactics' viewpoint DIDAC certainly offers an important surplus value to the existing traditional teaching strategies, as well as to the challenging new problems and demands arising from the advancing teaching of rather virtual chemistry, because DIDAC offers material and ideas for good visualization of chemistry, whatever should be the technical medium used.

Web Class Chemistry
Orientation of Secondary School Students to University Chemistry

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Introduction

Successful university studies start with making the right choice for a discipline. Knowing more about the discipline can help students to make the right decision about their study. The image secondary school students have of chemistry is unfortunately often different from reality. Visits to the university by the secondary school students are time-consuming and do not always fit into the school programme. We have developed a Web Class Chemistry to provide the secondary school students with information about university chemistry. It is not a guided information tour but a small distant learning course with the objective of introducing chemistry as a scientific discipline. The Web Class Chemistry is part of a broader project at the University of Amsterdam. This project started in 2001 with the first seven web classes. This year already 21 different disciplines are available with more than 600 students enrolled.

The Web Class approach

A Web Class is a completely on-line course. It is based on an active-learning approach and allows different learning styles. It takes place in the electronic learning environment *Blackboard*, which is the standard at our university. To gather the credit points and finally get the certificate of the Web Class the participants work on different assignments.

Each Web Class takes four weeks and it is offered twice a year. It should take in total 10 hours, 2.5 hours per week.

The Web Class Chemistry (scheme 1) is divided into four subjects (Scheme 2) which correspond to the weeks of this Web Class. The central theme is the sweetener Aspartame.

Scheme 1. The home page of the Web Class Chemistry

The subjects of the Web Class Chemistry are (Scheme 2):

Subject 1 (week 1): Aspartame as a Sweetener,

Subject 2 (week 2): The Three Dimensional Molecular Model of Aspartame,

Subject 3 (week 3): The Synthesis of Aspartame,

Subject 4 (week 4): Structure of Molecule and Taste

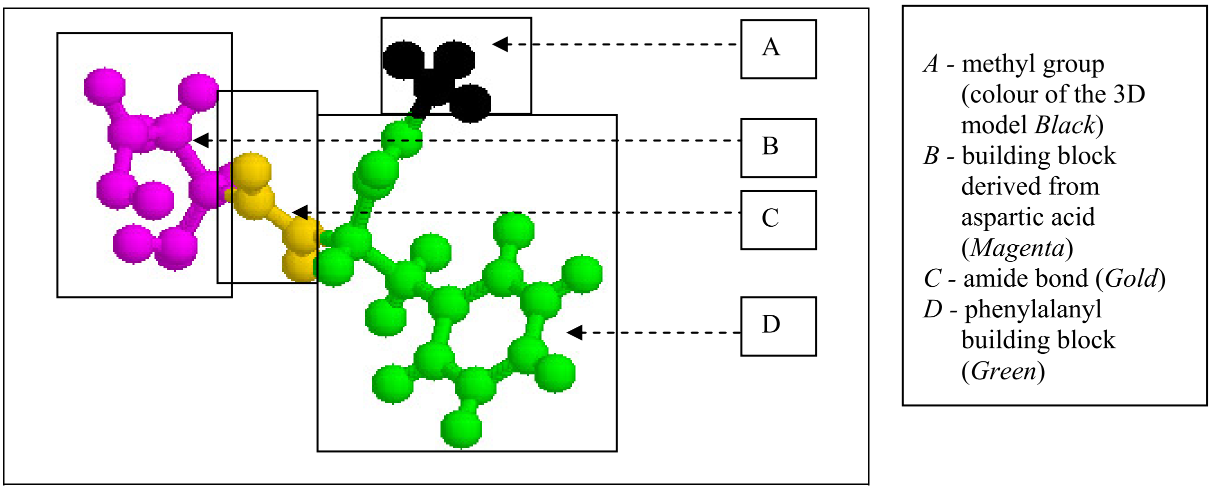
At the end of every week the assignments of the week should be submitted for assessment and feedback. The deadlines are necessary also to support collaboration between the students.

Scheme 2. The subjects of the Web Class Chemistry*
*the titles of the subjects are originally in Dutch

In every subject of the Web Class Chemistry, Aspartame is used to explain the chemical concepts. Doing the assignments within the subjects the participants meet the way chemists *think*, the way they *act* and how they *reason*.

In the first week the participants get acquainted with each other. In several discussion groups they discuss the importance of sweeteners. At home they make several solutions with different concentrations of Aspartame and a solution of sugar. They compare the sweetness of the solutions with a number of test persons. The results of all participants are published together in the *Blackboard* site and analysed by the participants.

In the second week the participant *think* as chemists do. They use simple 3D models in which they can change the substituents to study the principles of stereochemistry. They use this knowledge to analyse and understand the more complex models of the Aspartame molecule and its stereoisomers. In one of the assignments they visualize the building blocks of Aspartame in 3D using the plug-in Chime (Scheme 3).



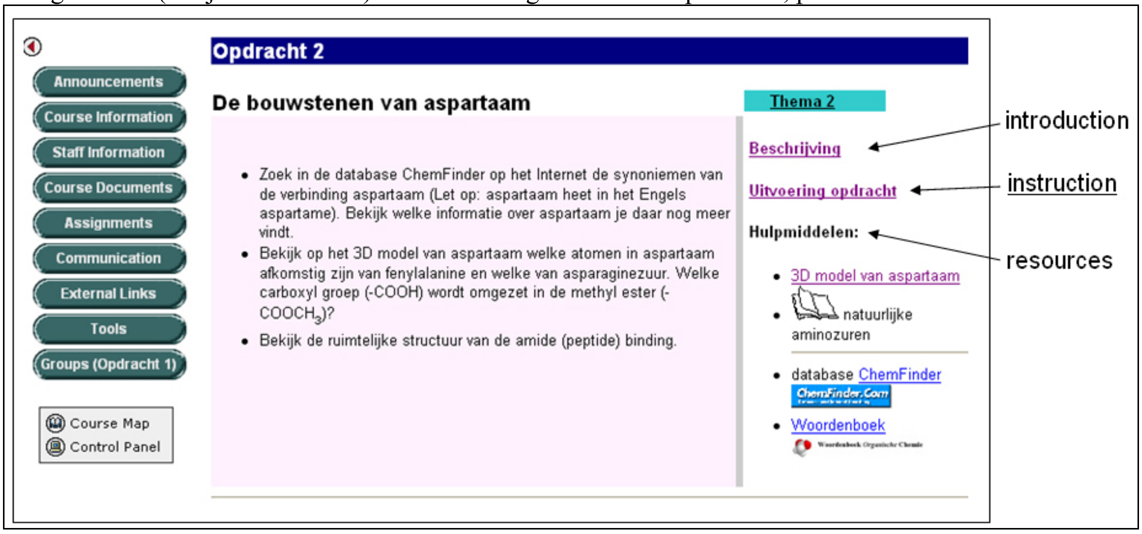
Scheme 3. The model representing building blocks of Aspartame

In the third week the students *act* as chemists. They observe a laboratory synthesis of Aspartame in a movie and make decisions about what happens at different moments during this process. They learn about the role of enzymes in chemical synthesis.

In the last week of the course they are *reasoning* as scientists. With the knowledge about how the taste works and about the chemistry of sweeteners they predict a structure of a new sweetener. During the whole course the participants search for information about Aspartame on the Internet. They evaluate the sites they find and publish the links with their comment on the External Links site of the Web Class Chemistry to be used by everybody enrolled in the course. On the basis of this information they formulate an advisory report “for the Ministry of Health” about the safety of Aspartame.

All the assignments have the same design and navigation (Scheme 4) but different teaching activities: *Left:* navigation buttons of the Web Class Chemistry, *Centre:* material to read or carry out, *Right:* The navigation of the assignment: Introduction, Instruction, Resources.

Assignment 2 (Subject 2 / week 2): "The Building Blocks of Aspartame", part Instruction



Scheme 4. The design of the assignments

As a part of the assignments the participants can use different interactive teaching materials such as three-dimensional molecular models, short explanations combined with diagnostic tests with automatic feedback and they can find links to relevant databases and interesting websites to get more information if they want to. They gather the credit points by taking part in discussion groups, doing simple experiments at home and writing reports about them and by making on-line tests. The participants regularly get feedback from the instructor. The communication instructor-participant and participant-participant takes place exclusively on-line in an organized as well as in a spontaneous way.

Results and Conclusions

The experience with the Web Class Chemistry is very positive. An extended independent evaluation took place about all the web classes in the project. In the evaluation the participants were positive about the parts of this on-line course. They found it pleasant to work on line and were satisfied with the digital contact that they had with their instructor. The statistics showed us that the participants logged in at different times of the day. Quite a lot of the participants worked also late in the evening and at the weekend. We, the instructors, found the web class exciting and challenging. Giving feedback was rather time-consuming.

While a part of the enrolled participants never showed up or stopped at a very early stage, most of those who really worked on the assignments also finished the course successfully. They still came to visit the site even after the course was finished and quite a number of them became afterwards our students.

Developing and working in the virtual environment of the Web Class Chemistry gave us new knowledge and experience about teaching methods and activities suitable to be used in an electronic learning environment. We use these for advising the lecturers who use *Blackboard* in their courses to support contact education at the Faculty of Science. The outcomes of the project Web Class are used in the new projects in education development and renewal.

References

1. URL Webklas Scheikunde: http://blackboard.ic.uva.nl/

   log in: Username: webclass, Password: webclass; find Webklas Scheikunde on the list of your courses (in Dutch), August 2004.

2. URL University of Amsterdam (UvA): http://www.english.uva.nl/, August 2004.

Acquired Knowledge in the Models Range (Atome Molecule): A Longitudinal Study from College to Lycée

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Abstract

The purpose of this study is to highlight the acquired knowledge individually as well as collectively by upper secondary school students (grade 10-12) and to identify and describe students' understanding and misconceptions related to the concepts of "atom" and "molecule". In order to understand these misconceptions better, the history of these two concepts has been studied and then, school science curricula and textbooks have been examined so as to identify the intended development of the conceptualisation of these concepts within the school curricula. This study is based on the written responses given by school students to different questions concerning these concepts. For it, we have elaborated a "questionnaire", which was presented to the students concerned. The analysis of the questionnaire shows the various misconceptions and obstacles that concern the concepts of atom and molecule at student level, and allows us to see their evolution during these three years.

Key words: Didactics of chemistry, didactical transposition, misconception, obstacle, atom, molecule.

Introduction

Students are presented with different models of the atom and the molecule during their education at Secondary school level. These models originate from the various forms of knowledge that have been successively admitted by the scientific community during the construction of science, and which we will name "**reference knowledge**" (savoir de référence). A first task is to turn that knowledge into teaching objects: the "knowledge to be taught" (savoir à enseigner) as in Official Instructions and textbooks. Then teachers must put this knowledge to use by proposing class activities that are likely to support the students' training. It will thus become "**school knowledge**" (savoir enseigné). Finally, the last stage of the students' work is to interpret the knowledge "as they can" during various steps which will lead them to transform it into "**acquired or assimilated knowledge**" (savoir appris) in a particular context.

In reference to the models used by scientists to interpret the data obtained through the experiments and to anticipate events, such forms of knowledge are labelled "**mental models**" by some and "**conception**" by others. According to Vosniadou (1994) mental models refer to a specific mental representation, analogical representation, made up by an individual during his/her cognitive functioning. Giordan and Vecchi (1987) define a conception as a "unity of coordinated ideas and coherent clarifying images used by learners to reason when confronted with problem-situations". To describe a heterogeneous image elaborated from data originating from learners, Watts (1983) and Taber (1998) suggest the notion of “alternative structure” ("alternative framework").

1 From reference knowledge to knowledge to be taught

1.1 A historical study of the construction of reference knowledge

From the historical research we have conducted, six models of reference for the composition of matter can be derived.

Particle atom

For Greek philosophers, any observable object is a mere cluster of separable particles: atoms. These atoms, too small to be perceived, are made of resisting and solid matter. They only differ in shape, size and form of arrangment, then, with Epicures, in mass. They are perpetually moving in a void. During the XIV century the properties of matter would be attributed to particles.

With Newton, particles, hard spheres, are the same for all bodies and are objects to distant attraction and repulsion forces. These attraction forces, which will later be labelled aggregation affinity, lead to the forming of particles of various degrees of combination by successive adding of particles.

In such a model – although in 1637, Gassendi introduced the neologism of "molecula" to name the smallest mass into which matter can be decomposed – the distinction between atom and molecule is not made.

Chemical atom

This is the atom introduced by Dalton (1808). To every simple body a particle is joined, and to every particle a symbol and an atomic weight are associated. In the formulas of compounds, symbols (circles) are repeated as often as necessary to satisfy the reciprocal proportions of the present atomic species. A molecule is then made up through the adding juxtaposition of atoms. If this model proposes confusion between atom and molecule of the simple body, the differentiation between both concepts being generalised only after the Congress of Karlsruhe (1860), it nevertheless allows for a distinction to be made between simple and compound bodies (Chevreul, 1818).

Interactions between atoms within a molecule will successively be attributed to electrical forces of opposed signs (Berzelius), to the common use of affinities (Kekulé) or to the exchange of unities of saturation (Wurtz). These unities of affinities or saturation will turn into atomicity or valence, and the possibility of multiple bonding will appear.

From 1861, the chemical formula will develop and the line of force of affinities will be labelled chemical bonding.

Electrical atom

It is the study of cathode rays by J.J.Thomson that will lead to the elaboration of the hypothesis of existing small particles charged with negative electricity within atoms, that will later be labelled electrons. Thomson then proposes a model for the atom, according to which the negative charges of small dimension and mass in relation to the atom are distributed within a homogeneous sphere of positive electricity until equilibrium is reached, for every one of them, between Colombian attraction and the repulsion due to the other electrons. This static model was labelled "*Thomson's plum pudding model*".

Then, to interpret the deviation of alpha particles by matter, in 1911, Rutheford proposes a structure of the atom in which the positive charge and the atom mass are concentrated into a very small volume (10,000 times smaller than the atom's) in the centre of atom, and electrons fill in the space outside the nucleus: the atom is then essentially made up of empty space! In 1912 he chooses a model according to which: "*...an atom consists of a positively charged nucleus of very tiny dimensions, surrounded by a distribution of fast moving electrons, in probable circles of electrons turning in a plane.*". The number of unities of the nucleus's positive charge is then identified (1914) as the atomic number, a label Mosley gave in 1913 when studying X-rays emission spectra by pure elements. In 1919, Rutheford postulates that the unity of the positive charge is ion "H+", which he labels "proton". The search for an answer to the enigma represented by isotopes, elements that bear identical properties but are different in mass, leads Chadwick to underscore the existence of a new subatomic particle: the neutron.

The chemists' atom in shells

From 1916, chemists will endeavour to elaborate a model for the atom that agrees with the Mendeleev periodic table and that allows for the variable valence of elements and the bonds between atoms. This opens the way to the search for electron arrangement within the atom. This is how Kossel lays out the first basis of the relationship between the atomic structure and chemical behaviour of atoms (1916). For him, atomic number, which underlines each element's position in Mendeleev's periodic classification, is merely the number of the electrons corresponding to this element and equals the number of the positive charges of the nucleus. He introduced the notion of "*valence electrons*", which determine the properties of the atom and the successive filling in of shells by adding one electron. On this basis, Kossel interprets the mechanism of ionisation by the gain or the loss of electrons so as to acquire a configuration similar to that of the rare gas that is "nearest" in the classification, and he introduces the model of ionic bonding.

In the same year, Lewis proposed an atomic model that relied on identical postulates as Kossel's, with a few precisions nevertheless. According to this model, the tendency of the atom is to reach as many as 8 electrons on its outside shell or the fact that a chemical bond results from the sharing of two electrons. He represents the heart of each atom in a compound by the use of the symbol of the element and the electrons in the outside shell by pairs of dots. In 1919, Langmuir develops Lewis' model by the introduction of the notions of shell and cells (complete with two electrons) and formulates a rule that was to become famous, *the octet rule*, according to which the largest number of electrons on the outside shell is 8 (two for the first line). We also owe to Langmuir the invention of the label of *covalence* to represent the sharing of two electrons and the introduction of the use of attributing a formal positive charge $\delta+$ to the atom that gives out the electron pair, and a formal negative charge $\delta-$ to the one that receives it.

Spectroscopic atom

In 1913, from spectroscopic considerations, Bohr proposes what can be considered the first quantic model of the atom: the nucleus of the atom, positively charged, is surrounded by electrons that are organised in successive orbits (each one being characterized by a distinct quantic number initially labelled τ, later n) and that are likely to '"jump" from one to the next orbit by the absorption or the emission of a luminous quantum that corresponds to the energetic difference between the two orbits. In such a model the energy associated with the process of transition is what becomes the fundamental variable while pushing the material nature of electrons into the background. The electron is no more characterized by its granularity, its position in space and the evolution of its position in time, but by the energetic state in which it finds itself. The model of Bohr's "jumping peas" was born.

Between 1922 and 1924, many studies were published on the numbering of the under-levels of energy as associated with the levels of K, L, M, ... in the X-rays spectra and led to the multiplication of quantified variables on which the state of electrons in the atom relies (magnetic kinetic moment, spin). It then becomes possible to establish the exact electronic structure of the whole elements of the Mendeleev table. With the four quantic numbers n, l, m, and s, the elements can be described in terms of shells, sub-shells and quantum levels.

In 1913, Bohr applies his atomic model to the chemical bond within molecule of hydrogen. The two atomic nuclei could be situated on the rotation axis of a circular orbit as chosen by the two electrons involved in the bond, on each side of the orbit. For multiple-electron atoms, Bohr suggests that part of the electrons remains near the nuclei to form a system with electrons and low-charged nuclei, the bond then being made up by only a few electrons.

Quantic atom

Following de Broglie's and Schrödinger's research (1924 and 1926 respectively), the state of an electron in the atom is described by a wave function which will later be qualified "orbital" (Mulliken, 1932). For Schrödinger, the material electron is barely an appearance, therefore it can be allotted a trajectory. Its energy is of undulatory nature and it is only because of the localisation of that energy in a very small space that it can be considered as a particle.

A differing interpretation was proposed by Born (1926). For him, the character of the wave remains purely statistic, likely to describe probabilities of localization of the state of movement in space and time. Born's principle is as follows: *"the square of module of the wave function Ψ measures, in each point and at every moment, the probability so that the associated body could be observed at the point"*.

According to the quantic theory, the state of electrons engaged into a bond is described by a wave function. Two methods will be used to express it. The method of valence bond, according to which the orbital is situated within atoms, as Heitler and London initiated and which will lead Pauling to introduce the notion of hybridation of the orbital; and the method of molecular orbital, developed by Mulliken and Hund and which will lead to the notions of the delocalised orbital, σ and π.

1.2 Longitudinal presentation of the knowledge to be taught

Here shall be presented the modeling of matter constituents as it is introduced by Official Instructions (see Bibliography) and can be seen in textbooks. Let us make clear that in Official Instructions, no mention to any reference model to be taught is made. Yet, in textbooks, the description of models is generally paired with a representation in the form of images or molecular models. Authors are therefore free to offer their representations in so far as they are compatible with the knowledge to be taught.

In Lower Secondary School:

Grade 8 (age 13-14)

⇒ The molecules are made of assembled atoms.

- molecules are the smallest pieces of matter;
- molecules are infinitely small (nanoscience)
- they can be represented by molecular models (space-filling models); they bear a characteristic geometric form.
- they are symbolised by formulas that indicate the nature and number of atoms (in subscript) of each constituting species.

⇒ The atoms are represented as spheres. They are made distinct by a symbol.

So, it is a chemical atom (Dalton's atom model) within the framework of an atomico-molecular theory which must be taught.

In all the textbooks, atoms are represented by hard spheres of different sizes (Dalton's model), and a colour code is given to each atom for molecular models.

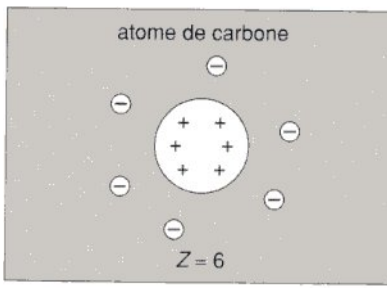
Grade 9 (age 14-15)

⇒ An atom consists of a positively charged nucleus and of negatively charged electrons that move (revolve) around the nucleus. The atom nucleus contains as many unities of positive charge as there are electrons in the cloud: the atom is neutral.
- the set of electrons in an atom is labelled electron cloud;
- all electrons are identical, they bear the same mass ($9{,}11 \, . \, 10^{-31}$ kg) and the same charge ($e = 1{,}6 \, . \, 10^{-19}$ Coulomb);
- the mass of the atom is basically concentrated inside the nucleus.
- The diameter of an atom nucleus is roughly 100,000 times as small as the atom: matter is above all made of void.

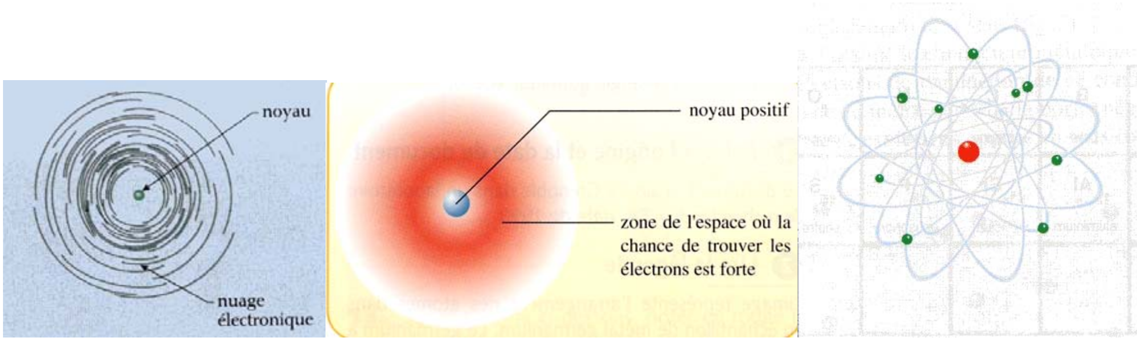
⇒ As far as molecules are concerned, at the end of grade 9, a student must be able to realize the molecular model of simple molecules: O_2, H_2O, CO_2, CH_4 (that were met in grade 8).

Thus, what must be taught is the neutral electric atom, and more precisely *the Rutherford atomic model*.

In grade 9 textbooks, the representation of atoms is diversified, but it is the model of the neutral atom (the number of - charges of electrons equal to the number of + charges of the nucleus) which is more generally presented.



In some textbooks, one can find a probabilistic representation of the electron cloud or the solar system model of the atom:



As far as the representation of molecules is concerned, textbooks present the space-filling molecular models of the following molecules: H_2O, O_2, CO_2, CH_4 .

In Upper Secondary School:

Grade 10 (age 15-16)

⇒ The atom is made of a nucleus consisting of Z protons and of (A-Z) neutrons and of an electron cloud (or rotating electrons) that contain Z electrons (or negative Z electrons)

- the nucleus of atom is marked $^{A}_{Z}X$; A is the number of nucleons (protons and neutrons); Z is the atomic number; it characterizes the element and represents the number of protons that the nucleus contains.
- proton and neutrons bear the same mass;
- the mass of atoms virtually equals the sum of the mass of the nucleons that constitute it.
- isotopes are atoms of one chemical element (identical Z) but that own different numbers of neutrons.
- electrons are distributed in shells, K, L, M that are further and further from the nucleus;
- the highest number of electrons in shells is 2 for K, 8 for L and 18 for M;
- an atom or a monoatomic ion can be symbolized by its electronic structure: K^X, L^Y, M^Z;
- with the exception of the helium atom, all atoms of noble gases bear 8 electrons on the outside shell;
- during chemical transformations, atoms evolve so as to acquire the electronic structure of the nearest noble gas in the periodic classification.

Therefore what must be presented is a mix model consisting of *the Rutherford model completed by Chadwick* and of *the chemists' model in shell* (Lewis, Langmuir and Bohr).

⇒ In a molecule, atoms are linked by covalent bonding. Each bonding is made by a linked electron pair that results in the sharing of two electrons from each of the linked atoms.

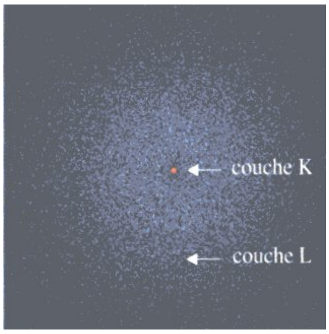
- between two atoms many linked electron pairs can be found;
- the electron pairs are represented by dashes;

- a electron pair of the outside shell that is not shared by two atoms is a non-linked electron pair;
- the association of atoms within a molecule can be represented by the Lewis representation: a plane developed formula of molecule;
- a linked electron pair and a non-linked electron pair repel one another and position themselves so as to be as far away from one another as possible.
- the Cram representation allows for modeling in a plan the spatial geometry of a molecule.

In commentaries, the curriculum authors make it clear that:

- the Lewis representation of atoms with electrons associated in electron pairs must not be used.
- to establish the representation of a molecule, the use of systematic exploration is recommended: the electrons of outside shells in the atoms that exist in the molecule are first numbered and then associated in electron pairs; the electron pairs are then shared between atoms (linked electron pair) or around atoms (non-linked electron pair) so as to satisfy the rules of "duet" and octet.

In textbooks, there exist only few representations of the atomic model and, when they are present, they are similar to the ones that are used in the textbooks of grade 9, neutral atom and probabilistic representation (plus, in one textbook, distinct K and L shells). No representation of the solar system model in shell is provided.



As far as molecules are concerned, the model of covalent bond being already introduced, ball and stick models appear. Each stem between atoms can then be associated with a linked electron pair.

The interpretation of the geometry of some simple molecules that relies on taking into account the repulsion of the linked electron pair and non-linked electron pair around the central atom, the visualization of the repulsion is done through the use of balloons, some of which – the non-linked electron pair – being more swollen than others.

In grade 11, the representation of molecules with the use of molecular models is generalized in organic chemistry. What is new is the introduction of the polar character of bond, thus of molecules.

Last, it is only towards the end of the Physics curriculum in grade 12 that *the Bohr model* is introduced. It will then not appear in our study.

2 Longitudinal analyse of acquired knowledge

Review of the literature

The synthetic presentation of the students' misconceptions identified by different researchers will be done by the use of the same classification as in historical models of reference.

Particle atom

A large part of research shows that students find it difficult to differentiate between atom and molecule (Ben-Zvi et al., 1988; de Vos & Verdonk, 1996; del Pozo, 2001; Griffiths & Preston, 1992): atom and molecule are considered as the smallest portion of a given matter (Ben-Zvi et al., 1988; de Vos & Verdonk, 1996; Taber, 1998). This conception, according to which an atom is a particle that makes matter persists after the teaching of students in Lower Secondary (Brehelin et al., 1994). An atom is often qualified as round, solid, hard (Harrison & Treagust, 1996; Griffiths & Preston, 1992) and defined as a "ball» or "sphere" (Harrison & Treagust, 1996). Therefore, the water molecule consists of two or several solid spheres (Griffiths & Preston, 1992). Another frequent conception consists of attributing to atoms and molecules the properties of matter (Albanese & Vicentini, 1997; Johnson, 1998; de Vos & Verdonk, 1996; Andersson, 1990; Pereira & Pestana, 1991): expansion, contraction, fusion, explosion, conduction of electricity. When the change of state occurs, water molecules freeze and grow (Lee et al., 1993). Water molecules depend on the nature of the phase (Griffiths & Preston, 1992).

As far as the size of atoms is concerned, it is often considered at macroscopic level (Griffiths & Preston, 1992; Brehelin et al., 1994): the atom is very small, too small to be seen, but it can be seen under a very powerful microscope (Brehelin, 1998; Harrison et Treagust, 1996; Lee et al., 1993). Lastly, some students have a poor perception of the mass of one atom (H: 1g. for 35.5% of students) or believe that all atoms have the same weight (Griffiths & Preston, 1992).

Chemical atom

Atoms are generally grouped (Harrison & Treagust, 1996) and the molecules are considered as groups of atoms rather than basic chemical entities (Taber, 1998; Brehelin and al., 1994). For instance, the water molecule can contain atoms other than Hydrogen and Oxygen (Griffiths & Preston, 1992). What is more, some students believe that some substances can be made of objects other than atoms (dust particles, microbes,…etc.) (Harrison et Treagust, 1996). Such a combination of atoms to form molecules is schematised by the joining of the circles or spheres that represent the atoms (Griffiths & Preston, 1992).

As far as molecular models are concerned, three quarter of the students favour the space-filling model to represent the molecule, whereas the remaining quarter prefers the ball and stick model (Harrison & Treagust, 1996). For the schematisation of molecules (H_2O more precisely), representations evolve, during the process of learning, from space filling model to structural formula (Pereira & Pestana, 1991). Three sorts of mistakes are underlined: a) mistakes in representing the bond between atoms (Keig & Rubba, 1993), b) mistakes in representing angles, c) bond orders (Keig & Rubba, 1993; Pereira & Pestana, 1991). The relative size of atoms is generally not respected and the length of bond O-H increases when one goes from solid state to gas state (Pereira & Pestana, 1991).

Wrong understanding of the meaning of the formula that represents a molecule leads some students to have an additional misconception of the molecule (de Vos & Verdonk, 1987). The transcription H_2O is then interpreted as the association of H_2 and O, or of one atom of hydrogen and two atoms of oxygen, which leads to a wrong schematisation of the molecule (Ben Zvi et al., 1988; Keig & Rubba, 1993).

Electric atom

Brehelin (1998) shows that only slightly over one third of the students that have followed a classical course of studies and have left Lower Secondary School (beginning of grade 10) have integrated the minimum formulation level required at the end of grade 9: the atom is made of one nucleus and electrons (electron cloud). An identical observation is brought out by Harrison and Treagust, (1996). Four categories of models are generally schematised by students: atom as a sphere, solar system atom, neutral atom (+ charges of the nucleus equal to - charges of the electrons), and atom as an electronic cloud. By the end of a classical course of studies, the first two models are used by the students (41% and 48%) (Brehelin, 1998). According to Harrison and Treagust, (1996), many students represent the atom as a "simple circle" within a large circle.

Even after teaching, there remains among students a certain degree of confusion between the terms used - not only particle, atom, molecule, but also nucleus, proton, neutron and electron - and their interrelationships (Osborne & Freyberg, 1985; Johnston, 1988). Interactions between constituents (atoms, molecules, protons, neutrons, electrons) are either totally unknown or insufficiently perceived by students, even at the beginning of university studies (Cros & al., 1984 and 1986). Interactions between atoms are neither covalent nor ionic, but a mere force (Taber, 1999).

The atom is often perceived as a sphere with its components inside (Griffiths & Preston, 1992; Taber, 1998); electrons, that have no mass but bear a mere charge, rotate on orbits around their nucleus (Griffiths & Preston, 1992; Pereira & Pestana, 1991). For some students, the number of electrons, protons and neutrons is the same for one given atom (Tsai, 1998).

If students find it difficult to appreciate the relative size of atom and nucleus, the students who think that electrons are far from the nucleus believe that the atom is hard at the centre and soft on the outside and that it can recover its initial form after compressing (Harrison & Treagust, 1996).

As far as ionic compounds are concerned, ion is considered a distorted atom rather than an entity that constitutes matter (Taber, 1998). In crystal, there exist two kinds of interaction: ionic bonding between the elements that constitute the molecule, and 'forces" between molecules (Taber, 1999).

Atom in shell

Many students consider electron shells as envelopes that wrap and protect atom (Harrison & Treagust, 1996), electrons move on that surface (Harrison & Treagust, 2000). Keig and Rubba (1993) reveal that for many students (45%), electrons are pre-assembled in electron pairs within the atom. According to Taber (1995, 1998) and Robinson (1998), students use the rule of the octet as a basic principle, a heuristic, to explain chemical bonding, chemical reaction and ion formation. An atom is said to be stable if its valence shell is filled, and is said to be unstable otherwise. The formation of ions or a covalent bond during a chemical reaction results from the need of atoms to complete their valence shell and reach the number of eight - or two - electrons to be stable. Taber (1995, 1998) points out that even when students know that energy is necessary to ionise positively one sodium atom, ion Na+ is considered more stable than the atom. Moreover, there exists a confusion between octet, full shell and electronic configuration of noble gases (Taber, 1998), which can also be noticed in teaching textbooks: *"Noble gases are not much reactive because they bear a complete outside shell"*.

At university level, students find it difficult to understand the electronic structure of atoms (Keig & Rubba, 1993): mistakes concern the representation of shells and sub-shells, of orbits and of the number of electrons. Moreover, they find it difficult to go from the electronic representation of atoms to the representation of the molecules that they form, by their formula as well as their molecular model.

Quantic atom

The quantic model of the atom gives birth to the representation of an electron cloud. But, it is not because the students are willing to use this representation at the end of grade 9 (Brehelin, 1998) that they understand its meaning. Harrison and Treagust (1996 and 2000) show that, for students, the electron cloud protects the nucleus, that it is considered as a matrix in which electrons are embedded (the way water drops are in a cloud), and that it is often mistaken for electronic shells even by very bright students.

3 Purpose

The purpose of this study is to highlight the knowledge acquired individually as well as collectively by upper secondary school students (grades 10-12). Our research questions are:

- Which models of the atom and the molecule do they favour?
- How does this modeling develop from the beginning of grade 10 to the beginning of grade 12 of upper secondary school?

4 Methodology

In order to understand the misconceptions better, we have studied the history of these concepts, and then we have examined school science curricula and textbooks in order to identify the intended development of the conceptualisation of these concepts within the school curricula.

The investigation was carried out with 930 students of various upper secondary schools: 239 grade 10 students (age 15-16), 422 grade 11 students (age 16-17), and 269 grade 12 students (age 17-18) of upper secondary schools. In order to collect the data, four open questions were proposed to them using a written questionnaire. The questions concerning the concept of atom are:

- schematise the hydrogen atom (grade 10), oxygen atom (grades 11 and 12),
- describe the hydrogen atom (grade 10), oxygen atom (grades 11 and 12), and two other questions concerning the concept of molecule which are:
- schematise the water molecule,
- describe the water molecule.

The answers to each pair of questions will allow one to complete and confirm the data: as all information cannot indeed appear in a schematisation.

After reading the answers, different levels on the schematisation and integration of the models were defined.

Atoms

Levels of schematisation:

N.0: no answer, or answer impossible to classify: biological cell, particle association, atom and molecule confused with one another.

N.1: atom symbol, and symbol and electron pairs for grade 11 and 12 students

N.2: sphere

N.3: composite atom: varied representations where a nucleus and electrons are visible, or representation of the neutral atom as in lower secondary school grade 9.

N.4: solar system (2D or 3D)

N.5: electron cloud

Examples of such schematisations are given in figure 1.

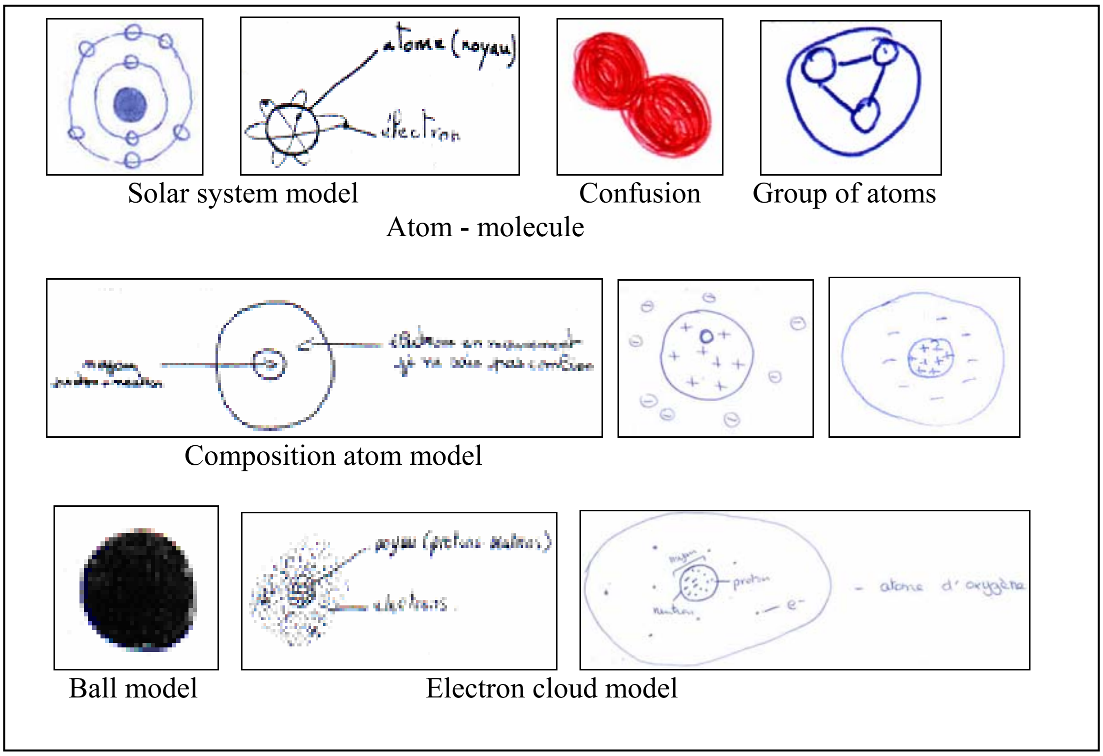


Figure 1. Examples of the schematisation of the atom according to the students in the inquiry.

Levels of integration

N.0: Other and no answer

N.1: Atom made of a nucleus and an electron cloud (or nucleus and electrons),

N.2: Atom made of a positive nucleus and an electron cloud,

N.3: Atom made of a nucleus that contains protons (Z) and neutrons, and an electron cloud (or negative electrons),

N.4: Atom is made of a nucleus that contains (Z) positive protons and an electron cloud that contains (Z) negative electrons. The number of positive charges equals the number of negative charges. *[For 0 (8 protons and 8 electrons)],*

N.5: Atom is made of Z protons, A-Z neutrons and Z electrons,

N.6: Atom is made of a nucleus that contains Z protons and A-Z neutrons, and of an electron cloud (or electrons that revolve) that contain Z electrons (or Z negative electrons).

Remarks in *italics* concern grade 11 and 12 curricula. Level 1 can be considered as the minimum level required at the end of grade 9 (Lower Secondary), level 2 is the level of formulation in that class (if we add that the atom must be natural), level 3 is the minimum level required in grade 10 (Upper Secondary) and level 6 corresponds to the level of formulation in that class.

Molecule

The same students, in the same questionnaire, were asked to

- schematise the water molecule,
- describe the water molecule.

The number and percentage of answers to each question, for each population is as follows:

- schematisation: grade 10: 207 (87%); grade 11: 419 (99%); grade 12: 267(99%)
- description: grade 10: 178 (74%); grade 11: 419 (99%); grade 12: 222 (83%).

The analysis of the students' answers leads to defining different levels of schematisation and integration, as for the atom.

Levels of schematisation

N0: Erroneous answer or no answer

N1: Space-filling model

N2: Ball and stick model

N3: Lewis structural formula

N4: Lewis formula

Examples of such schematisations are given in figure 2.

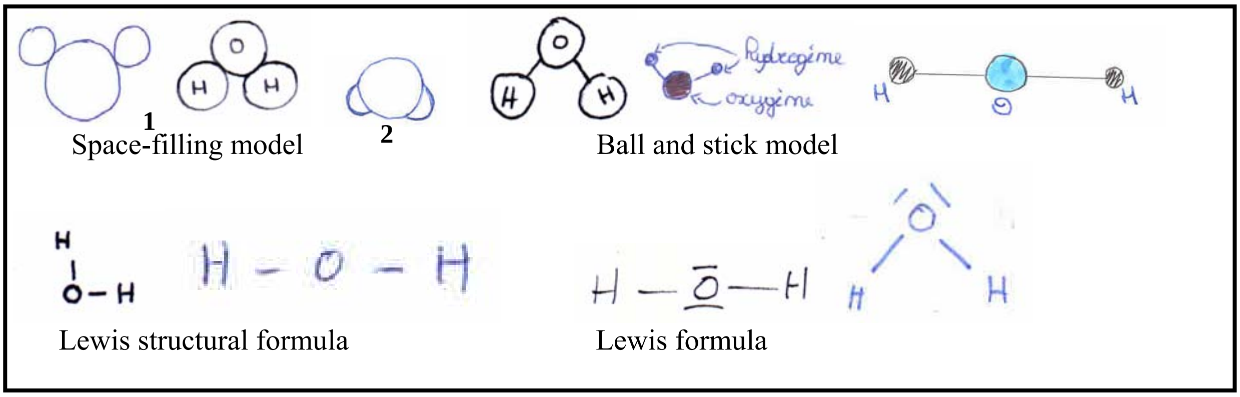


Figure 2. Examples of schematisation of the water molecule

Levels of integration

N0: Erroneous description or no answer

N1: Water molecule is made of two atoms of hydrogen and one atom of oxygen.

N2: Water molecule is made of two atoms of hydrogen linked to one atom of oxygen

N3: Water molecule is made of two atoms of hydrogen linked to one atom of oxygen by a covalent bond (or simple bond)

N4: Water molecule is made of two atoms of hydrogen linked to one atom of oxygen by a covalent bond composed of two electrons (or linked electron pair)

N5: Water molecule is made of two atoms of hydrogen linked to one atom of oxygen by a covalent bond. Each atom gives one electron to make the bond.

Level 1 can be seen as the required level at the end of grade 9, level 3 can be seen as the required level at the end of grade 10, and level 5 corresponds to the level of formulation in that class. Key words appearing in the descriptions were visible. They can be read in table 2 (Appendix).

5 Results and discussion

5.1 Acquired knowledge on the modeling of the atom

Results

The number and percentage for each question, in each group, is as follows:

- Schematisation: grade 10, 185 (77%); grade 11, 400 (95%); grade 12, 246 (91%).
- Description: grade 10, 172 (72%); grade 11, 364 (86); grade 12, 167 (62%).

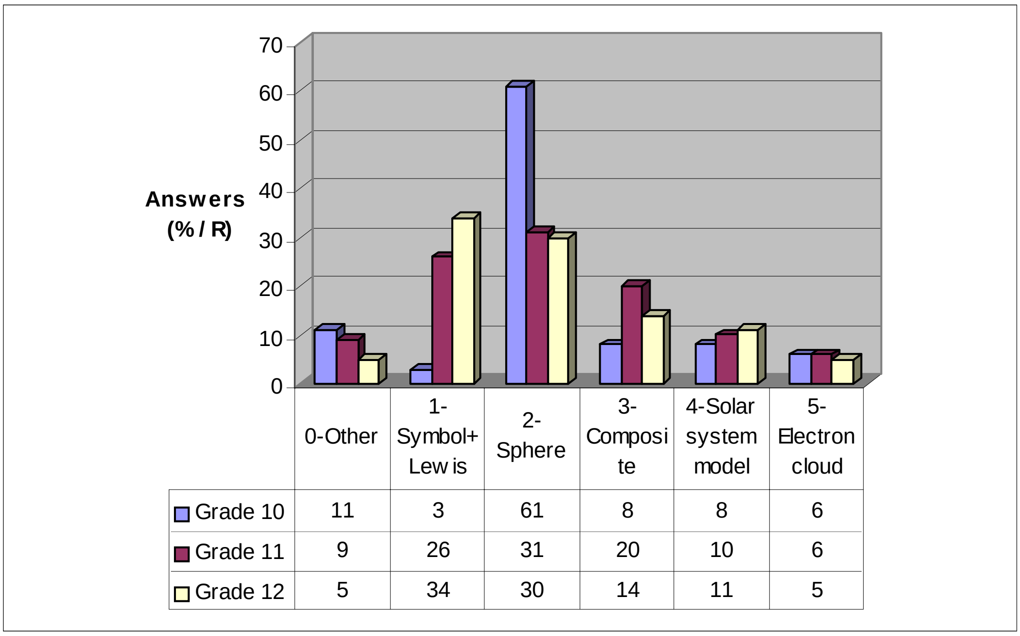
Research of key words

In order to identify the characteristics of the model that were understood, and also the misconceptions, a certain number of key-words have been picked out in the written descriptions: they have been collected in table 1 (see Appendix).

Analysis of results

On atom schematisation

The percentage of students who produce a representation of an atom is higher at the beginning of grade 11 and 12 than at the beginning of grade 10. Does this mean that the concept of the atom is more familiar to those students? This is not necessarily so, for the differential between the percentage of schematisation and that of description increases from grade 10 to grade 12 (-5%; -9% and –29%). It may be explained by the forgetting of the characteristics of the atom among grade 12 students, or more probably as we shall see later, by the stronger comprehension of electron pairs that has blocked out these characteristics. Figure 3 allows for the comparison of the evolution of choice in the different schematisations throughout Upper Secondary School.



R: percentage worked out from the number of schematisations.

Figure 3. Comparative study of the levels of schematisation of the concept of atom

For the main part of students entering grade 10, the atom is represented as a mere sphere (61% of schemes; 63% if we add the key words sphere or ball as used in the descriptions of other models). If a remarkable decrease in the percentage can be noticed in the following two grades, one is surprised to find still around one-third of the students that remain on the same description in grade 11 (31% of schemes; 35% schemes + descriptions) and grade 12 alike (30% of schemes; 35% schemes + descriptions). This was already identified by Harrison and Treagust (1996). Moreover, for other representations of the models of atoms, there emerges a tendency that was already confirmed (Harrison and Treagust, 1996; Griffiths and Preston, 1992; Taber, 1998) to include them into a spherical envelope (around 9%).

One should also wonder at the second favourite schematisation of grade 11 and 12 students as the Lewis representation of the atom (symbol and electron pairs). Indeed, this mode of representation is refused by Official Instructions. Does this mean that some teachers do not follow the given instructions, or that the representation is attractive due to its perception as a simplified image during the modeling of bonding in the molecule? Students favour the representation of the eight electrons of oxygen in the form of four electron pairs around the symbol of the element (and this accounts for 13% and 10%), followed by the taking into account of the six outside electrons (10% and 7%).

The use of the model of the composite atom, and more particularly that of the "*neutral atom*", reaches a maximum when students enter grade 11, whereas it accounts for a majority of representations in the textbooks of grade 9. Therefore, its integration, however low, is favoured in the teaching of the electronic structure and nucleus composition.

A low percentage in the choice of electron cloud model can be perceived among different grades, whereas it is the description that is favoured by textbook authors as well as curricula developers. Thus, as Harrison and Treagust (1996, 2000) proved in their work, such a model is not correctly grasped by students.

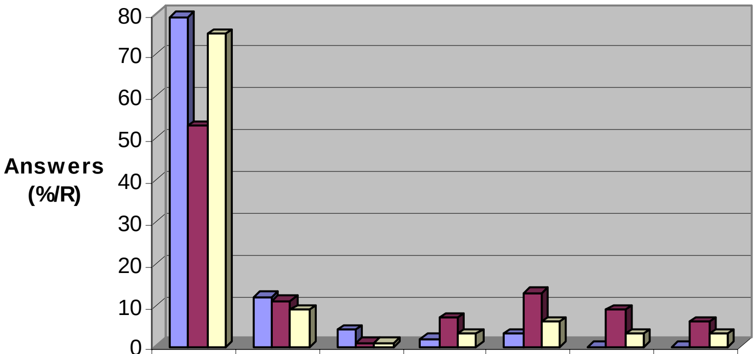
Another interesting remark to be noted is that the use of the solar system model of the atom increases from grade 10 to grade 12. Yet this model is not frequently relied on in textbooks as it appears only in documents with historical contents. Moreover, although Official Instructions forbid the representation of the solar system model in shells in 2D, some students (who account for 4% in grade 10, 8% in grade 11, and 5% in grade 12) choose this schematisation. Is that a consequence of school knowledge or is it the students' own conception of how to represent electronic shells?

Lastly, as far as other representations are concerned, they can mainly be explained by the confusion between atom and molecule. One can regret that 5% of grade 12 students remain still at this level!

As far as the description of atom is concerned:

A vast majority of students cannot produce an acceptable level of formulation of the concept of atom. The differences observed between the three grades prove that if the teaching in grade 10 brings along a clearly positive evolution, the concept is not integrated well. Indeed, whenever it is not the object of teaching (i.e. in grade 11), its minimum characteristics have been forgotten by the following year.

The minimum level required at the end of grade 9, (N1) is only reached by 21% of grade 10 students, 47% of grade 11 students, and one is brought down to 25% at the beginning of grade 12 students. As far as the required minimal level of grade 10 is concerned, only 35% of grade 11 students and 15% of grade 12 students manage to reach it.



	N.0	N.1	N.2	N.3	N.4	N.5	N.6
Grade 10	79	12	4	2	3	0	0
Grade 11	53	11	1	7	13	9	6
Grade 12	75	9	1	3	6	3	3

R: percentage worked out from the number of schematisations.

Figure 4. Comparative study of the levels of integration of the concept of the atom

From the schemes and key words, we have tried to discover what competences were expected at the end of grade 10 as visible on the students' papers (grades 11 and 12).

– *knowing the composition of the atom - knowing that the atom is electrically neutral.* If 46% of grade 11 students and 47% of grade 12 students make it clear that the number of protons equals that of electrons, only 9% and 4% of them state explicity that atom is electrically neutral. The composition of the nucleus of atom oxygen (8 protons and 8 neutrons) is only precisely referred to by 13% and 10% of the students.
– *discriminating between the electrons from inside shells and electrons from outside shells:* 19% and 14% mention a clear organization of electrons in shells, but only 12% and 9% have a clear understanding of the right repartition of electrons in shells K and L (K^2 L6).
– *numbering the electrons of the outside shell:* the presence of six electrons on the outside shell is clear in some productions (Lewis representation of atom, K^2L6, mention of the six electrons in the description) among 22% of grade 11 students, and 17% among grade 12 students.

Considerations about the mass of atom concentrated around the nucleus, or about atom as mainly constituted of empty space, are only visible in a very low number of students.

On students' misconceptions:

The representation of atom by the Lewis model is very often chosen by grade 11 and 12 students. It is visible not only in schematisation but also in the descriptions of atom, either under written or symbolic forms, even when other representations are relied on, with a percentage that reaches 46% in both classes. This result is in accordance with Keig and Rubba's work (1996). One may therefore assert with Taber (1995, 1998) and Robinson (1998) that the octet rule corresponds to a "mental model" that the students have integrated. Such a model leads them to a static conception of electrons within the atom; they are already grouped in electron pairs: “atom is made of, consists of, possesses, contains,...“ electron pairs. And for some of the students, these electron pairs are already organized as a linked electron pair or as bonds (3%, grade 11 and 10%, grade 12).

Other erroneous conceptions to be picked out in schemes and key words:

- atom and molecule confused with one another (13%, grade10; 6%, grade 11; 5%, grade 12)
- a confusion between the different concepts relied on to describe atom: proton - neutron, neutron - electron, ion - charged particle, ... (respectively 4%, 3% and 2%) as already identified by Osborne and Freyberg (1985).

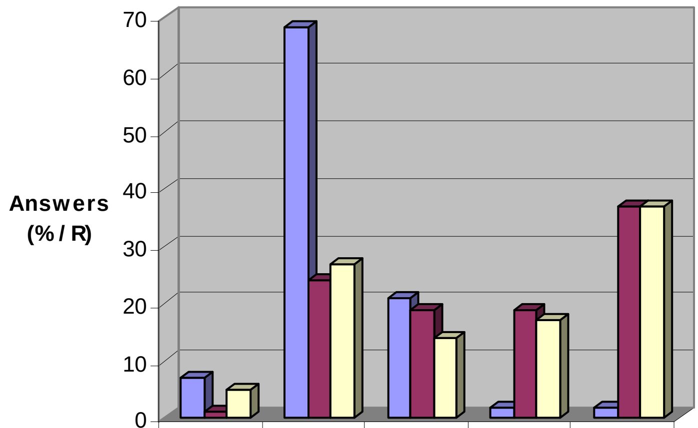
5.2 Acquired knowledge on the modeling of water molecule

Analysis of results

On the schematisation of the water molecule.

The percentage of answers to this second question is higher than that of answers on the atom. Students seem more familiar with water molecule than with atom. Yet it is puzzling to note that the differential between the two percentages of response is higher for grade 12 students (−16%) than for grade 10 students (−13%), although the description of water molecule is the teaching object of grade 10 and 11 curricula.

As Pereira and Pestana (1991) and Harrison and Treagust (1996) showed, figure 5 proves an evolution in the schematisations along Upper secondary school. When entering grade 10, a vast majority of students (68%) chooses the model that was introduced at Lower Secondary level: the space-filling model. In grades 11 and 12, they mainly rely on the Lewis formula model which was studied in grade 10 (37%). In grade 10, ball and stick models of molecule are also used to represent molecules. Therefore, it is surprising to witness a preference for the space-filling model by a quarter of grade 11 and 12 students, and to see a decreasing use of that model from grade 10 to grade 12.



	0-Other	1-Space-filling model	2-Ball and stick model	3-Lewis structural formule	4-Lewis formula model
Grade 10	7	68	21	2	2
Grade 11	1	24	19	19	37
Grade 12	5	27	14	17	37

R: percentage worked out from the number of schematisations.

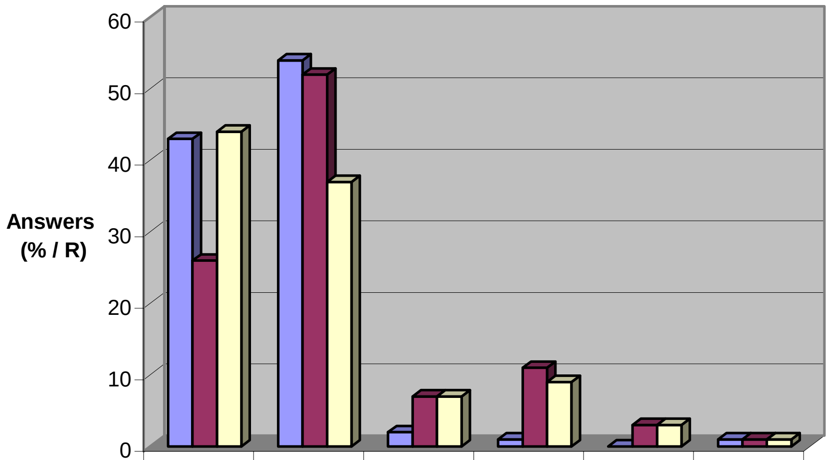
Figure 5. Comparative study of the levels of schematization of water molecule

As underlined by Griffiths and Preston (1992), 70% of grade 10 students represent the Space-filling model where they put the hydrogen atom and oxygen atom together (scheme 1), whereas the students in the following grades produce more correct representation: hydrogen atoms are "integrated" to the oxygen atom (scheme 2). Lastly, the representation in the guise of angled geometry of these different models increases noticeably from grade 10 (71%) to the higher grades (84%).

Let us underline that in grade 11.3% of the students feel it necessary to represent the molecule by the symbolization of each constitutive atom with the use of the solar system model in 2D.

On the description of water molecule

Figure 6 shows clearly that students seem more familiar with the concept of molecule than with that of atom, since the percentage of non-satisfactory descriptions is lower in all grades. Nevertheless, it is surprising to see that grade 12 students are not any better than grade 10 students as far as the description of molecule is concerned. If the minimum level is expected at the end of grade 9, it is reached or exceeded by 58% of grade 10 students, 74% of grade 11 students, and only 57% of grade 12 students. As far as the minimum level expected at the end of grade 10 is concerned, it is reached by only 15% of grade 11 students and 13% of grade 12 students.



	N.0	N.1	N.2	N.3	N.4	N.5
Seconde	43	54	2	1	0	1
Première	26	52	7	11	3	1
Terminale	44	37	7	9	3	1

R: percentage worked out from the number of schematisations.

Figure 6. Comparative study of the levels of integration of water molecule

It is not surprising that the idea of chemical bonding appeared in only few of the grade 10 students' descriptions (12%), as it does not belong to the curriculum at that level. Yet, the idea of bonding, explicitly or implicitly formulated (respectively with the use of the word or that of the verb) is visible in around one-third of the students' productions in the following grades, whereas covalent linked is studied in grade 10. The percentage of students who mention covalent bonding between hydrogen and oxygen atoms is very low: 7% in grade 11 and 5% in grade 12.

In some descriptions of the water molecule, the following can be observed:

- the notion of polarity of the molecule (11% of grade 11 students), a notion that was introduced at the beginning of grade 11, so at the moment when the students answer the questions. In grade 12, only 2% of the students refer to it.
- an explicit mention of the angle between O-H bonding (5%, grade 11 students; 10%, grade 12). The accurate value is not often given.

On students' misconceptions:

As noted by Pereira and Pestana (1991), when dealing with the schematisation of molecule with the help of space-filling models and ball-and-stick models, students do not always respect the respective size of atoms: 33%, grade 10; 7%, grade 11; 15%, grade 12. The radiuses of the circles that represent oxygen and hydrogen atoms are generally equal.

Some students confuse atom and molecule in the description: *"the water molecule consists of two molecules of hydrogen and one of oxygen"* (12%, grade 10; 3%, grade 11 and 8%, grade 12). In grade 10, they also sometimes refer to dihydrogen or dioxygen to name atoms (7%), thus showing another confusion in their conceptions.

Attributing colour to atoms remains from grade 10 to grade 12 (6%, 3%, 5%), and 8% of grade 12 students still consider that the molecule possesses macroscopic properties. These students thus seem to have difficulty in distinguishing model from reality. Indeed the colour code for atoms is developed when the representation of molecules relies on the use of molecular models.

The poor mastering of what the spelling of H_2O chemical formula represents (Ben-Zvi et al., 1988; Keig and Rubba, 1993) leads some students to produce an erroneous description or schematisation of the water molecule: H and 2O (or H_2 and O): 5%, 4%, 7%.

Lastly, 5% of grade 11 and 4% of grade 12 students believe that the bond between atoms is the ionic type (molecule consisting of ions or bonding resulting from an exchange of electrons between atoms).

6 Conclusion

The results of the present study show:

- that the model the students favour along their years of study is that of the spherical atom. Nevertheless, the choice of such schematisation decreases from grade 10 to grade 12 to the benefit of the Lewis representation (symbol and electron pairs). But, for many students who rely on that representation, electrons are “pre-assembled” in electron pairs within the atom.
- that for the representation of the water molecule, they move from a strong use of the space-filling model (where all atoms are put side by side) to the schematisation according to the Lewis formula as taught in grade 10. But it is to be noted that an explicit mention of covalent bonding between atoms when describing the molecule is not often found.
- that the levels of integration of the concepts of atom and molecule are much lower than the required levels of formulation at the end of the different grades.
- that from grade 10 to grade 12, for some students, a confusion remains between atom and molecule and between model and reality.

The students' conceptualisation of microscopic models of atom and molecule is therefore really problematic. Attempts at interpreting the origins of such difficulty were suggested by Barlet and Plouin (1997) and Tsaparlis (1997):

- the concepts involved are abstract and cannot be put into relation with everyday experience. Their understanding requires a high level of abstraction from the students, which seem to be the case for only some 50% of them when entering university.
- real training cannot happen unless students manage to give a meaning to the new knowledges they are presented with. To do so, they rely on the knowledge available in their long-term memory. Whenever such knowledge is not available, or is wrongly structured, the result leads to superficial mechanical learning.

Therefore, it is no surprise that in the phase of the first confrontation with complex knowledge, students cannot easily integrate it. This seems confirmed by the fact that, if after teaching of the models, a positive evolution can be observed in the students' answers, when they are not studied any longer, many students go back to initial levels of schematisation and integration.

Bibliography

ALBANESE, A., VICENTINI, M. (1997). Why do we believe that an atom is colourless? Reflections about the teaching of the particle model, Science &Education, 6, pp. 251-261

ANDERSSON, B. (1990). Students' conceptions of matter and its transformations (age 12-16). *Studies in Science Education,* 18, pp. 53-85.

BARLET, R. & PLOUINl, D. (1997). La dualité microscopique-macroscopique : un obstacle sous-jacent aux difficultés en chimie dans l'enseignement universitaire. *ASTER*, 25, pp.143-173.

BEN-ZVI, R., EYLON, B., SILBERSTEIN, J. (1988). Theories, principles and laws, *Education in Chemistry*, May, pp. 89-92

BREHELIN, D., CROSS, D., SIVADE, A. (1994). Images spontanées et induites par l'enseignement du concept "atome" pour les élèves de collège, *Bulletin de l'Union des Physiciens*,763, pp. 711-729

CHARLET - BREHELIN, D. (1998). Contribution à l'enseignement - apprentissage du concept d'atome au collège, Thèse, Université Montpellier II.

CROS, D. et al. (1984). Atome, acides-bases, équilibre, quelles idées s'en font les étudiants arrivant à l'université, *Revue Française de Pédagogie,* 68, pp. 49-60

CROS, D., MAURIN, M., AMOUROUX, R., CHASTRETTE, M., LEBER, J., FAYOL, M. (1986). Conceptions of first-year university students of the constituents of matter and the notions of acids and bases. *European Journal of Science Education*, vol. 8,3, pp. 305-313.

de VOS, W, VERDONK, A.H. (1987). A new road to reaction. Part 4. The substance and its molecules. *Journal of Chemical Education*, vol. 64, 8, pp. 692-695.

de VOS, W, VERDONK, A.H. (1996). The particulate nature of matter in science education in science, *Journal of Research in Science Teaching*, vol. 3, 6, pp. 657-664

del POZO, R.M. (2001). Prospective teacher' ideas about the relationships between concepts describing the composing of matter, *International Journal of Science Education,* vol. 23, 4, pp. 353-371

GIORDAN, A., G. de VECCHI, (1987). *Les origines du savoir*, Delachaux et Niestlé, Neuchâtel, Paris

GRIFFITHS, K. A., PRESTON, R. K. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules *Journal of Research in Science Teaching*, vol. 29,6, pp. 611-628

HARRISON, A.G., TREAGUST, D.F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching chemistry. *Science Education*, vol. 80, 5, pp. 509-534

HARRISON, A.G., TREAGUST, D.F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education*, vol. 84, 3, pp. 352-381

JOHNSON, P., (1998). Progression in children's understanding of a 'basic' particle theory: a longitudinal study, *International Journal of Science Education*, vol. 20, 4, pp. 393-412

JOHNSTON, K. (1988). Learning and teaching about the particulate theory of matter : A report on a teaching scheme in action, pp. 55-79

KEIG, F. P., RUBBA, A. P. (1993). Translation of representations of the structure of matter and its relationship to reasoning, gender, spatial reasoning, and specific prior knowledge. *Journal of Research in Science Teaching*, vol. 30, 8, pp. 883-903

LEE, O., EICHINGER, C. D., ANDERSON, W.C., BERKHEIMER, D. G., BLAKESLEE, D. T. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching*, vol. 30, 3, pp. 249-270

OSBORNE, R., FREYBERG, P. (1985). Learning in science: The implications of children's science. Auckland:Heineman. (cité par Griffiths & Preston, 1992, p. 612)

PEREIRA, M.P., PESTANA, M.E.M. (1991). Students' representations of models of water, *International Journal of Science Education*, vol.13, 3, pp. 313-319

ROBINSON, W.R. (1998). An alternative framework for chemical bonding. *Journal of Chemical Education,* vol. 75, 9, p. 1074

RUTHERFORD, E. (1912). *Philosophical Magazine*, 6, 24, P. 453

TABER. K.S. (1995). Prior learning as an epistemological block? The octet rule- an example from science education. A paper to the session Children's learning in science, 14th September 1995, at the European Conference on Educational Research.

TABER, K.S. (1998). An alternative conceptual framework from chemistry education, *International Journal of Science Education,* vol. 20, 5, pp. 597-608

TABER, K.S. (1999). Alternative frameworks in chemistry, *Education in Chemistry,* vol. 36, 5, pp. 135-137

TSAI, C.-C. (1998). An analysis of Taiwanese eight graders' science achievement, scientific epistemological beliefs and cognitive structure outcomes after learning basic atomic theory, *International Journal of Science Education,* vol. 20, 4, pp. 413-425

TSAPARLIS, G. (1997). Atomic and molecular structure in chemical education. *Journal of Chemical Education,* vol. 74, 8, pp. 922-925

VOSNIADOU, S. (1994). Capturing and modelling the process of conceptual change, *Learning and Instruction,* 4, pp. 45-49

WATTS, M. (1983). A study of schoolchildren's alternative frameworks of the concept of force, *European Journal of Science Education*, 5, 2, pp. 217-230

Official Instructions :

B.O.E.N. – N° 5 du 9 mars 1995, Programmes du cycle central des collèges

B.O.E.N. –H.S. N° 4 du 22 juillet 1999, Programmes des 3ème des collèges

B.O.E.N. –H.S. N° 6 du 12 août 1999, Programme de la classe de seconde

B.O.E.N. –H.S. N° 7 du 31 août 2000, Programme de la classe de 1ère, série scientifique

B.O.E.N. –H.S. N° 4 du 30 août 2001, Programme de la classe de terminale, série scientifique

APPENDIX

Table 1. Recapitulated table (descriptions of the concept of atom).

DESCRIPTIONS			Beginning of grade 10 Nb.	Beginning of grade 10 % (172)	Beginning of grade 11 Nb.	Beginning of grade 11 % (364)	Beginning of grade 12 Nb.	Beginning of grade 12 % (167)
Attribution	Colour		12	7	18	5	16	10
	Form		20	12	26	7	16	10
	Total		**32**	**19**	**44**	**12**	**32**	**19**
Characteristics	Symbol		12	7	15	12	4	2
	Mass		6	4	7	2	7	4
	Charge		12	7	27	7	6	4
	Size		13	8	5	1	1	1
	Place in the periodic table		4	2	-		1	1
	Empty space in the atom		1	1	3	1	1	1
	Total		**48**	**28**	**57**	**16**	**20**	**12**
GR(electrons revolve around the nucleus)			**22**	**13**	**88**	**24**	**32**	**19**
Composition	**Electron**	N total $e^- = Z$	9	5	167	**46**	79	47
		N total $e^- \neq Z$	32	19	13	**4**	2	1
		Ne^- of valence correct			8	**2**	2	1
		N e^- on shells K et L correct			36	10	21	13
		e- on shells K,L,M et n $e^- > Z$			17	**5**	2	1
	Nucleus	Z protons	3	2	79	**22**	22	13
		Z protons et Z neutrons	6	4	48	**13**	24	14
		Incorrect composition			8	**2**	3	2
	Total		**50**	**29**	**376**	**103**	**155**	**93**
Confusions	Atom / molecule		14	8	14	**4**	9	5
	Other		11	6	6	**2**	3	2
	Total		**25**	**15**	**20**	**6**	**12**	**7**
Electron pairs/or bonding	It can give two bondings/two linked electron pair				21	6	24	14
	Octet rule/ 4 bondings or linked electron pair / 4 free electron pairs				18	5	14	8
	2 or 3 free electron pairs				6	2	1	1
	6 electron pairs / bondings				2	1		
	Total				**47**	**13**		

Table 2. Recapitulated table (descriptions of the concept of water molecule).

DESCRIPTIONS		Beginning of grade 10		Beginning of grade 11		Beginning of grade 12	
		Nb.	% (178)	Nb.	% (402)	Nb.	% (198)
Constitution	2 atoms H and 1 atom O	110	62	311	77	125	56
	2 atoms O and 1 atom H (et H_2 et O)	9	5	18	4	14	7
	2 molecules of hydrogen and one of oxygen	22	12	13	3	16	8
	Confusion atom - molecule	36	20	-	-	-	-
	Others (in term of atoms)	14	8	6	1	3	1
Bonding	Implicit idea of bondings	15	8	57	14	35	16
	Bondings	3	2	18	4	11	6
	Covalent bonding – linked electron pair	-	-	28	7	21	5
	Bondings by transfer of e^- - composed molecule of ions	-	-	20	5	7	4
	Other	3	2	14	3	2	1
Attributions	Bond angles	-	-	17	4	19	10
	Polarity	-	-	45	11	5	2
	Colours on atoms	10	6	12	3	9	5
	Macroscopic properties	-	-	6	3	15	8

Understanding of Basic Chemical Concepts and Motivation for Learning Chemistry of Pre-Service Primary School Teachers

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Introduction

Teachers' knowledge can be classified into three categories: (1) content knowledge; (2) general pedagogical knowledge and (3) pedagogical content knowledge (Shulman, 1987). All three levels of knowledge should be adequately connected to construct mental models of educational strategies that a good teacher could implement in the classroom. A part of content knowledge also includes scientific literacy and should be developed during teacher training to a level that enables rational planning of science teaching strategies of topics covered in the national curriculum. Because of that, basic chemical concepts knowledge is an important aspect for primary school teachers too. Considering also the none too strong intrinsic motivation for learning chemistry, pre-service primary school teachers have great difficulties in passing through the science course at university level (Devetak, et al., 2001).

Many primary school teachers are competent and motivated for most subjects they teach, but do not enjoy science and do not feel comfortable teaching it. Teachers' instructional behaviours are influenced by their attitudes toward science, a fact that does not go unnoticed by students (Vadya, 1993). It is important that students receive specific science knowledge to help them teach school science in an interesting way for pupils. Such lessons develop pupils' accurate attitude towards science and their ability to correctly implement science knowledge in everyday activity (Butts, et al., 1987). Teaching is a very complex activity and teachers' intentions are subjected to many task-specific, but also general influences from the complex task environment (van der Valk, Broekman, 1999). Teachers need to know both science content and pedagogy to teach science well (Vadya, 1993).

Researchers have confirmed that especially girls lose motivation for science during schooling (Brickhouse, et al., 1999, Weinburgh, 1995). Low teacher expectations, gender-biased teaching and counselling, and parental discouragement contribute to girls' diminishing interest in science. Scientists have searched for reasons for these observations in the fact that primary school teachers are not sufficiently motivated for science teaching and learning new science concepts, so they pass their view of science education on to their pupils. Female primary school teachers use the same strategies to teach science that failed to excite them as students. This results in a cycle of lack of interest in science

(Friedman 1999). The teachers' way of teaching science at primary level is influenced by their personal background, especially their own experiences with science courses taken when they themselves were learners at school or university (Huibregtse, et al., 1994; de Jong, et al., 1999).

It can be speculated that first year university students are mostly motivated only by the macroscopic component of science knowledge, but not at the submicro and symbolic level. Submicro and symbolic levels are the most abstract and the most difficult even for university students to understand (Johnstone, 1991). For sufficient understanding of science phenomena, future teachers must be able to achieve and demonstrate the transfers between the phenomenon, its microscopic and symbolic representations (Gabel, et al., 1987; Johnstone, 1991). It was found out that Slovene university students have difficulties in interpreting the connections between the particle world of matter and phenomena at the macro level (Devetak, Glažar, 2001, 2002; Devetak, Urbančič, 2003).

Parker and Spink (1997) quoted a definition of an effective teacher that says: "The effective teacher is a professional communicator who can, within the context of teaching, think analytically and critically, who can make decisions and solve problems, who can manage and not just survive change and who can be a significant influence in a democratic and ethical society".

It is important to emphasise that all teacher educators should try to establish an environment that enables development of the above described effective teacher

The purpose of the study was twofold. Firstly, the level of science content knowledge among first year university students for pre-service primary school teachers was studied along the semester's chemistry course, and secondly, the motivation for learning science was explored and related to the determined level of students' knowledge.

Method

Participants

A total of 140 first year pre-service primary school teachers (136 females, 4 males) participated in the study. All students attended lessons regularly, on average they were 18.5 years old at the beginning of the university year.

Instruments and Procedures

To determine the basic science knowledge and the progress of students' understanding of chemical concepts as the effect of the chemistry course the *Test of Basic Science Knowledge (TBSK)*[2] was applied twice during the university year (*TBSK pre-test* in October 2002 and *TBSK post-test* in May 2003). *TBSK* comprises 14 chemistry problems which require understanding of chemical concepts at all three levels (i.e., macro, submicro and symbolic level) and connections between them.

[2] Devetak, 2002, following the work of Mulford, Robinson, 2002.

In both administrations the instrument showed satisfactory internal consistency: Cronbach' alpha was 0.68 and 0.62, respectively.

The chemistry course was planned in 54 lessons (30 lectures, 20 lab-work, 4 field work) during an 8-month period to prepare students to teach science to children aged from 6 to 11 years. It was orientated toward stimulating the students to connect the three levels of chemical concepts and to construct more stable mental models in order to integrate adequately their basic conceptual knowledge in future educational strategies in teaching science.

Students' motivation for learning science was measured at the end of the university year with a questionnaire *Internal motivation for learning science (IMLS)*[3]. The 125-item *IMLS* assesses internal motivation for learning biology, physics and chemistry as well as general internal motivation for studying and motivation for learning mathematics and foreign language; *IMLS's* special attention is devoted to assessment of students' internal motivation for learning chemistry at three levels (i.e., macro, submicro and symbolic level). The internal consistency reliability of *IMLS* was 0.78.

Results

1. Pre-service primary school teachers' science knowledge

The scores on the *TBSK pre-test* of 140 students averaged 10.84 points out of 27.25 (SD = 4.14), and on the *TBSK post-test* averaged 14.58 points out of 27 (SD = 3.82).

The knowledge of students about science throughout answers to different chemistry problems changed during the semester (*Figure 1*). The statistical analysis showed statistically significant differences between first (*TBSK pre-test*) and second (*TBSK post-test*) assessment ($t = 11.01$; $df = 139$; $p \leq 0.000$) in favour of the positive effect of the university science course carried out.

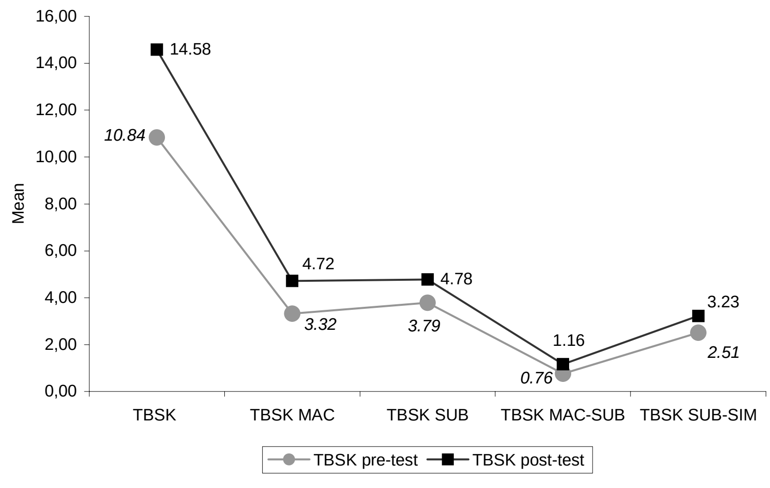

Figure 1. Students' science knowledge

[3] Devetak, Juriševič, 2002

2. Students' intrinsic motivation for learning science

The results in *Table 1* show that pre-service teachers in their first year of university studies are not highly intrinsically motivated for learning chemistry; they are indeed more deeply motivated for learning biology (see also Weinburgh, 1995) and physics, too.

Table 1. Descriptive statistics of intrinsic motivation for learning

Content area	Max.	Mean	Std. Deviation	Skewness	Kurtosis
General studying	65	47.42	4.29	-0.285	0.164
Chemistry	70	44.72	6.87	-0.075	0.097
Biology	70	50.73	6.04	-0.044	0.173
Physics	70	46.91	6.66	-0.187	0.188
Mathematics	70	46.84	7.24	-0.019	-0.054
Foreign language	70	45.98	8.68	-0.076	0.161

Among the three measured levels of chemical concepts the students' internal motivation for learning was highest at the concrete – macro level of understanding (M = 50.12, SD = 6.02), while the other two levels, more abstract in their content, were found to be represented to a much lower degree (submicro, M = 40.45, SD = 7.26 and symbolic level, M = 37.74, SD = 8.35). Because teachers emphasise only the symbolic level of chemistry (Lee, 1999), and because students at all levels of chemical education do not connect the three levels of concepts in a reasonable mental model, students have even at the university level the lowest internal motivation for learning science at the symbolic level.

3. The relation between knowledge and motivation

The correlation between knowledge and motivation for learning chemistry is rather low (r = 0.23) but positive and significant statistically at the 0.01 level (2-tailed). Similar results were obtained in a study of motivation and science knowledge at primary school level (Juriševič, 2003). It is not obvious that students must be intrinsically motivated to "pass succesfully" – it is possible that other motivational constructs (extrinsically based) participate in this process that we must explore in the future, as we believe that they might strongly influence the formation of the preservice teacher's pedagogical approach.

Conclusions and Implications

The findings of this study seem to clearly confirm the nature of pre-service teachers' science knowledge. In fact, they are more familiar with the concrete level of science, and their understanding of basic chemical concepts is also at a more superficial level. On the other hand, it is interesting to focus on their motivation to learn science; Brickhouse, et al. (1999) noted that "neither the students, teachers, nor parents talk about understanding when they are talking about success in school science" (p. 456). According to the authors, understanding plays a marginal role, since in schools – also in Slovenia – the success in science is measured mostly in terms of grades and points. This raises the question about the whole vertical of compulsory education.

The results of the study indicate that more precise research on the influences on the development of motivation for studying and teaching science, especially chemistry must be conducted. When a source and reasons for negative motivation in science learning have been revealed, special strategies to stimulate teachers' and students' positive (internal) motivation should be developed and applied in the school environment, that would stimulate higher cognitive reasoning. It can be concluded, that chemical education at all levels would become more suitable, once it becomes more meaningful for students.

References

1. Brickhouse, N. W., Lowery, P., Schultz, K. (1999). What Kind of Girl Does Science? The Construction of School Science Identities. *Journal of Research in Science Teaching*, 37 (5), 441-458.
2. Butts, D. P., Dennison, J., Simpson, R. (1987). Making Science User Friendly for Teachers and Their Students. *Education*, 108 (2), 193-203.
3. de Jong, O., Ahtee, M., Goodwin, A., Hatzinikita, V., Koulaidis, V. (1999). An International Study of Prospective Teachers' Initial Teaching Conceptions and Concerns: the Case of Teaching "Combustion". *European Journal of Teacher Education*, 22 (1), 45-59.
4. Devetak, I., Razdevšek–Pučko, C., Šteblaj, M. (2001). Ali je motivacija temelj trajnostnega razvoja v naravoslovju?. *Okoljska vzgoja v šoli*, 3 (1-2), 46-52.
5. Devetak, I., Glažar, S. A. (2001). Using Submicroscopic Representations as a Tool for Evaluating Students' Chemical Knowledge. *Programme and abstracts*, Aveiro, Portugal, 157-159.
6. Devetak, I., Urbančič, M. (2003). Razumevanje osnovnih kemijskih pojmov pri bodočih profesorjih razrednega pouka. in: Glavič, P. (ed.), Brodnjak-Vončina, D. (ed.). Slovenski kemijski dnevi, Maribor, Zbornik referatov s posvetovanja. FKKT, 8 pp.
7. Friedman, D. L. (1999). Science, YES! Constructing a Love for Teaching Science. *The Clearing House*, 72, 269-274.
8. Gabel, D. L., Samuel, K. V., Humm, D. (1987). Understanding the Particulate Nature of Matter. *Journal of Chemical Education*, 64 (8), 695-697.
9. Glažar, S. A., Devetak, I. (2002). Submicrorepresentations of Chemical Concepts. in: New Strategies for Chemical Education in the New Century, Proceedings. Beijing, Chinese Chemical Society, 352.
10. Huibregtse, I., Korthagen, F. A. J., Wubbels, T. (1994). Physics Teachers' Conceptions of Learning, Teaching and Professional Development. *International Journal of Science Education*, 16 (5), 589-561.
11. Johnstone, A. H. (1991). Why is Science Difficult to Learn? Things are Seldom what They Seem. *Journal of Computer Assisted Learning*, 7 (1), 75-83.
12. Juriševič, M. (2003). Motivacija za učenje. in: Čuk, M., Glažar, S. A., Bajd, B. Kurikularna prenova in načrtovanje ter izvajanje vzgojno-izobraževalnega procesa pri predmetu Spoznavanje okolja in pri Naravoslovju: evalvacijska študija, Pedagoška fakulteta, Ljubljana, 61-70.
13. Mulford, D. R., Robinson, W. R. (2002). An Inventory for Alternative Conceptions among First-Semester General Chemistry Students. *Journal of Chemical Education*, 79 (6), 739-744.
14. Lee, K. W. L. (1999). A Comparison of University Lecturers´ and Pre-service Teachers´ Understanding of a Chemical Reaction at the Particulate Level. *Journal of Chemical Education*, 76 (7), 1008-1012.

15. Parker, J., Spink, E. (1997). Becoming Science Teacher: an Evaluation of the Initial Strategies of Primary Teacher Training. *Assessment & Evaluation in Higher Education*, 22, 17-32.
16. Shulman, L. (1987). Knowledge and Teaching: Foundations of the New Reform. *Harvard Educational Review*, 75 (1), 1-22.
17. Vaidya, S. R. (1993). Restructuring Elementary and Middle School Science for Improved Teaching and Learning. *Education*, 114 (1), 63-70.
18. van der Valk, T., Broekman, H. (1999). The Lesson Preparation Method: a Way of Investigating Pre-service Teachers' Pedagogical Content Knowledge. *European Journal of Teacher Education*, 22 (1), 11-22.
19. Weinburgh, M. (1995). Gender Differences in Student Attitudes Toward Science: a Meta-Analysis of Literature from 1970 to 1991. *Journal of Research in Science Teaching*, 32 (4), 387-398.

Interactive Virtual Chemical Laboratory

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Abstract

The article describes the design of an interactive virtual chemical laboratory, presents its aims and gives results of the preliminary testing of its pedagogical impact. In the laboratory, chemical experiments are introduced through multimedia content on the macroscopic (images, videos) and sub-microscopic (structures, animations) level. Interactive exercises and a substance database were added to test and expand the knowledge acquired. Most importantly, the learner can correlate the observations of experimental results with theoretical explanations at the particle level. Although the results of preliminary testing are positive, more evaluation of this approach is needed. The laboratory encourages learning through observation and helps to improve information literacy.

Key words: interactive virtual chemical laboratory, experiments, animations.

Introduction

MacFarlen (1998) in his analysis of correlation between information, knowledge and learning stresses the importance of the role of lifelong learning in the information-based society. Lifelong learning takes place at the workplace and at home and its quality depends to a great extent on the use of information communication technology. Therefore, according to Wilson (2001), the basic precondition for qualitative life-long learning is well-developed information literacy, which is a skill common to all disciplines and educational environments. Education institutions must adopt new trends in designing their educational programmes.

Cooperation between Faculty of Science and Engineering, Faculty of Computer and Information Science, Faculty of Chemistry and Chemical Technology and University College of Health Care within the framework of the project »ICT in learning and teaching chemistry« resulted in the development of the Interactive Virtual Chemical Laboratory (IVCL), which aims to be a new multimedia educational tool for teachers and students. It enables the introduction of new teaching strategies and supports the development of higher skill levels: communication and information literacy, independent knowledge management, problem solving and individual and collaborative learning.

Methodology of the design

In the initial project phase, multiple activities were planned to be incorporated into and interlinked within the interactive chemistry laboratory. The main activity is learning chemical concepts and processes on the macroscopic, sub-microscopic and symbolic levels. Other activities are: discovering the properties of reagents and products of chemical reactions, using the database, and knowledge testing.

IVCL was developed in multiple steps:

- Selection of experiments
- Videos of the experiments: design and optimization, photos, video recording and editing
- Animations of the reactions: scripts, 3D models, animation and editing
- Correlation of macro and sub-microscopic levels
- Compound database
- Interactive exercises on macro and sub-microscopic levels
- Construction of the web based portal

Selection of experiments

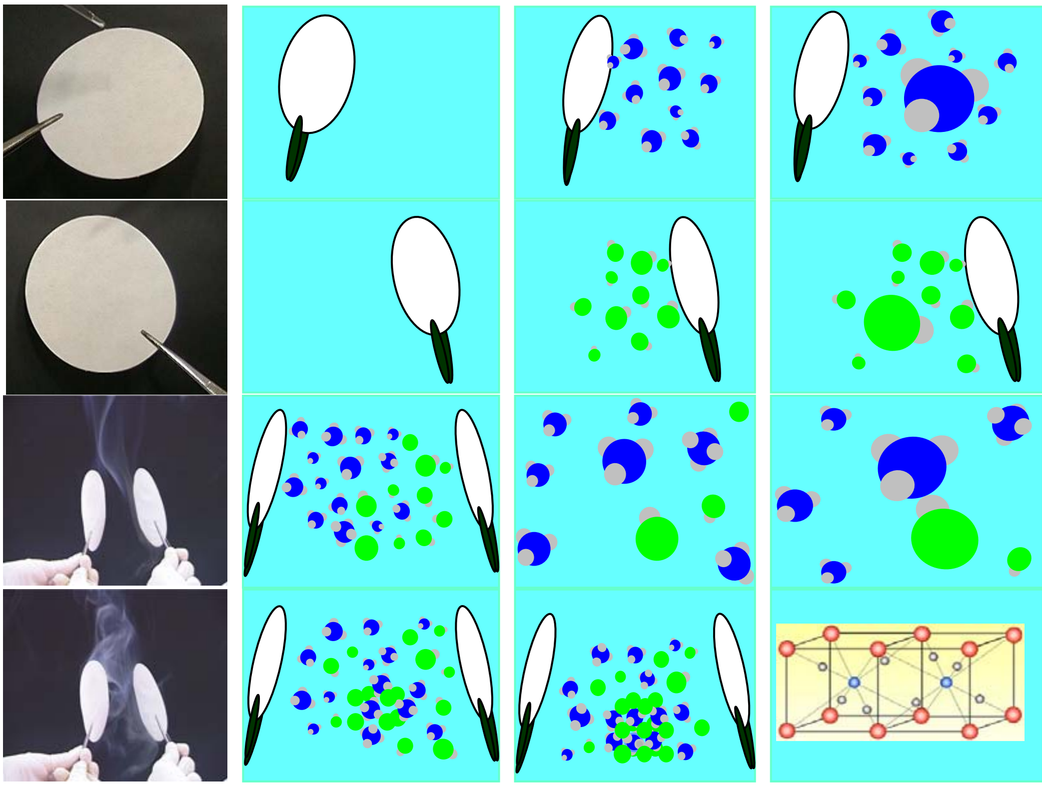
First, the content from the chemistry curriculum for primary and secondary schools was selected based on the suitability for multimedia presentation, and applicability to everyday situations. The chosen topic was "Particles and Reactivity", in which the main concepts presented were: diffusion in comparison with solvatation and precipitation, differences between the reactions occurring among ions in a water solution and among molecules in gaseous or dissolved state.

Video of the experiment

Our next task was to design individual experiments for visualisation of selected chemical concepts and processes on the macroscopic level. Different clips of each experiment were recorded with a digital video camera, aimed at finding the optimal viewing angle, lighting, contrast, hand movement, effectiveness of the experiment (quantity of reagents used to achieve the maximum visual effect). The best material was selected for video editing. Narrative explanation, captions and pointers were added to support the understanding of experiments. Hazards symbols for the substances involved were also incorporated in the clip. Attractiveness and didactical suitability of the resulting videos were then tested on a group of chemistry teachers and students, which was followed by optimization of the experiments. On the macroscopic level, still photos of all reagents and products were taken, to be later linked with the compound database.

Animation of the reaction

In parallel with the experiment design, we studied the sub-microscopic level of each reaction and wrote the animation scripts (scenarios) on the particle level. For each reaction, first the properties of particles taking part were specified (i.e. shape, relative and absolute size, relative and absolute speed at the reaction temperature). The scenarios themselves consist of the series of scenes. For each scene we had to define the number of particles, their movement in virtual space, types of collisions, change in size and shape of particles after collision. The organization of particles in a crystal lattice, when the reagents or products of the reaction were in solid state, had to be described. The correlation between the individual animation scenes and the corresponding macroscopic visual change was indicated in the script. In the step that followed, and before performing the actual animation, molecular models (molecules, ions and crystal structures) of the reagents and products were prepared with the 3D modelling software (Spartan, ChemSketch, MoluCad).



Picture 1. Insert from the visual part of the animation scenario (reaction: formation of ammonium chloride)

Selection of the appropriate animation software was another important task. While the animations were first made with a simple chemistry animation tool, Molucad, we hoped to find a suitable powerful software package to produce more complex and more realistic animations. Modern technology offers many options for 3D animation. Initially we wanted our animations to be interactive, but also avoid hardware limitations and software compatibility issues. We needed portability between different operating systems. In the end, we decided for Maya, a powerful modelling and animation software. Our solution did not enable interactivity, but the animated video clips that were created can be used on different systems. The animation process was demanding and time consuming. Molecular models were imported into Maya and then manipulated with Maya scripting language: random movement/distribution, collisions, reaction mechanism, geometry change and crystal formation. We tried to incorporate the highest possible number of particles in an animation, but the hardware limitation turned out to be about 400 particles. The key mechanism of each reaction was illustrated by focusing on a small number of molecules. In the video editing process short animated sequences were combined with narration and captions. Sometimes, the picture within a picture effect was used to reinforce the concepts.

As previously mentioned, the correlation between the macro and sub-microscopic level of the experiment was planned for and specified in the script (see Picture 1). It was practically achieved through video editing, when we combined the macroscopic sequences with the animation sequences. Transitions between the two levels were indicated with the zoom effect and separate narration was added, emphasizing the correlation.

Database

A searchable database containing data on the properties of common laboratory chemicals, and including all reagents and products taking part in the selected reactions, was set up. It gives information on the physical/chemical properties of the compounds, hazard and toxicology information. The first aid scheme is also given for each compound, where standard procedures are described and illustrated with photos.

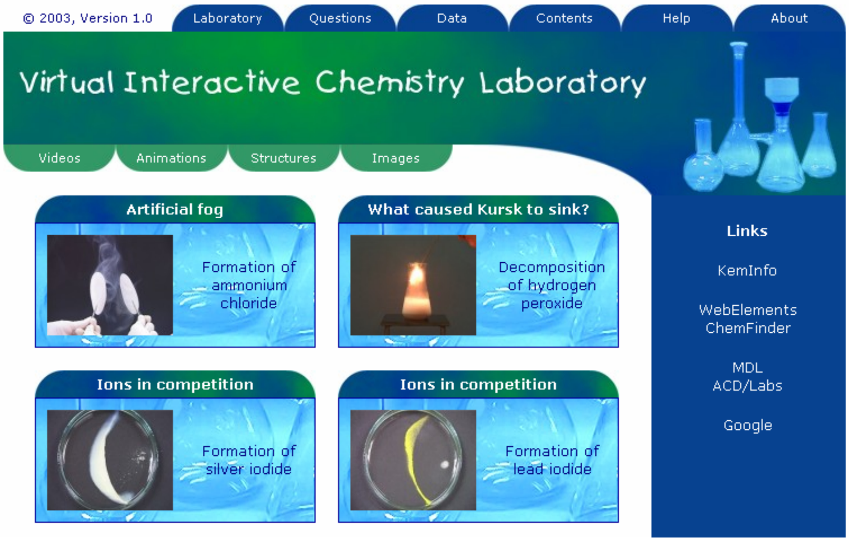
Interactive exercises

Various types of interactive exercises (questions) were developed for each video and animation (or combination of both), testing the observation skills and understanding of the changes on the macro and sub-microscopic level. In the case of combined clips, the user needs to associate the results of the experiment with the particle nature of matter. Some questions are raised about the properties of reagents and products – the lookup into the database is needed. Explanations and correct solutions are provided for every exercise.

Web portal

In the final phase the online portal of the Virtual interactive chemistry laboratory was set up. To reach the broadest spectrum of users, both the English and Slovenian version were created. The web address of the laboratory is http://www.ntfkii.uni-lj.si/crp2-eng/frame.htm and http://www.ntfkii.uni-lj.si/crp2-slo/frame.htm

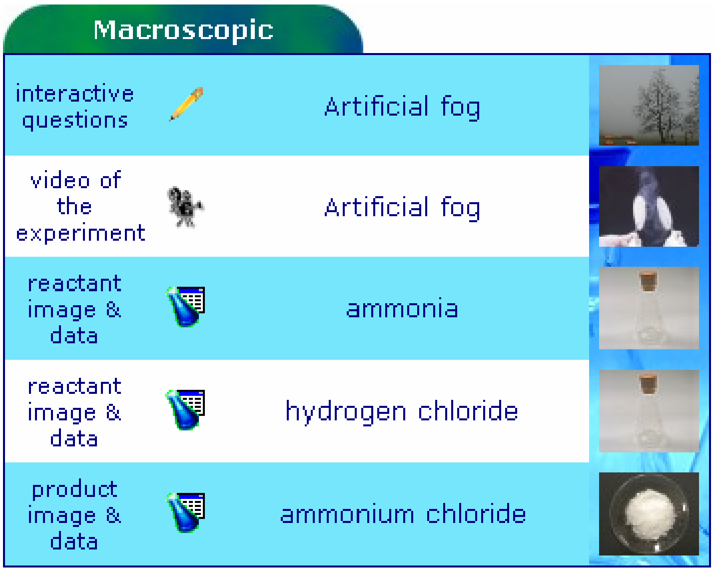
The content of the virtual laboratory can be accessed from different entry points: experiments (micro/sub-micro level), media elements (videos, animations, 3D molecular models, images), interactive exercises, compound database and safety information (first aid). At present, there are 9 experiments in the Slovenian and 4 experiments described in the English version.



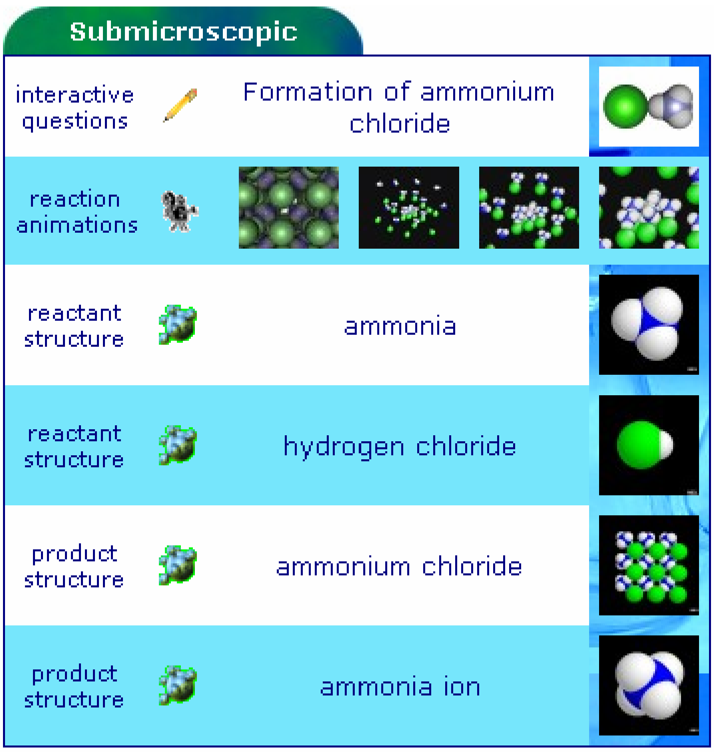
Picture 3. Title page of the English version of the interactive laboratory (4 experiments translated so far, more to follow)

On the macroscopic level of each experiment, we get the experiment video, interactive exercises and pictures of reagents/products (connected with the database on properties).

On the sub-microscopic level of each experiment, there are one or more animations of the reaction (where already implemented, a combined video/animation), interactive exercises and interactive 3D models of reagents/products (using Chime plug-in).



Picture 4. Formation of the ammonium chloride – macroscopic level



Picture 5. Formation of the ammonium chloride – sub-microscopic level (the first animation was made with Maya, the rest – in three variations – are simpler, made with Molucad)

Picture 6. The compound database - physical/chemical properties of ammonium chloride, not translated yet (Database segments: ID, physical/chemical properties, hazard, first aid, handling, reactivity, toxicology, environment, fire suppression, transport)

Preliminary analysis on the didactical value of the interactive laboratory

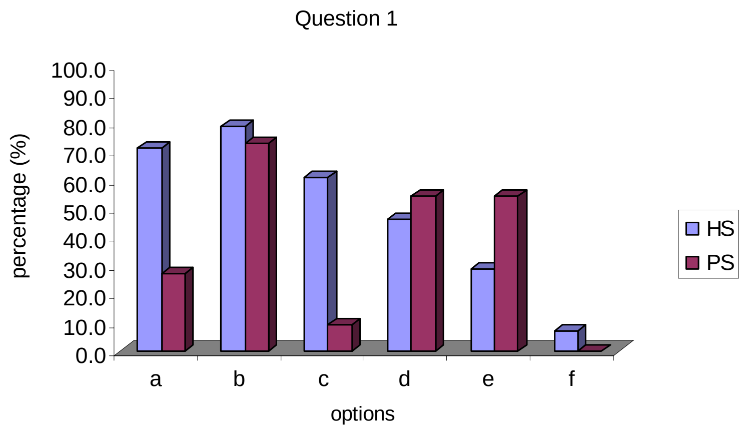
A questionnaire was prepared, comprising of twelve questions related to the experiment “Artificial fog” (formation of the ammonium chloride). Our aim was to find out whether the methodological design of the experiment, macroscopic representation and explanation with the help of the animation, do contribute to the easier understanding of the experiment. In more detail, we wanted to know whether the students would identify the main steps and characteristics of the experiment, whether they would be capable of following the animation, and would take notice of the elements important for the theoretical understanding. The testing samples were made of 28 first-grade high school students (age 16) and 11 primary school students (age 13 and 14). Answers to five questions will be presented here.

The first question was checking the general opinion about the selected experiment. The majority of students found the presentation on the two levels helpful, and also found the approach interesting. Only a few answered that they didn't need the animation to understand the process on the microscopic level.

Question 1: The presentation of the experiment on macro- and sub-microscopis level is important because:

a. it is easier to follow the experiment
b. it is easier to correlate the results with the theory
c. it enables better visualization of the experiment
d. such presentation is more interesting
e. we can observe models of the particles, involved in the experiment

f. I don't need animation to visualize the experiment on the level of particles

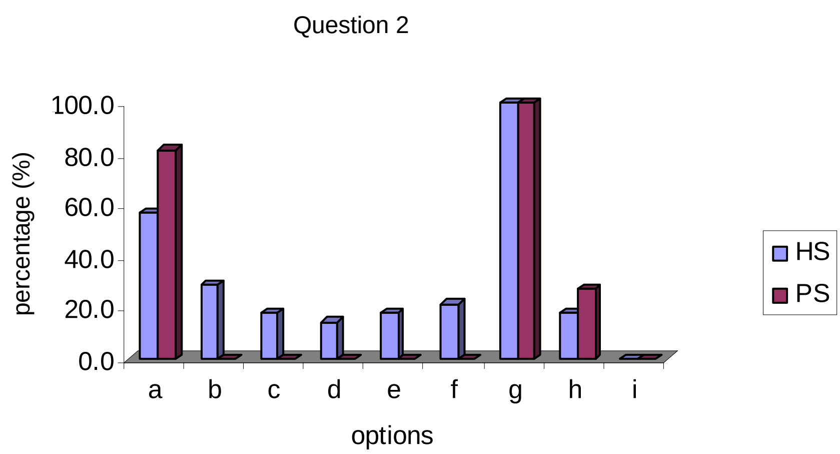


Picture 7. Summary of answers to Question 1

Observations on the macroscopic level were tested with the second question. All students noticed that the reaction product is being formed without the two filter papers coming into contact. This observation is crucial for understanding the reaction mechanism. Fewer students found it important that the reagent solutions were applied to two separate filter papers. Five students found safety equipment to be a key element of the experiment.

Question 2: What are the basic observations of the experiment at the macroscopic level:

a. few drops of HCl acid and conc. ammonia are added to two separate filter papers
b. filter paper is used as a support for the reagents
c. the experimentator holds filter papers with tweezers
d. we see the hand of the experimentator
e. the filter papers are spherical
f. the papers are white
g. the “fog” is formed between and around the papers which are not in the direct contact
h. the experimentator wears protective gloves
i. the experimentator uses a glass dropper

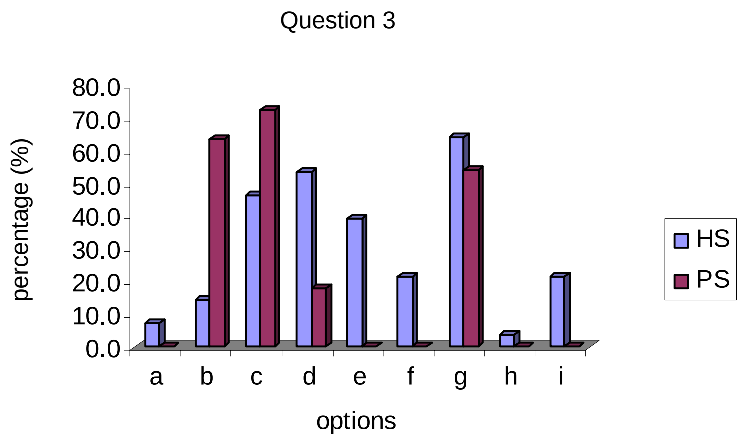


Picture 8. Summary of answers to Question 2

Student observations on the sub-microscopic level in the answers to Question 3 are dispersed. The highest number correctly identified the formation of the crystal structure. Fewer students noticed the geometry change following the proton transfer. Some students stated incorrectly that the new partcles form a molecule. The mixed results can be explained by the fact that animations were a novelty for students, as opposed to experiments where they had more experience in observation.

Question 3: Define the basic observations during animation of the reaction at the level of particles.

a. the model of the nitrogen atom is blue, and the chlorine atom is green
b. the model of ammonia has four atoms, while the model of hydrogen chloride has two atoms
c. the molecule of hydrogen chloride gives protone to the molecule of ammonia,
d. upon the addition of the proton, the form of the ammonia molecule changes
e. the radius of the chlorine model increases
f. the new particles form a molecule
g. the new particles form a crystal lattice
h. the particles in the crystal lattice of the product are randomly distributed
i. the particles in the crystal lattice vibrate



Picture 9. Summary of answers to Question 3

The fourth question was checking the role of interactive exercises (tasks). These proved helpful in the majority of cases. Still, a few of students found them redundant.

Question 4: Your opinion on interactive tasks:

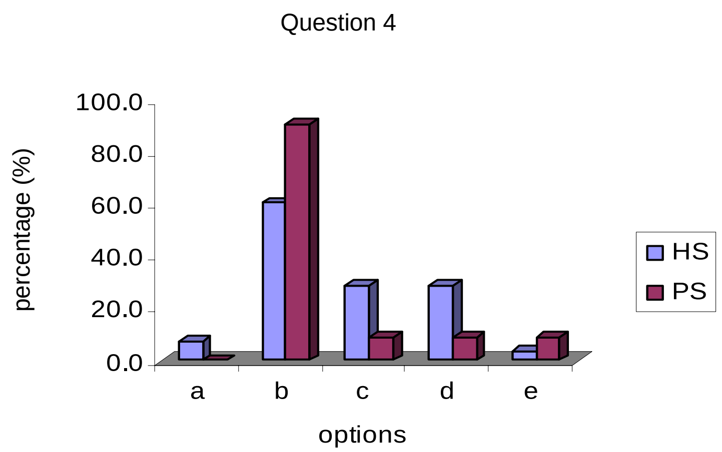
a. I solved all of them in my first trial.

b. They helped me to follow and to understand the experiment better.

c. I had problems with open-ended questions.

d. I solved less than half of the tasks without problems.

e. I think that interactive tasks are not necessary, it is more interesting just to observe experiments and animations.

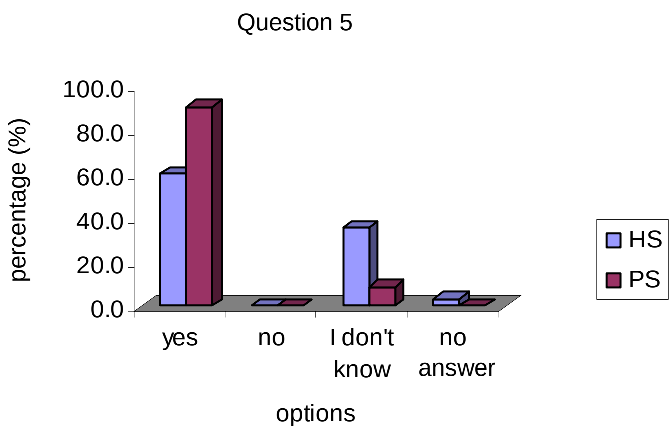


Picture 10. Summary of answers to Question 4

The overall educational value of the approach was tested by the fifth question. Most students are convinced that ours is the way forward, but several of them remain undecided.

Question 5: Do you think the approach presented through this experiment would help you better understand chemistry?

YES NO I don't know



Picture 11. Summary of answers to Question 5

Conclusions

From the students' answers to the questionnaire we can conclude that the didactical foundations of the virtual interactive laboratory are appropriate. The correlation between the macroscopic and sub-microscopic level contributes to the increased understanding of the reaction on the particle level. In accordance with our expectations it was easier for the students to identify the key elements in the video of the experiment, while on the sub-microscopic level they lack experience with this type of tasks. More such examples are needed to improve their skill.

Further development

We would like to include more experiments and translate all the content into English. We will strive towards greater interactivity. The most important task is to ensure further evaluation of the materials developed.

Acknowledgement

We wish to thank the Ministry of Education, Science and Sport of Slovenia for financial support to the project. We are also grateful to the students and teachers from II. Gimnazija Maribor and Primary School Bičevje, Ljubljana for their participation in the initial evaluation.

References

MacFarlane, A., 1998: Information, Knowledge and Learning. *Higher Education Quarterly*, vol. 52, no. 1, pp. 77-92.

Wilson, A. W., 2001: Information literacy: fluency across and beyond the university. In: *Library user education: powerful learning, powerful partnership*. Lanham, London: The Scarecrow Press, pp. 1-17.

A vital role for 'uncertainty' in the learning of chemistry by both teachers and students

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Introduction

This paper represents a development from the papers I delivered at earlier ECRICE meetings – from Pisa (1993) onwards – all of which focused on the learning of chemistry by teachers and trainee teachers. These papers examined in some detail the understandings of graduate trainee science teachers with regard to very basic science concepts such as chemical bonding, evaporation and boiling. These studies also developed my interest in my own understandings of what seemed to be very basic chemical phenomena since it was clear to me that my own ideas were still developing. Sharing these new (for me) perspectives with others – at ECRICE and elsewhere – has demonstrated that some of the ideas are controversial and colleagues, both chemistry teachers and chemists, hold a range of alternative conceptions that are at least as broad as those of the students we teach.

The 'science' questions that are summarized in this paper include:

- Are fizzing drinks examples of boiling solutions?
- Does salt melt when it dissolves in water?
- How can we explain that, *within* a galvanic cell the current flows such that electrons are transferred *to* the electrode labeled negative *from* the electrode labeled positive?

My answer to the first two questions is 'yes' although both are still open for discussion. The third is the subject of a poster that I also hope to present at this 7th ECRICE. In this case *my qualitative explanation* has generated comment and criticism that undermines *my* understanding of electrical conduction through electrolyte solutions and creates considerable personal uncertainty. The three questions are reviewed briefly below:

1. Are fizzing drinks examples of boiling solutions?

This question is now fairly well documented (Goodwin & Orlik 2000; Goodwin 2001) as is a full description of the research that led to this insight (Goodwin 2003a) Essentially the question arose whilst investigating graduate science trainee teachers' understandings of evaporation, boiling and systems involving 'bubbling'. A number of scenarios were introduced involving free evaporation;

forced evaporation, 'normal' boiling; boiling under reduced pressure; and opening cans of carbonated drinks before and after shaking. In all examples where bubbles were involved the question was asked 'Is this boiling?' In the last example the question seemed initially to be silly – since clearly fizzing drinks are not boiling. However, on second thoughts, carbonated drinks *are* solutions of carbon dioxide and flavours in water. A requirement for the formation of bubbles is that the saturated vapour pressures of the volatile components – mainly water and carbon dioxide – *together* equal the external pressure. This is the standard definition of 'boiling' for any solution. (When in a bottle or can under pressure aqueous solutions containing substantial amounts of carbon dioxide are well above their boiling points at normal room temperature, c.f. water in a pressure cooker well above 100^{o}C. The 'escape' of carbon dioxide, with a little water, as carbonated drinks 'go flat' in an open container is an example of fractional distillation.)

This still does not convince everyone (and some would like to confine the idea of boiling to something that only pure liquids do – if this were to become the definition then clearly solutions could not boil – but then solutes could not cause elevation (or depression) of boiling points.) Some however are so sure that the very idea is rubbish that they almost become abusive. My favourite example is the comment from an anonymous reviewer of my paper (Goodwin 2001) who opined:

"General evaluation: F Not suitable for publication (d) Contains errors

The beverage has been carbonated at a pressure of CO_2 higher than the normal atmospheric pressure. This follows Henry's law:

$$m_2 = k_2 P_2$$

where *m_2 = mass of gas dissolved; P_2 = pressure of gas; k_2 = Henry's law const.*
The gas under the bottle cap is then CO_2 saturated with H_2O vapor. When the cap is removed the liquid degasses until it is at equilibrium with the CO_2 partial pressure in the air. This is a relatively slow process since CO_2 dehydration kinetics are slow.
This has nothing to do with boiling. The boiling point of a liquid is reached when the vapor pressure of the liquid equals atmospheric pressure. This will be higher than 100^{o}C because of the boiling-point elevation caused by the dissolved substances in the soda pop.
This paper is absolute nonsense and must not be published.

Clearly s/he was very sure of the chemistry but did not perceive carbon dioxide as a solute in the solution? The answer to the question may still be 'No' but surely there is *some* uncertainty?

2. Does salt melt when it dissolves in water?

The words 'dissolve' and 'melt' are usually carefully distinguished, at least in science classes, in the primary school. Although not always clearly articulated, the difference seems to be (Driver et al 1994) that whilst both represent transition from the solid to the liquid state melting is something that occurs with a single substance whereas dissolving requires the presence of a second liquid substance (usually water) in which the solid (solute) can dissolve. (Early understandings may imply the need for the addition of heat energy – or high temperature – for melting although not for dissolving, but this is blurred by the fact that water is often heated to increase the *rate* with which solids dissolve in it.

At a more sophisticated level it seems to become more difficult to distinguish between the two terms. Chemists certainly do not restrict the term 'melting' to the liquefaction of pure (single) substances. Concepts such a 'freezing/melting-point depression', 'eutectic mixtures', 'alloys' and 'phase diagrams' all relate the idea freezing/melting temperatures to systems with multiple components. This is explored in more detail in a paper (Goodwin 2002) however, *if school science teachers are so sure that it is* ***wrong*** *to say* that 'salt melts in water', it seems to me that this *may* inhibit students' learning at higher levels. I do not take this to mean that distinctions should not be made but that meanings should (always?) retain a degree of *uncertainty* such that critical re-examination of that meaning in different contexts is encouraged or required. (In fact specialized scientific language does not easily transfer into the 'real world' – so despite my now firm belief that fizzing drinks *are* boiling solutions (1-above) I tend not to use the term in conversation or when ordering in restaurants unless I wish to promote discussion!)

From a pedagogical perspective however, the suggestion made above is controversial and some people are sure I am wrong. Once again an anonymous reviewer of my manuscript for (Goodwin 2002) provides some of the evidence (partially reproduced below):

> *"… Not only do I* ***not*** *believe that careful terminology will "*constitute a barrier to subsequent chemistry learning", *but I consider it the obligation of teachers to impart to their students valid science unsullied by the fuzziness of everyday speech.*
>
> It seems to me that this manuscript addresses a problem that does not exist, but a problem will be created if the message of the manuscript is followed. I do not recommend publication."

I *think* my argument is that 'fuzziness' to some degree is absolutely inevitable and as any word, especially one that relates to a complex idea, moves from author/speaker to a recipient the word does not necessarily carry a constant meaning with it. This therefore requires an appropriate critical reexamination to check that the *meaning* received is compatible with the meaning transmitted. This is a tall order even (especially) in international diplomacy and politics but in teaching generally and science teaching in particular the meanings of words and connections between concepts expressed by the words develop and change with the experience and maturity of the individual – as well as the developments, priorities and fashions within the scientific community. If only '*valid science'* could be "*unsullied by the fuzziness of everyday speech."*

3. How can we explain that, *within* a galvanic cell the current flows such that electrons are transferred *to* the electrode labeled negative *from* the electrode labelled positive?

This question came to my notice some forty years ago when a student (aged 17) asked me how it was that copper ions inside a Daniell cell are deposited on the copper (the positive) electrode when electric current is allowed to flow from/through the cell. At that time we negotiated an answer although this largely ignored the point that the copper electrode is positively charged relative to the zinc electrode. The explanation entailed noticing that the electrons flow, via the external circuit, from the zinc to the copper and thus *in the attempt to restore the equilibrium* in the electrode compartment (the electrode potential of the copper) it is necessary for positively charged ions to be deposited to restore the positive charge (or remove the excess of electrons)

Recently I have attempted to develop my understandings of this process further – to the annoyance and exasperation of colleagues who specialize in electrochemistry – and this is the subject of my Poster at this ECRICE.

A simple qualitative explanation is probably out of the question but some of the very basic problems I have noticed (or been made aware of) for the first time include;

(a) If the electrodes of any cell are labelled respectively (+) and (-) it is *logically impossible* for the processes of electron transfer to be from – to + in both the external circuit (the direction conventionally defined (by physicists) and within the cell (where the chemistry takes place).

(b) When no current flows – an 'electric double layer' of ions (definitely a 'fuzzy' concept) totally insulates the electrodes such that the ions within the bulk of electrolyte solution experience no force from the charged metal electrodes. This also implies that the bulk of the electrolyte solution in uncharged, with equal numbers of + and – ions in any small volume (It is not clear to me how this double layer 'transmits charge' when the current flows. Clearly it is no longer at equilibrium and presumably an electric potential within the electrolyte solution must cause migration of ions?)

(c) As the current flowing in the circuit increases significant concentration gradients of ions build up within the cell such that diffusion processes limit the current. (This requires a distinction between ion movement due to concentration differences – *diffusion* – and ion movement due to an electric potential gradient – *migration*. I have yet to sort out for myself a convincing qualitative picture that adequately describes the interplay between these two processes – nor can I find one in the literature. It seems clear however that (i) whenever there is an electric potential gradient there will be consequent ionic movement (drift) and (ii) that diffusion cannot of itself lead to charge transfer.

(d) There is a clear conceptual problem in using and separating concepts that are appropriate for a system in equilibrium from the dynamic system that exists when chemical reactions are proceeding.

(e) I am now experiencing more uncertainty than I expected (a sign of learning – or 'antiquity'?)

An interim description of my developing qualitative picture can be found in (Goodwin 2003b) but it does not address the remaining questions given above.

Conclusion

It is not in any way my intention to suggest that chemists, chemistry teachers and their students should not 'know and understand' their subject as well as possible. On the contrary they should extend their explanations and understandings as far as they are able in ways that are accessible to their students and acceptable to themselves, their peers and experts. However, the evidence is that there is inevitably some uncertainty in the understandings and explanations of aspects of chemistry that any of us holds individually and that these uncertainties increase rapidly when we seek to pass them on to others (our students).

This paper argues that these uncertainties need to be recognized and students encouraged to maintain a critical stance towards the sense and consistency of the information they receive from their teachers and other 'authorities'. This is problematic for a number of reasons that are summarized below;

- Teachers need confidence to encourage questioning and the 'system' does not always legitimate this.
- The 'system' often requires and rewards 'right answers' without allowing critical evaluation or exploration of ideas.
- Students often 'only' want to pass the examination – it is much more difficult for them to become and remain enthusiastically and intellectually involved with the chemistry they are learning.
- When teaching competence is 'measured' by student's examination success the previous point is significantly magnified.
- Science is perceived *only* as the facts to be learned rather than including ideas to be explored and actions to be evaluated.

None of this is easy and *there is need for balances to be achieved*. However, *some* uncertainty seems to be a necessary condition for intellectual engagement since, when we are certain, questioning stops? Of course, too much uncertainty undermines the sense and motivation for learning from any source beyond personal experiences – and purposeful, critical reference to specialists, experts, teachers and authoritative texts *really can* be useful.

Other science educators also value uncertainty. Richard Feynman for instance:

> *"I feel a responsibility to proclaim the value of this freedom to teach that doubt is not to be feared, but is to be welcomed as the possibility of a new potential for human beings. If you know you are not sure you have a chance to improve the situation. I want to demand this freedom for future generations.* p. 28. (Richard Feynman (1963) - published 1998.)

Moreover, in the past science teachers and scientists have laid immense value on certainty. It now seems clear that to be effective and useful in the 'real life' worlds of technology, conservation, environment and other global concerns science and education in science need to embrace an *appropriate* amount of uncertainty. A possible strategy is indicated in Matthews' (2002) review of Peat's (2002) book:

> *'Peat suggests that we might adopt one of Nature's preferred strategies, and encourage diversity in both thought and action wherever possible. A strategy that has served Nature well enough for a few billion years would seem as good as any.'*

Of course, this was aimed at scientists and science rather than teachers and science education, but at a time when we are focusing on 'subject standards' it may be that we have underemphasized the flexibility, negotiation, variety and wonder required to engage students (and teachers) in learning science. In reality the human condition on our small planet is terribly complex and ultimately uncertain.

The *relatively* predictable and easily examinable (although, not necessarily 'common sense' or easily understood) basic science that forms much of the school curriculum is important, but the contexts in which such science ideas are really applied are essentially complex and uncertain. Links to this uncertainty must be made especially when in real life; ethical, moral, economic, religious and cultural dimensions enter the equation. Just because something is known or can be done does not mean that it *should* be done or, even if it is desirable, that it has priority over other desirable actions. Even in the less contentious aspects of basic science *some uncertainty* gives room for improvement. It legitimizes each student's intellectual engagement with his/her own ideas and those being promoted by the teacher. It requires them to seek out, to examine and to evaluate evidence – and to question authority. It promotes debate with peers and teachers. Teachers need to contend science with their students and convince them, rather than tell them. This will require substantial knowledge and skill and a little humility. Overall it gives *learning precedence over knowing.* Less certainty would, *almost certainly*, be more educational for all engaged in the learning and teaching of science.

(A paper on this subject has recently been published (Goodwin 2004).

References

Driver R, Squires A, Rushworth P, Wood-Robinson W. (1994) '*Making sense of Secondary Science: Research into Children's Ideas'* Routledge, London & New York.

Feynman R P, (1963) Published 1998. *The Meaning of It All; Thoughts of a Citizen-Scientist.* Reading, Massachusetts, Addison-Wesley

Goodwin A & Orlik Y (2000) 'An investigation of graduate scientists' understandings of evaporation and boiling.' *Revista de Educación en Ciencias* 1 (2) pp 118-123.

Goodwin A (2001) 'Fizzing Drinks, are they boiling?' *Journal of Chemical Education* 78 (3) pp. 385-387.

Goodwin A (2002) 'Is Salt Melting When It Dissolves in Water' *Journal of Chemical Education*, 79 (3) pp. 393-396.

Goodwin A (2003a) 'Evaporation and Boiling – trainee science teachers' understandings.' *School Science Review,* **84** (309) pp 131-141.

Goodwin A (2003a) 'Conceptual understanding of Electricity: galvanic and electrolytic cells' a letter in *University Chemical Education.* **7** p59.

Goodwin A (2004) 'A Case for Some Uncertainty in Science Education.' *Revista de Educación en Ciencias* **5** (2) pp 84-86.

Matthews R (2002) 'The way it sort of is' a review of '*From Certainty to Uncertainty'* by Peat F D, in *New Scientist No.2345 1st June, p54*

Can the Periodic Chart of the Elements be Extended to Molecules?

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One imagines each compartment of the periodic chart as a window that may be opened to reveal all possible molecules and their ions, in all desired phases, containing the atom shown in the compartment. If these multitudes of species are arranged such as to show their periodicity, then the arrangement is a periodic system of molecules.

Periodic classifications of molecules have proven of intense interest to undergraduate students at our university in the last 27 years, with 42 students taking part in researching them and 21 being co-authors of scientific papers. The systems make it possible to predict molecular properties.

These systems bear the same relation to the chart of the elements as do diagrams of hadron particles to the diagram for the three (or four) lighter quarks, thus showing an underlying unity in nature.

The periodic chart of the elements has been likened to the scale of musical notes; the periodic system of diatomic molecules enables us to sing in two-part harmony!

Chemical periodic systems typically involve molecules with various numbers of atoms, as they exist at STP, and place the molecules on a flat surface. Examples are Dias's charts of polycyclic aromatic hydrocarbons[1] and Haas's system of functional groups[2].

Physical periodic systems typically include molecules with just two, or three, or more atoms; include, in principle, all of them; are multi-dimensional; and are more closely based on the chart of the elements. One such system is the outer matrix-product system developed at our university,[3,4] which subsumes the beautiful charts proposed by Boldyrev, Gonzales, and Simons[5,6] and by Kong.[7] The matrix-product system has made it possible to predict large numbers of molecular data with the use of neural networks and least-squares.[8,9]

The other physical system is based on bosonic group-dynamics. It was originally proposed in 1983 by Zhuvikin and has been developed jointly with St. Petersburg University and ours.[10]

An all-embracing "hyperperiodic" system, including most of the previously published systems and also building on an emergent property of molecules, has been proposed by

Babaev.[11]

References

[1] Dias, J.R., 1996. Formula Periodic Tables -- Their Construction and Related Symmetries. *J. Chem. Inf. Comp. Sci.* 36 pp 361 - 366.

[2] Haas, A. 1982. A new classification principle: the periodic system of functional groups, *Chemicker-Zeitung* 106 pp 239 - 248.

[3] Hefferlin, R., 1994. Matrix-product Periodic Systems of Molecules. *J. Chem. Info. Comp. Sci.* 34 pp 313-317.

[4] Hefferlin, R., G.V. Zhuvikin, K.E. Caviness, and P.J. Duerksen, 1984. Periodic Systems of N-atom Molecules. *J. Quant. Spectrosc. Radiat. Transfer* 32 pp 257– 268.

[5] Boldyrev, A. I., Nick Gonzales, and Jack Simons, 1994. *J. Phys. Chem.* 98 pp 9931-9944.

[6] Boldyrev, A.I. and J. Simons, 1997. Periodic Table of Diatomic Molecules (wall charts A, B, and C). JohnWiley & Sons.

[7] Kong, F.A., 1982. The periodicity of diatomic molecules. *Journal of Molecular Structure*, 90 pp 17 - 28.

[8] Hefferlin, R., W. B. Davis, and J. Ileto, 2003. An Atlas of Forecasted Molecular Data I: Internuclear Separations of Main-Group and Transition-Metal Neutral Gas-Phase Diatomic Molecules in the Ground State. *J. Chem. Inf. Comp. Sci.* to be published.

[9] Carlson, C.M., J. Gilkeson, K. Linderman, S. LeBlanc, and R. Hefferlin, 1997. Global Forecasting of Data using Least-squares Methods and Molecular Databases: a Feasibility Study using Triatomic Molecules. *Croatica Chemica Acta* 70 pp 479 – 508.

[10] Carlson, C.M., R.J. Cavanaugh, G.V. Zhuvikin and R.A. Hefferlin, 1996. Periodic Systems of molecular States from the Boson Group Dynamics of $SO(3)\mathrm{x}SU(2)_s$. *J. Chem. Inf. Comp. Sci*. 36 pp 396 - 389.

[11] Babaev, E.V. and R. Hefferlin 1996. The Concepts of Periodicity and Hyper-periodicity: from Atoms to Molecules, in Rouvray, D.H. and E.C. Kirby, Concepts in Chemistry, Research Studies Press Limited, Taunton, Somerset, England, pg. 62.

Microscale electrochemistry with Disposable Materials

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1 Introduction

Microscale Chemistry Experimentation (MCE) was introduced into research work by *Pregl* in 1910 by performing a quantitative analysis of the elements C and H using only 7 – 11 mg of an organic compound [1]. In 1923 the Noble Prize for chemistry was awarded to him [2]. The founder of microchemistry at university was Friedrich *Emich* [3].

At school level MCE means practical working with substances in the volume range between 5 and 0.05 mL (1 drop). MCE saves chemicals, waste, space, time („didactic money“) and energy. Quantities of less than 5 mL increase safety, allowing home experimentation [4], [5], [6] thus supporting creativity and self-confidence even of anxious girls and boys.

At the end of the eighties MCE appliances for electrolysis of brine were introduced into pre-service training by *El-Marsafy* [7] [8]. *Slater et al* [9] and *Skinner* [10] used disposable plastic pipettes, needles, pencil leads and neutral electrolytes to design different types of microscale Hofmann Apparatus. *El-Marsafy* and *Schwarz* [11] made Galvanic and Electrolytical Cells from pieces of a Cola can, pencil leads, 1-mL blisters and 2-mL injection bottles. Zhou [12] introduced a small and cheap plastic container with six 5-mL wells („wellplate6“) into schools and colleges of China: With a 2-mL plastic pipette pierced by two hypodermic needles and a 9 Volt battery enough oxyhydrogen gas can be made and transferred into a well for a safe explosion every minute [13].

Livneh [14] promoted MCE in high schools and middle schools of Israel by in-service training and by publishing a Microscale Lab Manual [15]. The results of their cooperation the authors recently presented to 25 participants of a workshop at the 7. International Chemistry Teacher Congress in Linz / Austria [16].

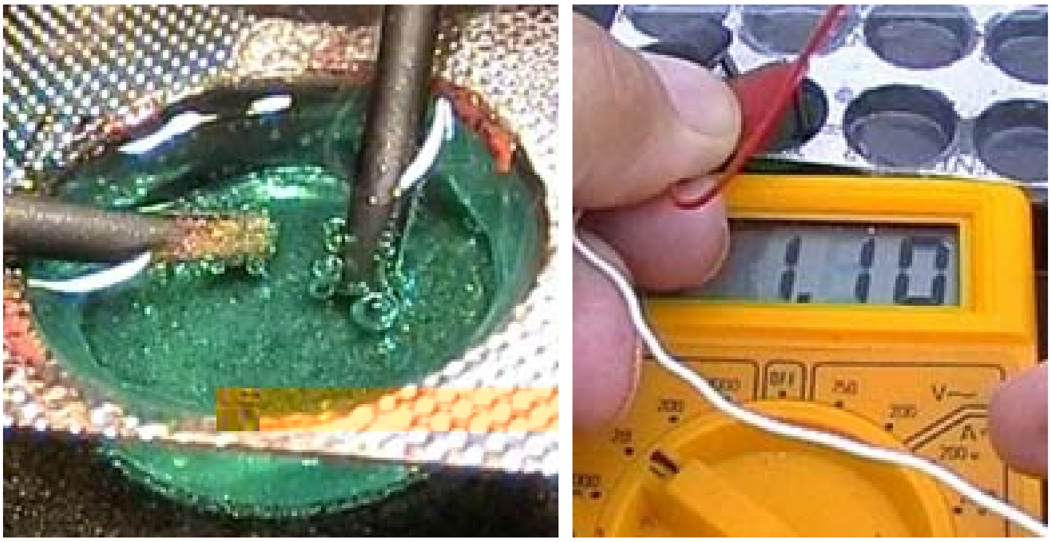
2 Experimental

Experiment 1: Electrolytic and Galvanic Cells in a blister

Materials

Blisters (1-mL), plastic pipette, 9-Volt battery, 2 short pieces of pencil lead, 2 insulated wires with crocodile clips, digital multimeter, dropper bottles with conc. HNO_3 and with salt water (brine), 1 mm of very thin copper wire.

1. In a blister add a drop of conc. HNO_3 to a 1-mm-thin piece of copper wire.
2. After 1 minute fill up with brine and mix using the pipette.
3. Connect the battery with the pencil leads, dip them into the solution for 2 minutes.
4. Replace the battery by the digital multimeter. Measure the voltage.
5. Write down all your observations.

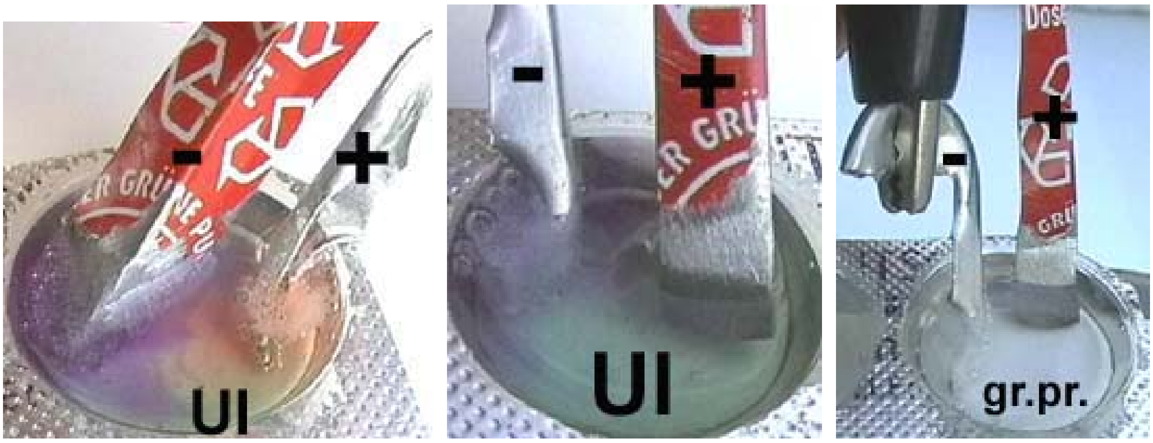


Photos 1. Electrolysis of $CuCl_2$ and the resulting Galvanic Cell

Experiment 2: Electrolysis of brine in a blister using Cola can metals as electrodes

Materials

Blisters (1-mL), 9-Volt battery, 1 x 3 cm pieces of a cola can (Fe), half of cola can closure, 2 insulated wires with crocodile clips, sandpaper, 5 dropper bottles containing: salt water (brine), universal indicator solution, solutions of potassium permanganate, potassium hexacyanoferrate(II), ammonium thiocyanate.



Photos 2. Electrolysis of salt water with aluminium anode (**1**) and with iron anode (**2** and **3**)

<u>Experiment **2a**</u> (**1)**: Electrolyse salt water and one drop of universal indicator solution (UI) in the cavity of a blister packing. Use the sanded piece of cola can metal (Fe) as negative electrode, the closure of the can (Al) as positive electrode. A strong flow of gas bubbles is observed at the Fe cathode. The green colour of UI turns to violet (alkaline).

Reduction: $4\ H_2O(l) + 4\ e^- \rightarrow 2\ H_2(g) + 4\ OH^-(aq)$

At the Al anode fewer gas bubbles come out, the green colour of UI turns to red (acidic).

Oxidation: $2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4\ e^-$

Redox reaction: $2\ H_2O(l) \rightarrow 2\ H_2\ (g) + O_2\ (g)$

Verification of this interpretation: The liquids around the two electrodes are mixed after the end of the electrolysis: The colours of UI return to green again. This proves that equivalent quantities of hydroxide and of hydronium ions have developed during cathodic reduction and anodic oxidation.
These ions neutralized each other during mixing

<u>Experiment **2b**</u> (**2** and **3**):

In this experiment the polarity of the electrodes is exchanged: the sanded piece of cola can metal (Fe) is used as the positive electrode, the closure (Al) as negative electrode. Both are dipped into the cavity of the blister packing with salt water + UI again.

Gas bubbles are observed at the negative electrode (Al). The colour of the UI changes to violet. (alkaline).

Reduction: $2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq)$

No gas is observed at the positive electrode (Fe), the UI remains green.

Oxidation: $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

Total reaction: $2\ H_2O(l) + Fe(s) \rightarrow Fe^{2+}(aq) + 2\ OH^-(aq) + H_2(g)$.

Verification of this interpretation:

This electrolysis is repeated without UI. The liquids around the electrodes are mixed:

A green slimy precipitatate (gr. pr.) appears:

$Fe^{2+}(aq) + 2\ OH^{-}(aq) \rightarrow Fe(OH)_2(s)$

By adding drops of diluted sulfuric acid this precipitate disappears:

$Fe(OH)_2(s) + 2\ H^{+}(aq) \xrightarrow[\text{neutralisation}]{} Fe^{2+}(aq) + 2H_2O$

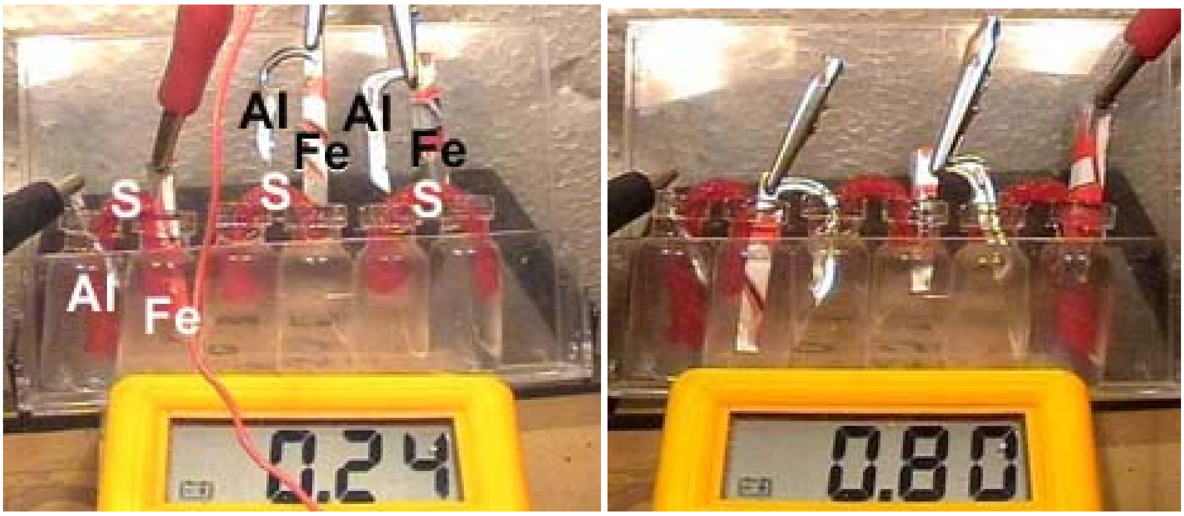
Drops of $KMnO_4$ solution lose their colour showing that Fe^{2+} ions were present:

$5\ Fe^{2+}(aq) + MnO_4^{-}(aq) + 8\ H^{+}(aq) \xrightarrow[\text{direct redox}]{} 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O$

In order to test for iron(III) ions, two drops of the solution are transferred into two other cavities of a blister. One drop of potassium hexacyanoferrate(II) solution is added to sample 1: A blue precipitate is observed. One drop of ammonium thiocyanate solution is added to sample 2: A red brown colour appears.

Experiment 3: Galvanic Cells made from can metals in 3-mL bottles with salt bridges

Materials: Music cassette box as stand, 6 injection bottles (3 mL) full of salt water (brine), 3 sanded and folded pieces of Cola cans (Fe) and 3 pieces of can closures (Al) fitting to these bottles, 2 insulated copper wires to connect with a digital multimeter, 2 crocodile clips for connections between Al and Fe electrodes of neighbouring Galvanic Cells, 3 red wool threads (S) as salt bridges between the Al and Fe half cells.



Photos 3. Potentials between Cola can closures (Al) and Cola cans (Fe) in 3 Galvanic Cells

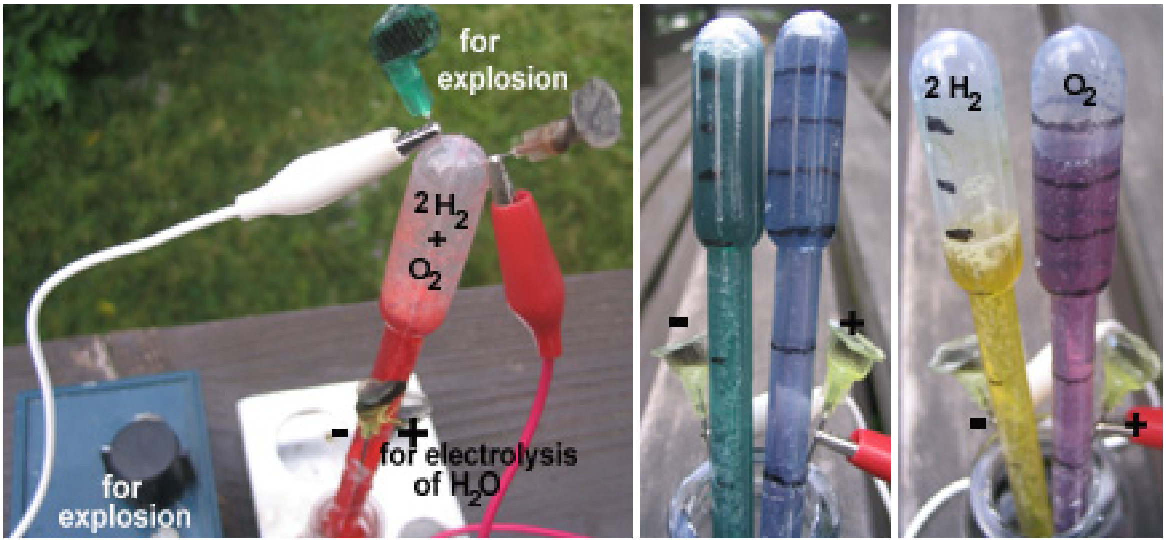
Experiment:

1. Connect an Al and an Fe half cell by a salt bridge (S) and by a multimeter.
2. Make batteries by connecting 2 and 3 of these Galvanic Cells in series.

Left: The potential of the single Galvanic Cell is 0.24 Volt. (No photo: 2 cells in series are 0.51 V)
Right: The potential of these 3 cells in series is 0.80 Volt.

Experiment 4: Microscaled water electrolysis with new options

Materials: Three plastic pipettes with 3-mL graduations and with 5 mL balls, 4 long and 6 short hypodermic needles, pliers, matches, candle, two insulated wires with crocodile clips, 9-Volt battery, spark giver, injection bottle 10 mL, infusion bottle 50 mL, 5-mL syringe with long blunted hypodermic needle, conc. sodium sulfate solutions with red colour (for 1) and with red cabbage extract (for 2, 3).



4. Volumetric explosion of oxyhydrogen gas, microscaled Hofmann Apparatus + red cabbage juice

Experiment:

1. Close the 10 hypodermic needles by compressing their heated plastic ends.
2. Pierce the <u>pipette for the left photo</u> with 2 long needles in the lower part (for electrolysis) and with 2 short needles in the upper part (to ignite the oxyhydrogen gas collected during electrolysis).
3. Use the syringe to fill this pipette with electrolyte, dip it into an injection bottle with electrolyte.
4. Connect the lower electrodes with the battery for electrolysis, collect 5 mL gas in the ball.
5. Remove the battery, connect the spark giver with the upper needles. Ignite the gas while pressing the pipette down. (As oxyhydrogen gas disappears and only a tiny quantity of water is formed A NEGATIVE PRESSURE will suck the electrolyte upwards).
6. Pierce each of the <u>two pipettes for the microscaled Hofmann Apparatus</u> with ONE long needle in the lower part (for electrolysis) and with two short needles in the upper parts.

7. Totally fill both pipettes with electrolyte + red cabbage extract using a syringe.
8. Dip these pipettes into an infusion bottle with 10 mL electrolyte.
9. Connect the electrodes with the battery for electrolysis, collect 4 mL gas in the cathode side.
10. Write down your observations. Exchange the polarity, go on with electrolysis until equal volumes are obtained. Repeat Nr. 5.

Explanations:

In the microscaled Hofmann Apparatus (photos 4 b and c) the following reactions take place in different pipettes resulting in a volume ratio of 2 to 1 for the two gases:

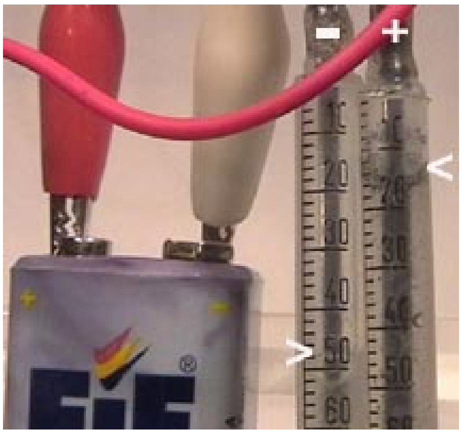
Cathodic reduction: $4\ H_2O + 4\ e^- \rightarrow 4\ OH^-(aq) + 2\ H_2(g)$

Anodic oxidation: $2\ H_2O \rightarrow 4\ H^+(aq) + O_2(g) + 4\ e^-$

Redox reaction: $6\ H_2O \rightarrow 2\ H_2(g) + O_2(g) + 4\ H^+(aq) + 4\ OH^-(aq)$

The hydroxide ions react with anthocyanins of the red cabbage forming a green colour which later changes to yellow. The hydronium ions transform the blue colour into red.

Experiment 5: Microscaled Hofmann Apparatus with pencil leads in insulin syringes



Left: Thick pencil leads are welded into 2 Insulin syringe cylinders as electrodes. Sodium sulfate solution is transferred into the cylinders and into a wellplate6. Electrolysis results in 48 units and 18 units of gases in the negative and in positive cylinders.

Middle and right: The electrolytic cell is connected with a multimeter measuring 1.826 mA and 2.04 V.

The power of this rechargeable Galvanic Cell is enough to light up a LED.

The Standard Reduction Potentials [$O_2 + 4\ H^+ + 4e^- \rightarrow 2\ H_2O$ and $2\ H_2O + 2e^- \rightarrow H_2 + 2\ OH^-$ are 1,23 – (0,83) V (2,06 V)]

3 Discussion

Microscale electrochemistry with pencil leads, injection needles or Cola can metals as electrodes, brine or Glauber salt as electrolytes, blisters, injection bottles, pipettes or syringes as cell containers and batteries or AC/DC adapters as power supply are useful tools for student experiments outside labs, schools or even houses. With a camera or an OH projector students might even be able to demonstrate their experiments to all their school mates and teachers.

Microscaling of experiments is no alternative to classical demonstration experiments:

- To test for oxygen and hydrogen in a Hofmann Apparatus small scale versions [20, 21] are needed.
- For demonstration experiments the classical Hofmann Apparatus with sulfuric acid as electrolyte is irreplacable for more than one reason.
- To measure standard potentials special appliances are necessary.

For didactic reasons it is indispensable to supplement demonstration experiments with student experiments. Many reasons for microscaling these activities are mentioned in the introduction.

4 Literature

[1] *Helmut Gekle*, Gestatten: Pregl, Fritz Pregl! Nobelpreisträger, Professor für medizinische Chemie, Tischler, Schlosser und Glasbläser http://www.kfunigraz.ac.at/ainst/uz/494/4-94-08.html

[2] http://www.nobel.se/chemistry/laureates/1923/press.html

[3] über Friedrich Emich http://www.aeiou.at/aeiou.stamp.1990.90012a

[4] *K. Wloka, K*., Heimexperimente, Unterricht Chemie **13** (70/71), 54 – 56 (2002)

[5] *P. Schwarz, M.K. El Marsafy*, Geräte zum Experimentieren im Kleinmaßstab, Unterricht Chemie **13** (70/71), 96f (2002)

[6] *Schwarz, P,* Weniger ist mehr, Mikrochemische Heimexperimente. in: Friedrich Jahresheft XXI, 2003, S.53-55

[7] *M.K. El-Marsafy*, www.microchem.de/chemarsafD11.html (1989)

[8] *M.K. El-Marsafy et al*, The microscale chemistry laboratory technology its implications on the future education. Symposium on Sciences and Engineering Education in the 21st Century. Book of Abstracts, 18 – 20 Cairo American University 1995

[9] A. *Slater, G.Rayner-Canham* in: Laboratory Manual. Addison-Wesley Publisher Limited Don Mills, Ontario 1994

[10] *The American Chemical Society,* "Hoffman apparatus". Chemunity News 1994cited from J. Skinner (editor) Microscale Chemistry. Royal Society of Chemistry 1997

[11] *M.K. El-Marsafy, P. Schwarz*, Mikrochemisches Experimentieren mit Pfennig und Dose, CHEMKON 9 (3), 147 –49 (2002)

[12] *Zhou Ning Huai*, www.microchem.de/zhouninghuairev.html

[13] *P. Schwarz*, www.microchem.de/linzDE14.html

[14] *M. Livneh,* www.microchem.de/dyes.html

[15] *M. Livneh,* Microscale Lab. Manual (hebräisch) 320 S. (hebräisch) Bar Ilan University 2002

[19] *M. Hugerat*, *M. Livneh, Z. Livneh, P. Schwarz,* Mikrochemische Experimente für Schüler jeden Alters (Workshop on Microscale Chemistry Experimentation [MCE] for students of all ages). 7. Europäischer Chemielehrerkongress Linz 2003 in:Chemie und Schule **1a**, 63 (2003)

www.microchem.de/linzDE.html

[20] *V. Obendrauf*, Low-cost Elektrolyse von Wasser www.microchem.de/obendraufelek03.html (2003)

[21] *P. Schwarz*, www.microchem.de/sinusmicWGKE3a.html

Simulation of classical inorganic analysis on-line How do the students react?

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Abstract

The goal of this research was to investigate undergraduate chemistry students' response to and learning gain achieved from working with the SimuLab computer-based learning environment, which simulates a 20 hours laboratory assignment. The SimuLab is a cognitive tool designed to help students to acquire experimental and analytical skills on the basis of the classical qualitative and quantitative analysis scheme. Consistent with the intentions behind the design, students seemed to acknowledge the learning potential of the simulation program. They found it motivating and designed to direct attention towards the practical application of declarative knowledge. We also found that SimuLab supported students in the accomplishment of cognitive tasks and enhanced their skills in context of the investigation.

Keywords: computer-based learning environment/simulated laboratory environment, identification of inorganic compounds, cognitive tool.

Introduction

Laboratory exercises, investigations, and experiments are invariably included in university chemistry teaching. The learning of empirical facts, chemical procedures and methods in chemistry depends heavily on the experience which may be obtained from such teaching activities[1]. Experimental work in teaching is, however, both expensive and time consuming, and may often consist of students simply following a recipe as a result of their cognitive limitations.

According to cognitive theories[2] human cognitive capacity is limited. We can only pay attention to a certain amount of information and perform a limited amount of the task at any one time. If the amount of information to focus on, or task to perform, exceeds our capacity it results in cognitive overload. However, by decreasing this burden more capacity is left over to accomplish the main task. Computer-based learning environments performing lower level tasks for the learner have been shown to share the cognitive load and result in the enhancement of students learning[3]. In the lab students often struggle with procedural issues like unfamiliar laboratory procedures and measurements related to the investigation while they are expected to interpret the data obtained. Performing procedures is a lower order cognitive skill, but perturbations associated with accomplishment of this activity may interfere and diminish students reasoning.[4]

Classical qualitative and quantitative analysis of relatively simple soluble salts or co-ordination compounds with inorganic ligands only, has for a long time been part of introductory inorganic chemistry in spite of the fact that professional chemical analysis currently is far more advanced than chemical separation and identification reactions in test tubes and volumetric analysis. The reason for keeping and using such an "anachronistic" element in teaching is first of all that this type of simple and classical procedure has a great learning potential. These simple procedures facilitate students' construction of knowledge about the field in the real context. In the theoretical part of the course students are taught and acquire theoretical or declarative knowledge, i.e. knowledge about the physical and chemical properties of common inorganic compounds. In the laboratory part of the course students are supposed to put this declarative knowledge into practice by using it in the context of a realistic problem-solving task.

At Roskilde University, the introductory course includes a 20-hour laboratory investigation where simple soluble inorganic salts, in solution or in the solid state, containing common p-block anions (of B, C, N, P, O, S, halogens) and alkali metal cations and/or ammonium are identified and quantified.

The aim is

1. to increase the students' acquaintance with simple semi-micro techniques used to follow simple reactions and the principles of classical quantitative, mostly volumetric, procedures and
2. to increase the students' experience and knowledge of the physical and chemical properties of common inorganic compounds.

To pursue such aims the experimental work should be coordinated with and supported by other activities. The use of pre- and post labs has been one way of improving teaching(5,6) (and learning). A preparatory worksheet was given to the students a week before the laboratory experiment session. Working with this worksheet was a vehicle to enhance the students' pre-knowledge and to make them consider a number of important issues in relation to the experiment. It was shown that the students performed better in the post-lab activities when they had completed this type of pre-lab(5,6).

Virtual investigations(7) seem to be a promising kind of learning tool, and recently we have introduced this type of learning environment in the course.

In this paper we will describe our experience with implementation of a computer-based learning environment in the chemistry course - SimuLab.

Idea behind the interactive computer programme

SimuLab is an interactive, self-instructive simulation of the laboratory investigation and has recently been developed in this Department*.This virtual laboratory environment is an example of a

* The programme is in Danish. A demo version in English may be found at http://virgil.ruc.dk/kurser/kemiopgaver/KcO2e/index.htm

cognitive tool[3], i.e. a tool which can assist learners to accomplish cognitive tasks – in this case the identification of inorganic compounds using classical laboratory procedures. The main rationale behind the design of this learning environment was to facilitate learner's knowledge construction in a virtual laboratory environment. SimuLab presents to students a task to solve and appropriate tools such as different laboratory procedures to enable them to solve the task. It also supports students with some degree of feedback and help functions.

Performing different tests and laboratory procedures is a lower order cognitive skill. However, it is necessary for students to carry out these tests in order to collect data that enable them to predict and support (or reject) a hypothesis about the components of the investigated substances. By running simulations of the tests and laboratory procedures the SimuLab provides support for lower cognitive skills and reduces the students' cognitive load. The SimuLab can therefore promote the higher order skills required for scientific reasoning, such as the interpretation of data obtained through the investigation.

In addition, the time consuming procedures are strongly accelerated in the SimuLab environment. Rather then spending time performing procedures students can concentrate on interpretation of the results achieved through simulation of different procedures.

The SimuLab provides opportunities for students to practice declarative knowledge acquired in the theoretical part of the course in the context of a realistic problem-solving task. At the same time the procedural challenges related to the accomplishment of tests in the real laboratory are avoided.

The SimuLab is provided on the web (fig.1) giving the students opportunities to experiment (perform different laboratory procedures and investigate different substances) outside the real laboratory at the time, speed, and place chosen by themselves.

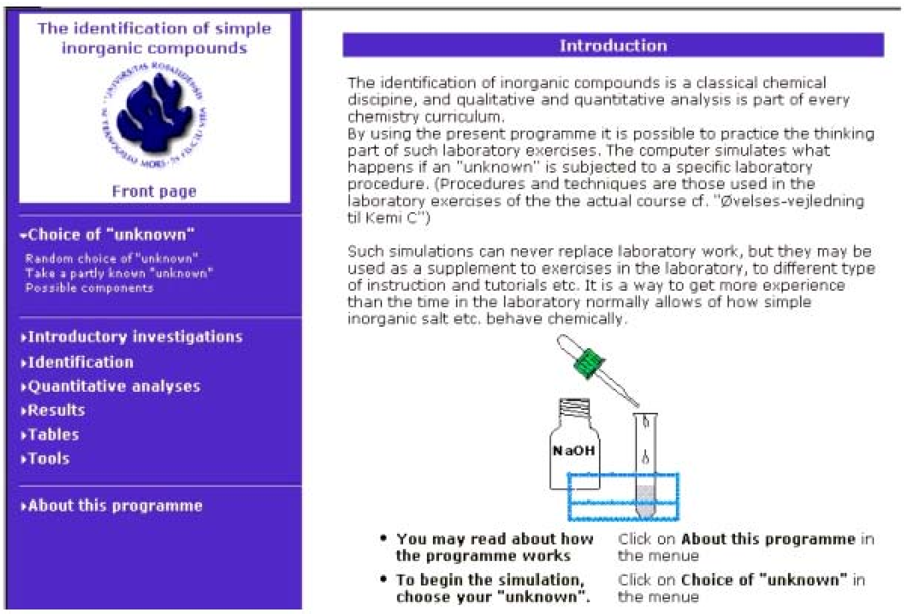

Figure 1. Appearance of the introduction to the programme SimuLab

How SimuLab works

The procedures in this electronic simulation follow the laboratory manual applied in the lab. SimuLab provides students' with an "unknown" substance; as shown in the illustrated case the "unknown" is a white solid, soluble in water. (fig.2)

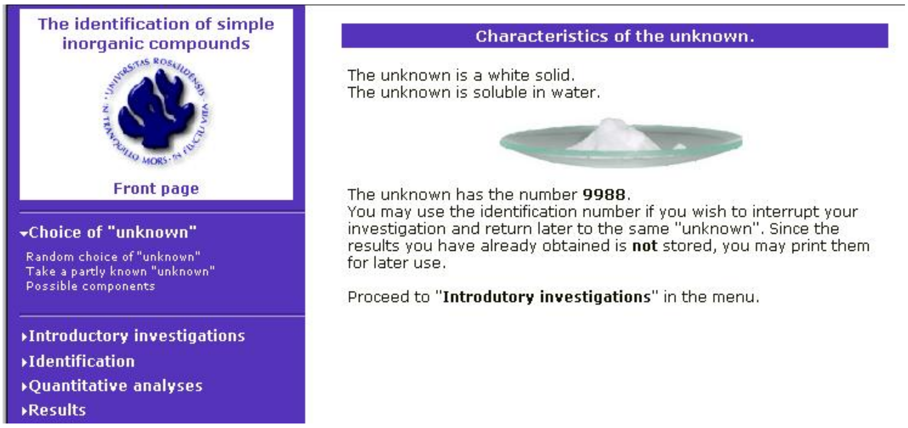

Figure 2. Choice of "unknown" substance.

Students are expected to perform some introductory experiments, as they would have done in the laboratory. There are several introductory experiments to be chosen. To investigate the components of the "unknown" students may choose one of the procedures provided in the introductory investigations (cf. menu on the left).

For example, different ways of heating the "unknown" can be chosen, one of which is to heat the solid in a flame. After having observed the colour of the flame (fig. 3), the students are expected to interpret the result and note their assumption/hypothesis (it is hoped that think of lithium). The programme gives back a response, which is automatically stored in a file,

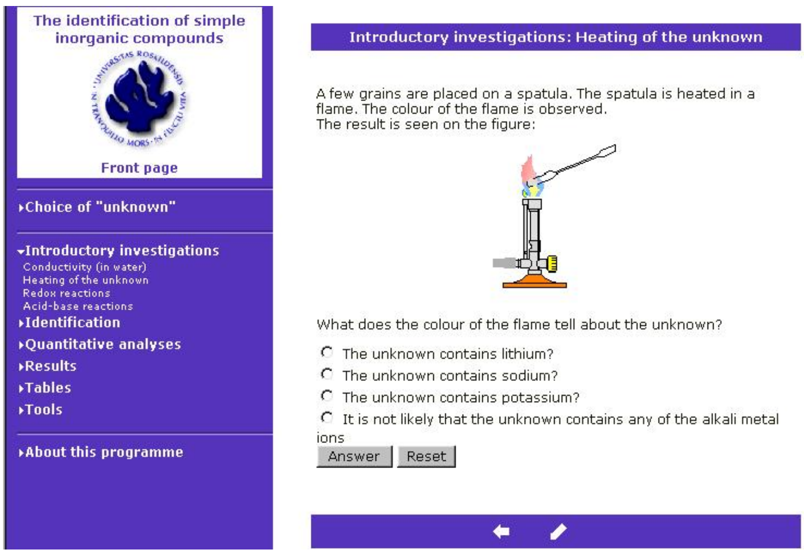

Figure 3. Heating of the "unknown" in a flame

accessible under Results in the menu. The next step is to accomplish another test. One may try redox properties (in the actual case, the result is shown in fig. 4) and acid-base properties (cf. fig. 5), both of which give important clues about distinctive features of the "unknown". Interpretation of these results may help to assert which components may and may not be present in the "unknown".

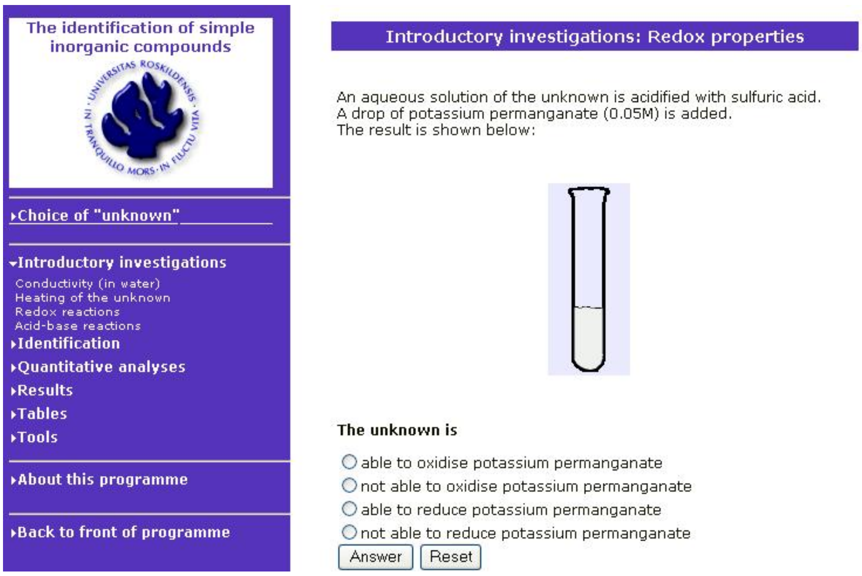

Figure 4. The result of adding a drop of potassium permanganate to an aqueous solution of the "unknown" indicates that it is reducing.

Further, the measurement of pH of an aqueous solution of the "unknown" (in this case the test leaves the universal indicator paper blue) shows, that we have sulfite. We expect student to infer that these results strongly suggest that we have lithium sulfite. After having completed the qualitative part of the investigation, the students are urged to make a quantification of both components. They are expected to use an acid-base or a redox titration, and a flame photometry measurement, preceded by a calculation (which is checked by the computer) of how much of the unknown should be weighed out in a given volume of water in order to get a relevant concentration, within the standard curve. The result of the flame photometry is illustrated in fig. 6 and subsequently this result should be utilised to give an equivalent mass with respect to lithium. This result and the result from the titration procedure(s) are then to be combined leading to a final conclusion about the formula of the "unknown".

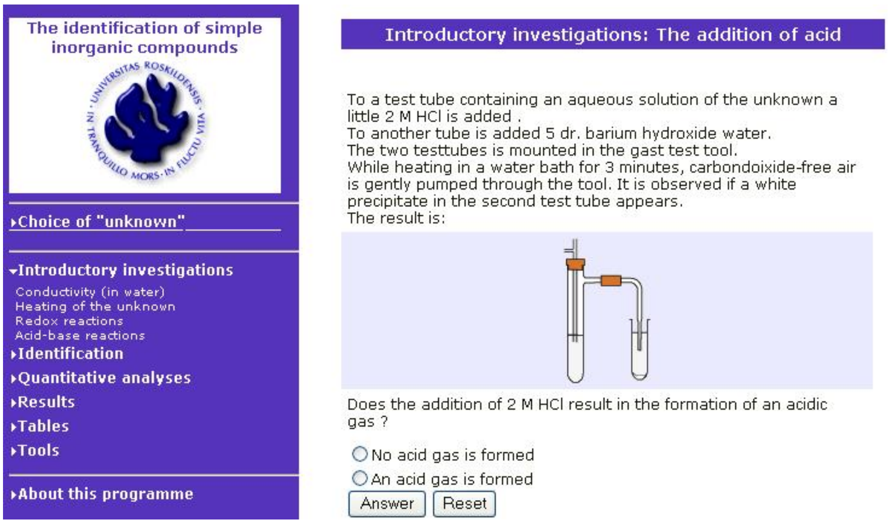

Figure 5. The result of looking for an acidic gas escaping from an acidic solution of the unknown indicates that it contains a base corresponding to either carbonic acid or sulphurous acid - and because of the result of the former experiment the component must be sulfite of hydrogensulfite

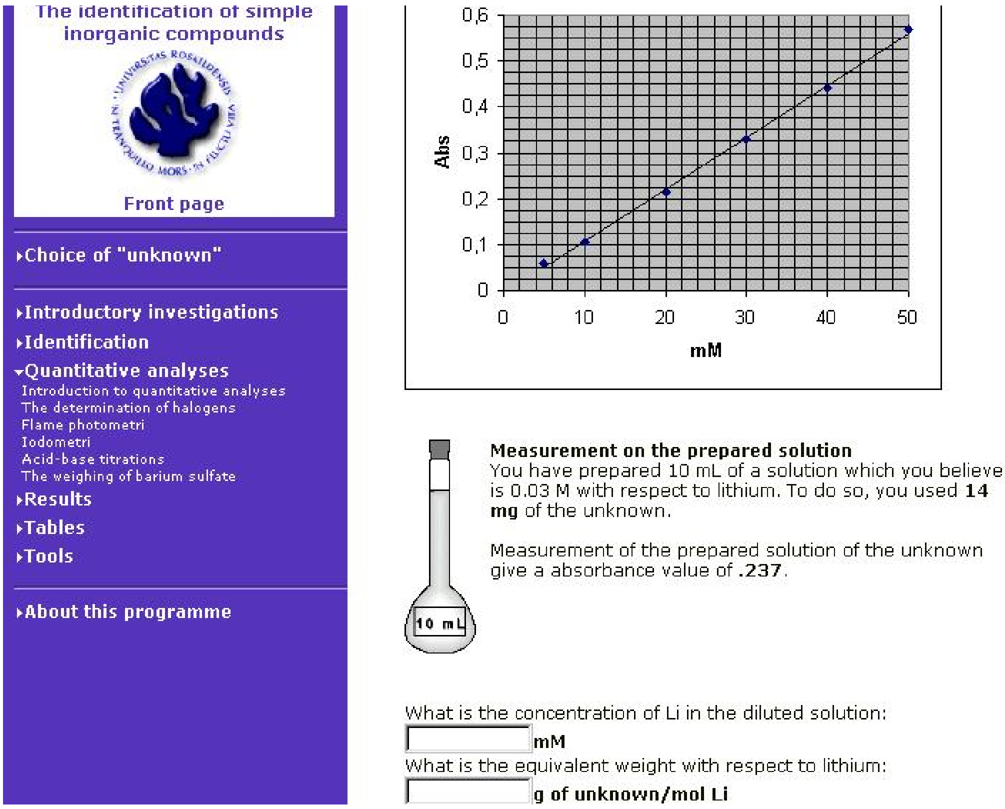

Figure 6. Flame photometric determination of lithium.

Methods

Three subsequent groups of students (n=92) recently participating in the chemistry course were introduced to the programme as a part of their lab course. All students were working in pairs for an hour, and their interactions (with the program and each other) were observed. After the session they were asked to fill in a questionnaire evaluating the session. The two last groups additionally took a written 15-minute pre- and post-assessment test (both tests were the same). The ten questions, which were weighted equally in the assessment (of one group of 32 students), explore the principles and calculation of stoichiometry and the use and interpretation of some of the simple tests in the laboratory. During the session four pairs of students were recorded on video for further analysis, and six of these students were interviewed using a semi-structured interview approach.

Results and discussion

Interviews with students after the session with SimuLab and the questionnaires revealed that the students appreciated working with this simulation program. They tended to enjoy working with it, they found it motivating, and they realised that it created a lot of experience, which they believed could be remembered more easily. We assume that the opportunity to practice the acquired theoretical knowledge in the context of a realistic problem-solving task, free of the procedural challenges, wakened the students' motivation, and joy to learn; by contrast, a lot of students normally find the memorisation of empirical facts to be dull and difficult.

The interviews demonstrated that students understood the purpose of the program and acknowledged its relation to other parts of the teaching set up; (as one of the students expressed it): *In the lab you practice skills - with the simulation you focus on principles* (our underlining). In other words, the students perceived SimuLab as a theoretical part of chemical experience with classical analysis, while they saw the real laboratory environment as an opportunity to practice procedural skills. This aspect was also a clear trend in the questionnaires.

However, the utterance of one of the students not only confirms the awareness of his own cognitive limitations but also emphasizes the supportive role of the programme in the learning process: *In the lab, you easily forget the principle of the experiment. You concentrate on following the procedure correctly. Here* [in the simulation] *this aspect is absent, and you can concentrate on what happens* (our underlining). This statement shows the student's consciousness regarding the SimuLab's role as a scaffolder of his reasoning. By allowing students to perform investigations without practicing "hands-on activities", they are spared from focussing on lower level cognitive skills. Furthermore, students confessed that in the laboratory they often make procedural mistakes, which implies a time consuming reproduction to reach the same stage of the procedure. This reproduction is much faster in the simulation and not only saves time but also frees up students' attention for the higher order processes, such as the interpretation of investigation results: *You save the time it takes to make an experiment - then you could focus on principles: why does the experiment turn out in this way* (our underlining). Students experienced the simulation as a time saving way to extend their chemical experience with simple salts and the laboratory procedures of this classical analysis scheme.

The simulation apparently inspired students to reflect not only on the learning method but also on the chemical contents. "*It helped me to think in a chemical way";* this means that by reducing the cognitive load SimuLab also has potentials of supporting students' development of meta-cognitive skills. We can therefore assume that, consistent with the intentions, SimuLab seems to provide help for the student by sharing the cognitive load, and thus scaffolds students reasoning and learning.

Furthermore, it was found that the SimuLab-programme initiates a dialogue among the collaborating peers. It provides a natural setting for explanation during investigation, and thus an opportunity for students to articulate and share their thoughts and knowledge in a problem-solving situation. Thus discussions during the session create premises for a better understanding of chemical concepts, principles and methods. *We talk about why we do this and that* [experiment in the simulation] *and then you become more conscious about the reasons - you argue instead of just trying* (our underlining). Apparently, in the lab, reasoning and arguing about which experimental step to take next may be replaced by trial and error.

The feedback from the programme and the fellow students' support the verbalization of the student's conceptions and understanding of procedures and concepts, thus functioning as a facilitator of the individual learning processes.

Verbal confrontation during collaboration may also assist students in elimination of some (silly) misunderstandings and help them to clarify their understandings right away. This may be illustrated by the following piece of dialogue on a screen-experiment showing how pH changed while drops of hydrochloric acid were added to an aqueous solution of the actual sample (which was neutral in the first place).

S1: *Our sample is strongly acidic.*

S2: *No, our solution went acidic as we added HCl.*

S1: *Oh, yes, of course.*

S2: *Our solution was neutral.*

S2 (Concludes*): It is not a buffer. We should think of an anion of a strong acid.*

S1: *Right.*

Another type of misunderstanding is the shaky use of words for concepts. This may be corrected immediately, if the peer knows. The benefit of such discussions is obvious here (In this test KI-paper is used to demonstrate a redox-property of the sample):

S1: *This is the test for reducing power, isn't it?*

S2: *No, oxidising.*

They observe a brownish colour on the paper

S1: *Something is happening. Our sample is oxidising, isn't it?*

S2: *Yes it is.*

The SimuLab setting apparently also helps the students to support each other by formulating and checking what they see and may conclude. As the following dialog illustrates, students deduce correctly from observation (here considering if alkali metal ions are present or not in the "unknown") in a discussion, which eventually falsify their own hypothesis/expectation. (A sample in a flame - cf. fig. 2 - not containing alkali metal ions):

S1: *Our flame is blue.*

S2: *It's blue, yes.*

S1: *It's not Li, then.*

S2: *No, neither Li or Na.*

S1: *Agree.*

S2: *Which color does K give?*

S1: *Don't remember, but Na is yellow.*

S2: *Na is orange and Li is red.*

A few seconds' break in conversation, obviously for thinking.

S1: *Normally a flame is bluish, isn't it?*

S2: *I think so.*

S1: *This means that we haven't got anything.*

S2: *Agree, but it would have been nice if we had K (hmmm) - the flame is blue in itself.*

S1 (concludes): *Not Li, not Na, not K.*

Since the SimuLab is provided on the web it allows students to access this virtual laboratory for practicing theoretical knowledge, and to improve their procedural skills at the time and place chosen by themselves. This aspect was also appreciated and emphasized by students, since *you can sit at home and practice in the laboratory.*

The students didn't consider the programme to be too simple or too difficult, because (as they state:) it simulates the actual laboratory procedures and techniques quite closely. They also state independently (they were not given a hint by a question about this aspect), that SimuLab is a valuable *supplement* to real laboratory work and other parts of the teaching. The reason is that it reduces the cognitive overload in the period where the tests and procedures in the laboratory are not familiar to the students; the absence of overload then makes thinking possible and stimulates reflection. On the other hand, the students stress the fact that a *simulation cannot replace laboratory work*. The authentic aspect apparently plays an important role for the students, who acknowledge that real experiments give a far more complete experience of reactions and other properties of compounds and mixtures. Indeed, the practising to a certain extent of procedural skills in the lab is necessary for the contextualisation of the students' declarative knowledge; in addition they have to become sufficiently confident with the procedures to use the inherent chemical principles in any situation. SimuLab can accordingly not be used as a pre-lab, but certainly as a post-lab and an "in-between-lab".

The pre- and post-test results illustrated in fig.7 (analysed for one group of 32 students only) suggest that the majority of students apparently increased their confidence with the laboratory procedures and stoichiometry (both of which areas were trained through the programme), and a better grasp of some relevant chemical concepts.

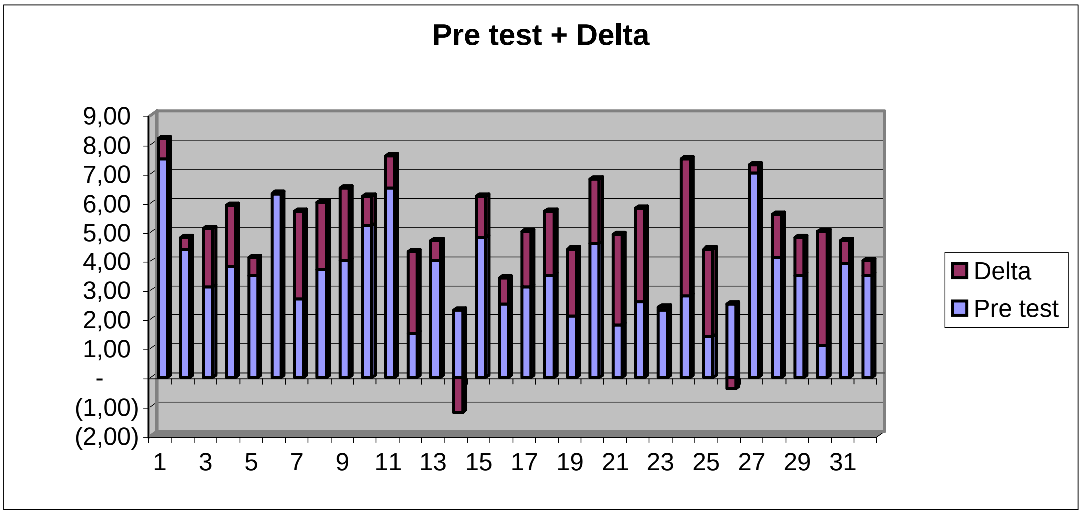

Figure 7. The result for 32 students of the pre- and post-test containing ten questions, which were assessed with equal weight.
Average score in pre test: 3.50; average gain (Delta): 1.54 in one hour.

Conclusion

SimuLab was intended to facilitate students' knowledge construction in a simulated laboratory environment by providing distinctive methods for letting students engage in cognitive activities that are out of their reach. In the real laboratory it is not always possible for the novice learner to abstract from challenges related to the accomplishment of procedures, the lower order cognitive skills, which increase students cognitive load. By performing tasks demanding lower level skills, SimuLab allows the students' attention to be directed towards the higher order processes and leaves more room for scientific reasoning.

This investigation of students' reactions and learning gain from the work with the program clearly indicates that the students acknowledge the learning potential of the simulation programme, and their improved learning of the performed task supports it. SimuLab seems therefore to provide opportunities for students to promote contextualised scientific reasoning, and support their learning. This result is in agreement with other studies investigating students' learning gain from work with computer-based learning environments that diminish cognitive load[3]. A virtual investigation that is thoroughly co-ordinated with other activities may certainly be a valuable teaching and learning tool.

References

(1) J. Josephsen, Chem. Educ. Res. Pract. 4, no. 2 (2003) 205, and references therein.

(2) A. D. Baddeley, Science 258, (1992) 556; J. Sweller and P. Chandler, Cognition and Instruction, 12, (1994) 185-233.

(3) S. P. Lajoi, Computer Environments as Cognitive Tools for Enhancing Learning. In: Lajoie, S. P. & Derry, S. J. (eds.), *Computers as Cognitive Tools*, (Lawrence Erlbaum Hillsdale, New Jersey 1993) pp. 261-288.

(4) A. H. Johnstone, Uni. Chem. Educ. 1 (1997) 8.

(5) A. H. Johnstone, R. J. Sleet, and J. F. Vianna, Stud. Higher Educ.19 (1994) 77.

(6) A. H. Johnstone, A. Watt and T. U. Zaman, Phys. Educ. 33 (1998) 22.

(7) C. J. Garrat, Uni. Chem. Educ. 1 (1997) 19.

Interdependence between students' science literacy and general reading comprehension

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Introduction

The modern life style in a highly scientific and technologically developed society demands a lot of knowledge and different skills. In the environment flooded with information it is very important to understand and correctly use information, otherwise it may be useless or even harmful. Using text books and other written sources for learning and teaching is very important. The main question is whether the chemistry lesson, including reading some texts with chemical contents published in popular magazines, is more interesting for pupils and students and whether it improves teacher's instructions.

Aims of the study

The study Interdependence between students' science literacy and general reading comprehension is a research with the following goals: a) to define students' general reading comprehension, b) to establish interdependence between students' general reading comprehension and their understanding of texts with chemical contents, c) to define the influence of the style of writing on students' understanding of a text with chemical contents, d) to define the influence of previous knowledge of chemistry on students' understanding of texts with chemical contents, e) to define the influence of some general factors such as gender, parents' degree of education, popularity of reading.

The theoretical part of the research introduces concepts of reading, reading comprehension and literacy. Reading is a highly organized brain process (Pečjak, S., 1993). Rayner and McConkie (in Pečjak, V., 1991) define reading as a series of readers' mental processes since they wish to get some information from the text. Several definitions of different literacies, such as functional, textual, documental, computational, reading and science literacy are provided. A review of different researches on reading, literacy and science literacy is introduced. The research methodology is precisely presented.

The science - chemical literacy in our research is defined as knowledge and the ability to read, understand and correctly use some written information with chemical contents important in students' learning process. A science literate student is able to read, understand and correctly use texts with chemical contents in the process of learning chemical rules and concepts.

Methods

Subjects

The subject of the research was to determine how students understand a text with chemical contents. The text represents an article taken from the science magazine GEA designed for pupils and high school students. The author showed a historical view of introducing some chemical concepts, such as the atom, and the molecule and some chemical rules and their discoverers.

The experimental part includes testing of 216 randomly selected fourteen-year-old pupils from different parts of the country attending the 8th class of 8-year primary school at that time. Theoretically predicted, they were listening to the same chemical contents in the 7th class of 8-year primary school, and their degree of cognition was the same as well.

Experimental design

The first part of testing included: (a) defining pupils' general reading comprehension and their (b) previous knowledge of chemistry, as well as comprehension of some general terms later used in the test text. To define general reading comprehension one narrative text and one graphic text have been taken from the material used in the International research of reading literacy conducted in 1990/91. The first part of our testing took 45 minutes.

The second part of the testing included: (a) reading a text with chemical contents and (b) checking understanding of texts with chemical contents. For the purpose of the experiment, we have prepared the article in two ways; the original text with chemical contents, and the transformed text with chemical contents including rules for better understanding. This means: use of short sentences, active voice, abstracts and examples in order to increase the reading comprehension. Altogether, 111 pupils read the original text with chemical contents and 105 pupils read the transformed text with chemical contents. To check the pupils' comprehension of the text, they were given the test with 10 questions. The categories of knowledge required comprehension of the tests: fact recognition, understanding and application. All pupils were administered the same test. The second part of our testing took 45 minutes, as well.

Results

The test results are shown in different figures for all pupils (n=216), for pupils who read the original text with chemical contents (n=111) and for pupils who read the transformed text with chemical contents (n=105). Some statistics of the results were made. The figures show interdependences between: (1) general reading comprehension and comprehension of a text with chemical contents for each group of pupils, (2) previous knowledge of chemistry and comprehension of a text with chemical contents for each group of pupils, (3) comprehension of a text with chemical contents and the grades achieved in chemistry in the 7th class of the 8 - year primary school. The figures show the comparison between (1) pupils' results of those who read the original text and pupils' results of those who read the transformed text, (2) results of tests by gender for each group of pupils. The test analysis for testing comprehension of the text with chemical contents is shown as well. Figure 1 shows the interdependence between general reading comprehension and chemical literacy for all 216 pupils. It is evident that with general reading comprehension chemical literacy increases.

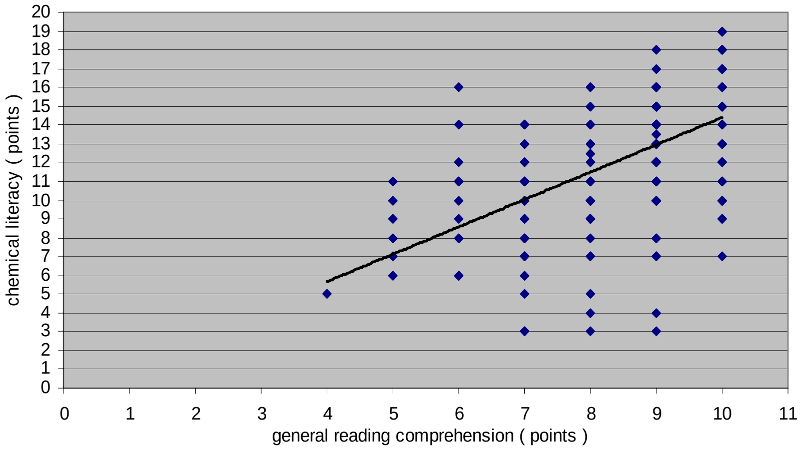

Figure 1. The interdependence between general reading comprehension and chemical literacy, n = 216

Figure 2 shows the interdependence between previous knowledge of chemistry and chemical literacy for all 216 pupils. It is evident that, with previous knowledge of chemistry, chemical literacy also increases.

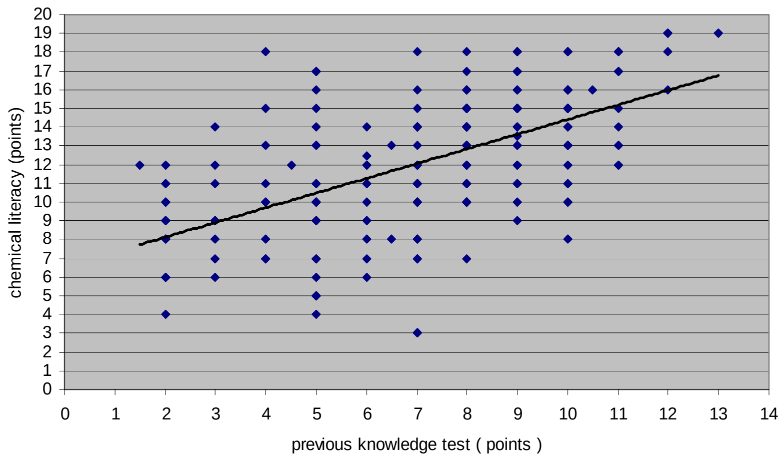

Figure 2. The interdependence between previous knowledge test and chemical literacy, n = 216

The pupils' achievements were divided into three categories; lower, medium and upper level, in both: general reading comprehension as well as previous knowledge level. Figure 3 shows chemical literacy depending on the general reading comprehension category. With general reading comprehension, comprehension of the text increases, and the best results were achieved by pupils who read the transformed text.

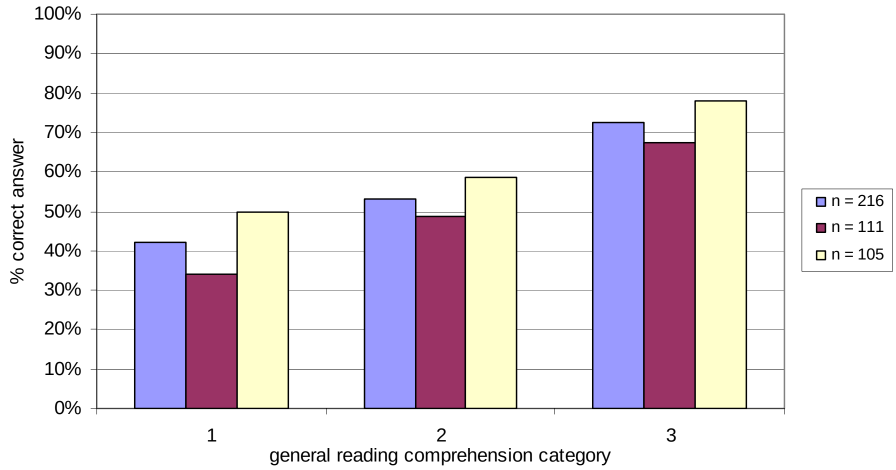

Figure 3. Chemical literacy of all pupils (n = 216), pupils who read the original text with chemical content (n = 111) and pupils who read the transformed text with chemical content (n = 105) depending on the general reading comprehension category

We found a very similar situation with chemical literacy depending on the previous knowledge category, which is show in figure 4.

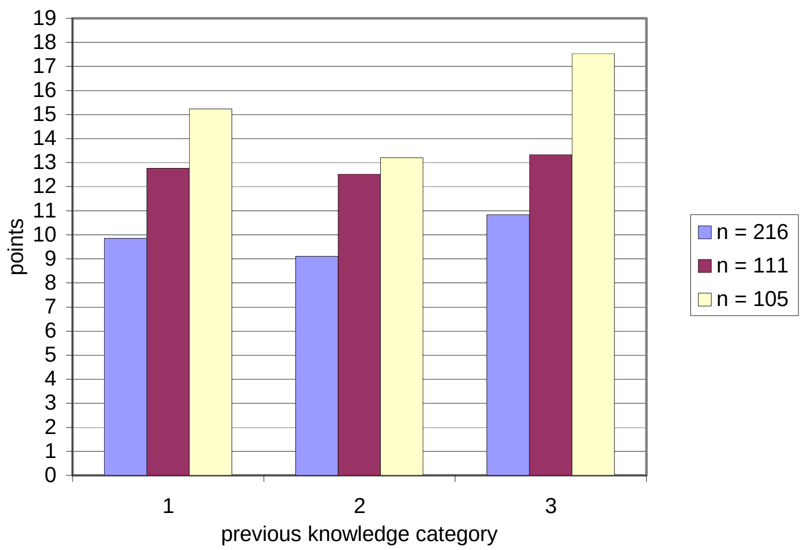

Figure 4. Chemical literacy of all pupils (n = 216), pupils who read the original text with chemical content (n = 111) and pupils who read the transformed text with chemical content (n = 105) depending on previous knowledge category

Figure 5 shows the comparison of chemical literacy of pupils who read the original text and pupils who read the transformed text. It is evident that the transformed text was better understood. The positive difference between the achievements of the group who read the transformed text and the group who read the original text has been also statistically proven.

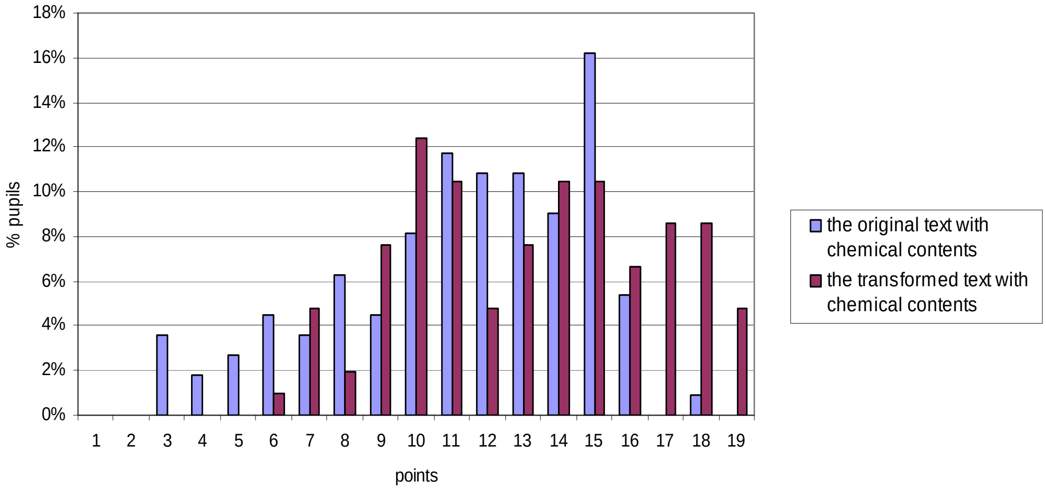

Figure 5. The comparison of chemical literacy of pupils who read the original text with chemical content (n=111) and pupils who read the transformed text with chemical content (n=105)

Table 1. The comparison of results of pupils who read the original text with chemical content (n=111) and pupils who read the transformed text with chemical content (n=105):

	ORIGINAL TEXT n = 111		TRANSFORMED TEXT n = 105	
	points	**%**	**points**	**%**
General reading comprehension Σ points = 10	8.48	84.8	8.52	85.2
Previous knowledge test Σ points = 13	6.89	53	7.56	58.2
Comprehension test of texts with chemical content Σ points = 19	11.27	59.3	13.19	69.4
Comprehension test of texts with chemical content – part 1 Σ points = 11	8.08	73.5	9.51	86.5
Comprehension test of texts with chemical content – part 2 Σ points = 8	3.13	39.2	3.66	45.8

If we compare pupils' achievements depending on grades of Chemistry in 7th class of 8-year primary school we clearly see that higher grades increase achievements on all three tasks: general reading comprehension, previous knowledge and chemical literacy.

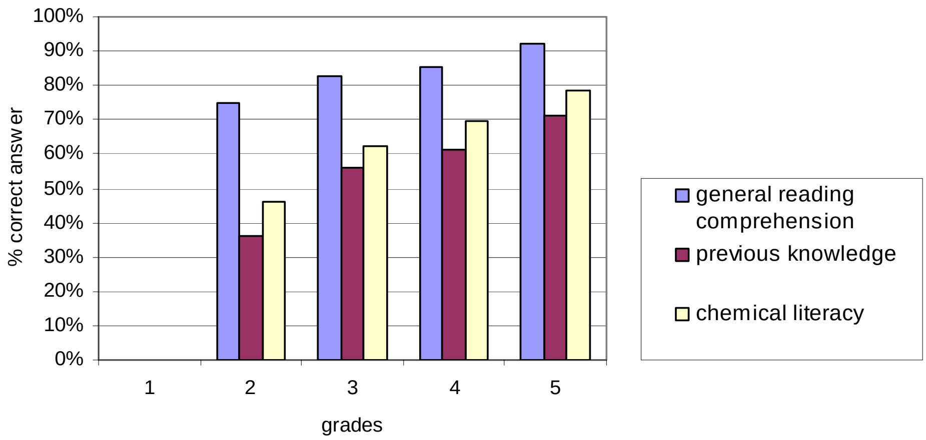

Figure 6. Pupils' achievements depending on grades achieved in Chemistry in the 7th class of 8-year primary school, n = 216

Figure 7 shows chemical literacy with regard to gender. It has been proven that gender has no influence on comprehension.

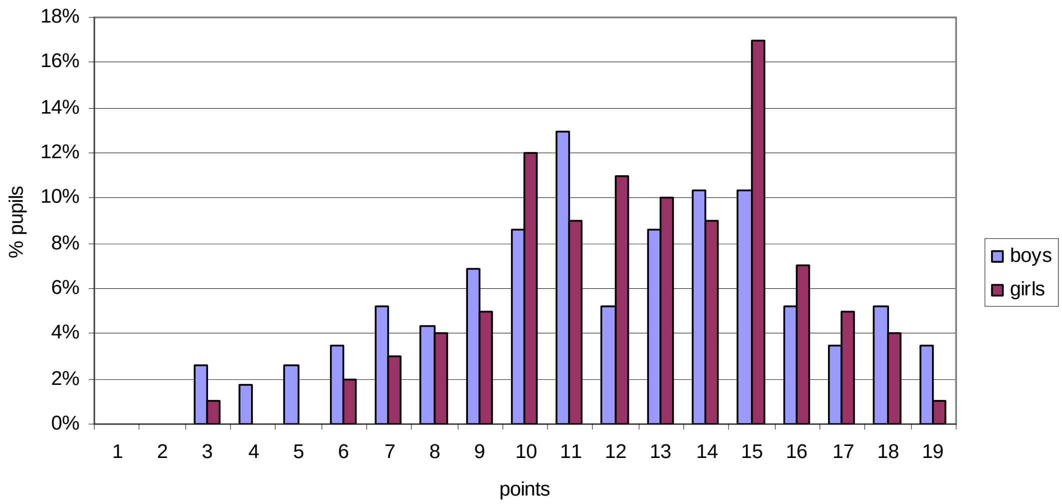

Figure 7. Chemical literacy with regard to gender (n=216)

Conclusion

Our research shows that there are several influences on students' understanding of texts with chemical contents. The interdependence between students' general reading comprehension and their understanding of a text with chemical contents has been proven (figure 1, figure 3, table 1). The interdependence between students' previous knowledge of chemistry and their understanding of a text with chemical contents has been proven as well (figure 2, figure 4, table 1). The positive difference between the achievements of the group who read the transformed text including rules for better understanding and the group who read the original text has been statistically proven (figure 5, table 1).

It has been proven that higher grades of Chemistry in 7th class of 8-year primary school increase understanding of texts with chemical content (figure 6). It has been proven that gender (figure 7) and parents' degree of education have no influence on understanding of the texts with chemical contents. In contrast with some other researchers, our research has indicated no influence of popularity of reading on understanding of the text. Most likely the influence could not have been demonstrated due to the method used in the research. We might assume that the questions used to define the pupils' popularity of reading have not been fully adequate.

Finally, some suggestions for future research are presented. It is recommended that future studies also focus on: 1) comprehension of other chemical contents and other science contents; for example: Physics, Biology, Maths, and Science in 9-year primary school; 2) students´ comprehension of texts with chemical contents in different high schools; 3) introducing reading techniques and strategies to enhance reading skills and thus to increase science literacy; 4) impacts of teachers' and writers' language and vocabulary on science literacy.

References

ANDERSON, C. W. 1999. Inscriptions and science learning. *Journal of Research in Science Teaching*, vol. 36, no. 9, p. 973-974.

DeBOER, G. E. 2000. Scientific literacy : another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, vol. 37, no. 6, p. 582-601.

ELLEY, W. B., GRADIŠAR, A., in LAPAJNE, Z. 1995. *Kako berejo otroci po svetu in pri nas*. Nova Gorica : Educa.

HURD, P. D. 1998. Scientific literacy : new minds for a changing world. *Science Education*, vol. 82, no. 3, p. 407-416.

KNAFLIČ, L. 2000. Opredelitev in merjenje pismenosti odraslih. *Sodobna pedagogika*, let. 51, št. 2, str. 8-21.

KOBAL, E. 1994. Atomi in molekule. *GEA*, let. 4. št. 10, p. 13-15.

LAUGKSCH, R. C.2000. Scientific literacy : a conceptual overview. *Science Education*, vol. 84, no. 1, str. 71-94.

NORRIS, S. P., in PHILLIPS, L. M. 1994. Interpreting pragmatic meaning when reading popular reports of science. *Journal of Research in Science Teaching*, vol. 31, no. 9, p. 947-967.

NORRIS, S. P., in PHILLIPS, L. M. 2003. How literacy in its fundamental sense is central to scientific literacy. *Science Education*, vol. 87, no. 2, p. 224-240.

PEČJAK,V.1991. *Hitro in uspešno branje*. Ljubljana : samozaložba.

PEČJAK, S. 1993. *Kako do boljšega branja*. Ljubljana : Zavod Republike Slovenije za šolstvo in šport. Str. 7, 11, 53-56.

PELLA, M. O., OHEARN, G. T., in GALE, C. G. 1966. Referents to scientific literacy. *Journal of Research in Science Teaching*, vol. 4, p. 199-208.

PIRLS – *Mednarodna raziskava bralne pismenosti,* 2004 [on line]. Pedagoški inštitut, obnovljeno 19. 12. 2003 [citirano 8. 1. 2004]. Dostopno na svetovnem spletu: http://www2.arnes.si/~uljpeins/czue/pirls/pirls.htm.

RIVARD, L. P., in STRAW, S. B. 2000. The effect of talk and writing on learning science : an exploratory study. *Science Education*, vol. 84, no. 5, p. 566-593.

YORE, L. D. et al. 2003. Examing the literacy component of science literacy : 25 years of language arts and science research. *International Journal of Science Education*, vol. 25, no. 6, p. 689-725.

Improving the quality of chemistry teaching at universities. Academic teachers' training - dream or reality?

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Status quo

A great number of chemistry students in many schools and universities of Western Europe are declining systematically [1]. Things have come to such a point that some of the chemical faculties must be suspended because of the insufficient number of candidates.

Reasons for such a condition of chemistry education at tertiary level of education, as numbered in many publications, are briefly:

i. experience from the secondary school making the subject in question boring and wearisome. Who is responsible for that opinion: teachers and their supervisors?
ii. image of chemical studies as difficult and requiring an effort incommensurate with the future qualifications needed at workplace, many memorizing methods instead of practical lessons – responsible: academic teachers?
iii. image of chemistry and specifically of the chemical industry, as the reason for pollution and aversion to chemical products perceived as unnatural - responsible: chemists or mass media?

While focusing on reason ii, everyone must admit that these are the teachers who are, to a large extent, responsible for the teaching quality [2].

Above all, it should be stated that the University is treated as a scientific centre rather than a didactical centre, both by the persons from outside and by its own employees. The beautiful descriptions of missions contained in the University documents or addresses voiced on the occasion of the beginning of the next academic year on the subject of increasing the quality of teaching, do not ensure this.

What is then the reason for the low didactical qualifications of some academic teachers?

1. <u>The authorities of many universities</u> do not find it particularly important to provide qualifications to teaching staff. In general, the evaluation of the education standards of the faculty is simply based on the number of students as compared with the number of teaching staff (the so-called

staff-student ratio), as well as the number of graduates, equipment of laboratories and lecture halls or scientific achievements of the teaching staff [3].

2. Experienced teaching teams do not see the need of continuous self-education and development, as the gratification comes mostly from scientific output. Publications running in magazines for teachers are a minor 'impact factor'. This method of evaluation of the employee forces him or her to increase the time spent engaged in research, which is usually accompanied by increases in time spent teaching [4].

3. The evaluation of the teaching quality provided by the particular employee leaves much to be desired. In some countries, this method is based upon the portfolio [5] – and this is something to boast of – but in other countries the evaluation in question is based merely on the number of textbooks published and printed series of lectures, i.e. the publishing business, and also on the fact of introducing new classes (without actually performing the evaluation of the quality of the latter).

4. Only some European countries hold a well-developed and diversified system of increasing qualifications of didactical staff, depending on the needs [6]. Young academic staff (especially doctoral students) in many countries have no practical possibility of gaining the proper level of educational skills, even when they feel such a need, because there are no appropriate courses available there.

5. There is no forum available to help gain and acquire the knowledge by way of discussing and transferring experiences (excluding "Variety of Chemistry Education"). In the course of many conferences, e.g. at the Annual Meeting of Polish Chemical Society, Division of Chemical Education, oral presentation regarding university education level as scheduled in the conference programme occupies not more than 20% of the entire conference time and usually involves detailed descriptions of new specialist laboratory practice with no interest seen on the part of other participants.

6. There is an absence of correct communication between the persons running various subjects or classes, and therefore there is an absence of correlations in the programmes, evaluation methods, etc.. There is an absence of communication between the divisions with regard to didactical questions, e.g. common seminars held once per semester.

7. There is an absence of comprehensive analysis of the studies syllabus, and this is the reason why it is incoherent. Teaching programmes regarding teaching particular school subjects are analyzed by means of the matrix or graph methods. There is, however, the question of whether it is possible to analyze the entire syllabus of the studies.

There are some solid myths in the mentality of teachers saying that: ‘Knowing your subject makes you a good teacher’ and ‘Experience makes a good teacher’ [7]

Solutions

There have been many efforts attempting to solve the problems presented above /3-5/ at the Faculty of Chemistry, Jagiellonian University.

Above all, the young academic staff was surveyed with regard to the problems they encounter while making their first steps as academic teachers. The surveys in question have shown that the following items are the most difficult ones, notably:

– evaluation of the students - 45% of respondents;
– inducing the students towards self-reasoning - 45% of respondents;
– motivating the students for learning– 25%
– evaluation of classes– 12%
– planning of classes– 8%
– discipline maintaining– 8%
– determining the objective of classes– 4%

Doctoral students at the Faculty of Chemistry (Jagiellonian University) are obliged to take up a 280-hour teaching load during their studies (90 hours per year in 4 years). Based upon the results of the survey and on consultation with the senior didactical staff of the faculty, as well as based upon the SQUADS Tempus project [2], the **course “Chemistry at Tertiary(University) Education Level’ for doctoral students** was introduced in the years 2001/2002 [8]. The classes cover 30 hours in the summer semester, and even the students of the first year may already have some experience in teaching, therefore it is easier for them to participate in the discussions.

The general **aim** of the course:
Acquisition of knowledge and skills in methodology of teaching adults (resident and non-resident students as well as postgraduates).
The following **topics** are included in the course programme:

– studies of chemistry in the period of educational reform in Poland (including the Bologna Declaration 3+2+4, core curricula (comparison: ECTN, Poland, JU), ECTS (exercises);
– requirements of labour market, profile of alumni (visualisation-poster), development of transferable skills, HOCS;
– aims of teaching chemistry (general- educational and operational), analysis of our ECTS guide book, writing aims for the particular course;

- organisation of teacher's work (planning and preparing for classes, safety in chemical laboratory)
- teaching principles; Principle of (adult) education: Kolb's cycle, (example for chemistry-exercise), Dale's triangle;
- teaching methods and techniques with special emphasis on active / open methods and group work (e.g. PBL), open and distance learning list of known problem based methods, preparation of a description of a particular course, in which these methods will be applied;
- work in groups aquarium - damage landing on the desert (stages of groups forming, roles in the group, advantages and disadvantages of work in the group);
- interdisciplinary courses, teaching / learning in context;
- student assessment (Students' assessment errors/traps), class evaluation, formulating evaluation questions;
- quality assessment (official - UKA,PAKA);
- other forms of activities with students: (scientific camps, summer schools, Association of Students of Chemistry , Students' participation in research etc);
- principles of communication (definition of teachers' own communication style in interaction with students, communication barriers, difficulties, gossip (exercise). Presentation – oral and written, lecture, poster, didactic tools, multimedia;
- outside University: international exchange, cooperation with secondary level of education (Open Door, Educational Fair);
- the portrait of an academic teacher - 'Teacher as a master or a partner?' – discussion.

The following **methods** of work are applied:
workshops in groups of ten, mini-lectures and problem solving methods, reflections on one's experiences, mutual class observations – participants and teacher.

We plan to organize peer evaluation - mutual attending of lessons by students-teachers, self-conducting a lesson which is then commented and evaluated by the group of colleagues and the academic teacher.

The propositions of scenarios of classes run by the students are introduced and presented in a broader way e. g. at the conference Variety on Chemistry Education [9]

Małgorzata Brindell, Małgorzata Meres, Patrycja Nowak – Śliwińska. Three ways of preventing students from falling asleep during classes

Agnieszka Drzewiecka- Matuszek, Tomasz Dylag, Agnieszka Skalna, Iwona Stawoska, Open your mind – the first step to the Nobel Prize

The first attempts at organizing the **forum of exchanging the ideas and experience** have already been undertaken:

- some lectures devoted to teaching problems have been chaired by foreign guests (thanks to the Tempus and Socrates/Erasmus programme) and discussed by teaching staff of the faculty
- information about foreign educational conferences is easily accessible
- young academic teaching staff are encouraged to make presentations of their teaching ideas for international conferences
- staff development subject matter is planned, and was introduced at Conference of the Deans of Chemical Faculties at Polish Universities (June 2004)
- teaching staff are encouraged to acquire some international experience in teaching/learning, e.g. under the umbrella of the Socrates/Erasmus programme. Experience gained from studies abroad has a positive impact on 'globalising' and improving the participants' teaching [10]

The Faculty of Chemistry and its operations frequently serve as the model for the outstanding units of the University. The following actions have been or are planned to be undertaken **at the Jagiellonian University:**

- the University **prize 'Pro Arte Docendi'** has been introduced for the best JU academic teacher Requirements:
- inter-faculty pedagogical study for the candidates for doctoral degree, where they could gain the knowledge and skills related to teaching at the secondary school and university
- 'Meetings with the Master', involving listening to a lecture in the particular discipline of knowledge, combined with the discussion on the subject of presenting this discipline of science to the students and public at large
- pilot, 50-hour classes for the young teaching staff - assistants and assistant professors (but not for the candidates for doctoral degree) will be introduced in the year of 2004/2005. The activities will cover as follows:
    - the evaluation of classes run by participants of the classes in question
    - the series of seminars on various subjects, run by experts (e.g. teaching psychology)
    - laboratory of academic didactics - preparing 30-minute fragments of proprietary classes to be evaluated by the rest of the class group (temporarily acting as group students), development of the list of didactical problems important from the viewpoint of the participants of the classes, searching for solution methods, peer evaluation.

What else can be done?

Seemingly, it is necessary to introduce the courses for the remaining didactical staff (as many of us remember, in the past century, in Poland and other central and east countries, the examination in pedagogy was necessary for obtaining the doctoral degree).

Separate courses should be proposed to the independent scientific employees – also containing elements of teaching the capability of managing human and financial resources (as is the case for e.g. the University of Lund).

The criteria regarding the employees evaluation, performed at the Jagiellonian University every four years, should be changed:

- the evaluation of the didactical activities should be rated higher in the general evaluation of employees;
- the preparation of the modern didactical aids should also be rated higher in this assessment
- the statistical analysis of marks from the examination correlated with examining the opinion of non-students should become part of the employee evaluation
- separate recompensations should be introduced for the persons responsible for the organization of classes and the coordination thereof.

It is worth organizing seminars and conferences on various subjects, such as the conference organized by the Polish Association of Pedagogy together with the Institute of Pedagogy of the Jagiellonian University in the year of 2002 "Searching for the academic didactics model", however with a larger extent of orientation towards the specific subject, i.e. pertinent only to chemistry or science subjects.

The participation of the academic staff should be co-financed not only with regard to scientific conferences, but also to didactical conferences.

The academic staff should be free to use the results of detailed didactics testing (e.g. through the subscription to the relevant papers and magazines).

Conclusion

The quality of chemistry teaching at universities may be improved through increasing staff qualifications. At some universities, academic teachers training is only a dream, while at some other universities, this scheme is reality. As shown by the experience of Chemistry Faculty of Jagiellonian University, undertaking the appropriate steps does not require either specific financial outlays or an extraordinary staffing effort. The effects of international programmes realized to date, such as Tempus, should be taken advantage of, as well as the new possibilities provided by Socrates and Leonardo da Vinci. The existing staff of school teachers may be used, following the previous complementation of their knowledge with academic didactics issues. The cooperation shall be undertaken among the various units of the University, e.g. chemistry faculty and pedagogy faculty, human resources department, career service, etc.

Bibliography

1. R. Wallace, Rethinking the Education of Chemists – the Odyssey is over, time for action!, 6th ECRICE, *Chemistry Education: Research And Practice*, 2003, Vol. 4, No. 1*, pp. 83-96
2. V. Cepujnoska, Teaching staff – The Most Important Factor of the Quality in High Education, *Wissenschaftliche Beitrage*, Technische Fachhochschule Wildau , 2001,
1. University Staff Training Project SQUADS, ed. A. Herbowski& W. Oleksy, Lodz 2002
2. J.F.Milem and J.B. Berger, Faculty time allocation: a study of change over twenty years, *Journal of Higher Education*, 71 (4), 2000, 454-475
3. D.Baume and M. Yorke, The Reliability of Assessment by Portfolio on a Course to Develop and Accredit Teachers in Higher Education, Studies in Higher Education, 27 (1), 2002, 7-25
4. For example:
   Learning and Teaching Development Centre University of Lund
   http://www.lu.se/lu/orgE.html –
   Staff Development and Training Centre at Keele University
   http://www.keele.ac.uk
   Staff Development Service, University of Valencia
   http://www.uv.es/dise/en/other3.html
5. N.Reid *Getting Started in Pedagogical Research in the Physical Sciences,* LTSN Physical Science Centre, Hull 2003
6. I.Maciejowska, PhD Students as Academic Chemistry Teachers: How Can We Help Them?, Variety in Chemistry Education 2003 Proceedings, 32.
7. R.Wietecha, J.Mania, M.Wozniakiewicz, K.Madej, I.Maciejowska, Is This Last Will Fraudulent? - an Experiment for the Forensic Chemistry Course for Undergraduate Students, Forensic Science International, Vol. 136 Suppl.1, Sept. 2003, 181-182
8. D. Sangren, N.Ellig, P.Hovde, M.Krejci and M.Rice, How international experience affects teaching: understanding the impact of faculty study abroad, *Journal of Studies in International Education,* 3 (1), 1999, 33-56

Students´ Questions as Organisers for Small Group Learning in Chemistry

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Abstract

Designing inquiry-based-learning with and for university students develops problem-solving skills, logical reasoning as well as reflective thinking. It involves working as a member of a team, questioning, being creative, and shaping the skills for continued intellectual development. It is argued that inquiry-based group-work is one of the most important learning experiences because it enables the exploration of theoretical ideas and conceptual change. This paper presents results about the use of students' questions to shape these processes. In fact, student-generated-questions can be used as efficient guides in the preparation, focus, diagnosis, development, implementation and evaluation of group-work.

This research has involved one group of three students developing a mini-project on the 'Thermochemistry of fitness'. The aims of the study are to

i) examine ways that university students use questions to organise and structure small group activities in their study of chemistry, and
ii) evaluate the effectiveness of these questions for the development of problem-solving skills.

Data was collected through participant observation of group meetings and of meetings with the tutor, through semi-structured interviews both with members of the group and the group as a whole, through an analysis of the questions asked by the group in the development of the project (oral and written) and through an oral presentation by the students. The students were aware of the investigation and were stimulated to formulate questions as explained elsewhere (Pedrosa de Jesus *et al*. 2003 a, b).

The results show that the questions formulated during the development of group mini-projects performed several important functions in the structure of the students' work such as: organising ideas, delimiting the scale of the project, identifying and reflecting on the many strands and sources of information, and in reflecting on the project as a whole. The 'function' and 'quality' of the questions varied with the context in which they arose: factual and conceptual questions are distinctive from organisational and reflective questions. It was found that students' need to articulate questions and to try answers within the group in order to choose the best solution for the initial problem. The questions used have contributed to students' engagement in the discipline, bringing an increase of interaction between teacher and students, an increase in the confidence and trust of the students in the asking of questions, and therefore an increase in the quality of classroom interactions in the learning and teaching of chemistry.

Acknowledgement

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Introduction: Organisational questions

This paper is based upon a growing body of work shaped by the 'Questions in Chemistry' project at the University of Aveiro, Portugal (Pedrosa de Jesus, Teixeira-Dias & Watts, 2003, Pedrosa de Jesus, Neri de Souza, Teixeira-Dias & Watts, 2003). The central strand to this work relates to the nature and quality of students' questions during the process of learning chemistry, and the ways in which university lecturers can manage the processes of teaching in response to these.

In much of this work our studies have augmented a growing emphasis on students' questions as these relate to conceptualising and structuring learning matters (Graesser & Olde, 2003; Marbach-AD & Sokolove, 2000; Maskill & Pedrosa de Jesus, 1997; Otero & Graesser, 2001; Pedrosa de Jesus et al., 2003; Watts et al., 1997). In this paper, however, we follow a different tack. Rather than explore the content of students' knowledge and understanding from the questions they ask, we examine instead their procedural knowledge in the context of inquiry-based-learning. We focus upon ways that university students use questions to organise themselves and structure small group activities, tasks undertaken as part of their study of chemistry. Procedural knowledge concerns the techniques and procedures for acquiring, organising, validating and evaluating knowledge. *Organisational questions* can be thought of as those that marshal, and lead to, procedural knowledge, the '*Knowing how to ...*? rather than the '*Knowing what ...*? of learning.

In our research we have identified two forms of organisational questions. First are those that are involved in organising cognitive processes, questions that allow learners to manage their thinking. Our data in these instances derives from recordings of students' cooperative learning dialogues as they 'think aloud' around the tasks with which they are occupied. Second are those questions that focus on organising and proceeding with the physical tasks at hand, and it is these that form the subject of this paper – we will deal with students' 'think aloud' questions in a future paper. Alfke (1974) uses the expression 'operational questions' to indicate those that imply what must be done - in her terms: 'questions which lead back to doing something with materials in order to derive answers' (p18). Hodson (1998), too, discusses operational questions, referring to questions that spark classroom activities and exploration. He says (p35) that stimulating classroom questions is important for:

> *First, creating a classroom climate within which [students] will be stimulated to ask questions; second, ensuring that questions are expressed in operational form (that is, they are in the form that supports investigation). Thus there are both affective and cognitive dimensions: we have to show that questions are welcomed and we have to ensure that students know what constitutes a good or productive question.*

Small group organizational questions

In this work we have focussed upon a specific initiative that involves small group activities within the broad pattern of teaching chemistry at Aveiro. Our research has entailed investigating ways that students use their own questions to construct and manage group tasks: activities that instigate inquiry into the chemistry subject matter to be learned.

The use of cooperative small group work is an important and well-researched element of learning and teaching (Barbosa, Jofili & Watts, 2004; Felder & Brent, 2001; Haller et al., 2000; Sisovic & Bojovic, 2000; Slavin, 1995). Small-group discussions have been advocated for a number of years as one of a range of learner-centred teaching approaches or 'active learning' strategies. These are where students have a significant degree of autonomy over the learning activity as a means of stimulating interest in what they are studying. Such groups are a fertile arena for researching students' questions because, as Wlederhold & Kagan (1992, p.206) say:

> *Students' question can be the focus of cooperative lessons, allowing time to think critically: first in constructing questions, second in asking them, third in responding, and again in paraphrasing, praising, and augmenting them.*

Cohen (1994) adds that:

> *Students in a group communicate about their task with each other. This includes* ***asking questions***[4]*, explaining, making suggestions, criticizing, listening, agreeing, disagreeing, or making joint decisions.*

Pearson (1999, p28) suggests that some broad organisational questions might be:

Where are we now?
Where do we want to get to?
How shall we get there?

And, once in progress:

How well are we doing?

More specifically, Jones et al (1992) illustrate how both teachers' and students' organisational questions can be used to develop 'open' investigations in science. Teachers can pose questions to students that suggest areas for investigation, but that then leave the process and content of the work open for the students to pursue. The students are encouraged to ask themselves a series of questions that help in the structuring and management of their work. For example:

What are we going to find out about?
What do we already know about this?
What do we think will happen?

[4] Emphasis added to the original text

What equipment will we need?

What will make it a fair test?

What have I found out I did not know before?

In the work described by Jones et al (1992), teachers too are encouraged to ask themselves questions in order to evaluate this kind of classroom work, for example:

Does this kind of open investigative work meet curriculum needs?

How much initiative am I prepared to give the students?

What changes are required to carry out this kind of work?

Like Pearson (op cit), Holcomb's work (1996) shows that questions can also be used as efficient guides to the performance of groups in the preparation, focus, diagnosis, development, implementation and evaluation of their work. Specific questions can be used to guide these group processes so that, for example in the 'focus' stage, the question might be: *Where do we want to go?* While implementing, monitoring, and evaluating on the other hand, the questions might be: *How will we know we have got there?*

Questions in undergraduate chemistry

The 'Questions in Chemistry' project is based within a programme for Year 1 university students in sciences and engineering at University of Aveiro. This work rests upon the conviction that it is possible to promote active inquiry-based learning in chemistry through promoting question-asking between teachers and students. With this in mind, patterns of teaching have been developed to encourage students to ask questions of their teachers, within two modules (Chemistry I and Chemistry II) in the academic year 2002-2003 (~100 students). Many of these approaches were developed during a prior investigative phase (Pedrosa de Jesus et al., 2001a, b) in cooperation with the staff of the Department of Chemistry at Aveiro. The main approaches are:

1. Tutorial lectures, centred on the resolution of particular case studies in chemistry
2. 'Questions in Chemistry' lectures, called 'Q/Q' lectures, based on students' questions on a specific theme
3. Conference-lectures, based on themes of high scientific, technological and social interest
4. Laboratory lectures, reconstructed to enable questioning and to promote student autonomy
5. Mini-projects, small group work to initiate investigations on themes chosen by the students.

These approaches to teaching have been supported by systems to promote the asking of oral questions, and to collect written questions through, for example, a software programme installed upon select computers distributed throughout the Chemistry Department buildings. This software programme includes Internet access for entries to be posted off-campus. A simpler, physical, system has entailed Question Boxes, prominently positioned in classrooms and in laboratories, where students could post written questions anonymously.

Within the lectures, tutorials and laboratory sessions, students have been asked to undertake ‘miniprojects’, relatively short investigations on topics in chemistry. Students choose from a list of 28 suggested themes such as: ‘Electric vehicles’, ‘Fuel cells’, ‘Greenhouse gases’, and ‘Terra-forming Mars’. One outcome of these mini-projects has been an oral presentation by the group to teachers and peers, followed by questions from this audience.

Questions that delineate a structure: a ‘thermochemical’ case study

In this paper we have chosen to discuss the cooperative teamwork of three students who developed a project on the ‘Thermochemistry of fitness’. Our data consists of participant observation of a group, their meetings and their meetings with their tutor. It is a case study, and we have added semistructured interviews with all members of the group and the group as a whole, along with an analysis of the questions asked by the group in the development of their project. As we observed this particular group, it became clear to us that their questions performed several important functions in the structure of their work in, for example, organising ideas, delimiting the scale of the theme, identifying and discussing the many strands and sources of information available to them, and in their reflections on the whole theme. The extent to which one can generalise from a case such as this is an open question. By definition, a case study is ‘the examination of an instance in action’ (Walker, 1993, p.163). As noted earlier, the present case study was undertaken as part of our wider research studies, and here the case is intended to ‘test’ the ideas we have discussed against data collected from these young people and teachers. The case works well – as we discuss in the final section.

These students’ organisational questions about thermochemistry have acted as a powerful management tool in the preparation for the oral presentation. We identified seven distinct phases to their work:

1. Team organization
2. Accumulation of ideas
3. Divergence of ideas
4. Structure and Production
5. Writing
6. Oral presentations and exhibition of the poster and
7. Assessment and evaluation of the overall process.

Needless to say, these phases are not rigidly marked by a sequence of occurrences, rather they were present to a smaller or larger degree in successive meetings as the group recapped and then made progress towards their aims.

The **first phase** was characterized by group organization and the initial choice of theme for the miniproject. At this point the three participants were not part of a friendship group and so there was a period of 'getting to know each other'. *Paula* had come from another classroom and was asked to join two established friends who had been together during the first semester. She joined *Inês* and *Cidália* to make this a more viable group of three people. The initial lack of immediate rapport within the group meant that each stage in the progress of the project was more drawn out and prolonged than for other groups based on established friendships. This feature enabled us to examine their processes in greater detail because each stage had to be explicitly and clearly articulated between themselves, rather than the group moving forward quickly on more implicitly and tacitly understood assumptions. By the last phase of the mini-project it was clear that *Paula* had become well integrated within this small group.

At the start the teacher led the sessions to set out the overall parameters and provide some options for ways of working. It was important, however, that this phase not be prolonged so that responsibility for their work is devolved quickly and unambiguously to the groups. As Light & Cox (2001, p.121) say:

Expecting students to be independent when they are uncertain both about themselves and the group might create serious difficulties.

The balance in the initial phase of the project can, to a certain extent, define the successful active involvement of the students in their projects. In this instance, the teacher led in asking the groups to nominate roles, choose themes and agree rules, and then handed the initiative over to the groups and took a 'facilitative role' only.

We call the **second phase** the 'accumulation of ideas' and, in our case study group, a great number of ideas was generated, mostly by Inês. The other two treated these ideas very seriously and enlarged upon them with their own suggestions. In Figure 1, we show a student's draft where we can see some of the accumulation of ideas. In this figure there are two questions in bold. The 'content' question: "Why is the percentage of corporeal fat different during the course of a day?" was stimulated by the instructions manual of a balance, brought by Inês, to measure the fat percentage through bio impedance. This indicated that percentages of fat could vary along the course of a day. Figure 1 does not represent all of the group's ideas - many were introduced along the phases but not recorded in this way. Inês's natural leadership in this phase was characterized by her many suggestions for sub-themes.

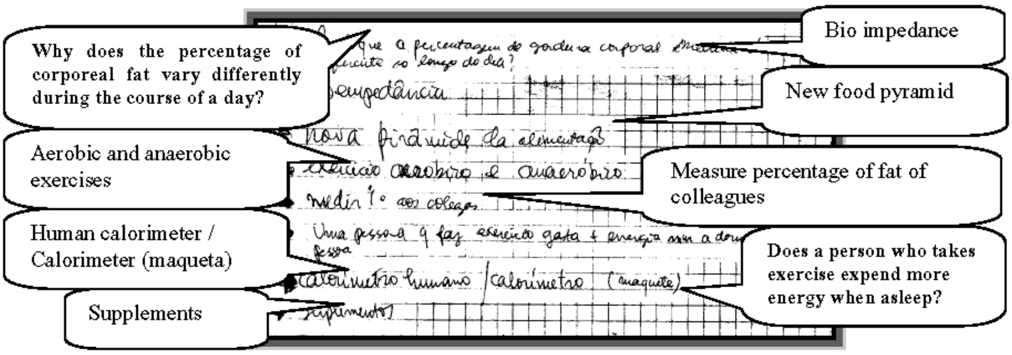

Figure 1. Student's draft during the 'accumulation of ideas'.

This was not an overt exercise in leadership, it was nevertheless present in many of the phases we identified, as she herself admits in the interview:

> Things could have run a different way, if I had wanted them to, though I did not have to 'command' anything to happen, right? Look, we would send each other text (mobile phone) messages: "Are we going to meet somewhere?", "Can you make this place?" and so on. It means everybody could take part in the same way - I did not have to order anybody around. They are both grown up people and each one knows what they have to do, don't they? But, there has to be some initiative.

This interview took place at the end of the mini-project, where she reflects upon the process as a whole. She felt a little that she had been pressed into leadership, not so much by her own inclinations (although some of that was evident) but by her two colleagues' dependence on her to make decisions. The **third phase** of the development of the mini-project was marked by a search for information through several sources, but mostly via the Internet. This information search brought a considerable number of further ideas and sub-themes that, although being linked to the main theme, could not all be treated in same mini-project. Here, the three discussed and diverged in the extent to which these, given the parameters in which they were working, could be treated in the project. For example, the students gleaned through the teacher that to undertake a calorimeter measurement in a real calorimeter – something they thought they might do – is not routine process. Moreover, the three also ran into comprehension difficulties with some of the texts, giving rise to a series of fact-finding questions. These questions were formulated so that Inês could represent the group in meetings with the teacher to generate some feedback and technical support. This 'information overload' contributed to a sense of loss in direction for the project. During an interview meeting with the researcher, *Cidália* relates how she challenged her colleagues with the prospect that they were losing sight of what they were trying to achieve because of the diversity of ideas and themes they were trying to develop.

The beginning of **phase 4** is marked by the point where *Cidália* suggests the creation of a fictional girl character (Lara), who is worried about her fitness and voices this through a series of questions. These questions bring into play many of the sub-themes the students would like explore.

'Lara's' questions are made to appear like a 'brainstorming session' (see Figure 2) that then serves to organize the group's work into several sub-themes.

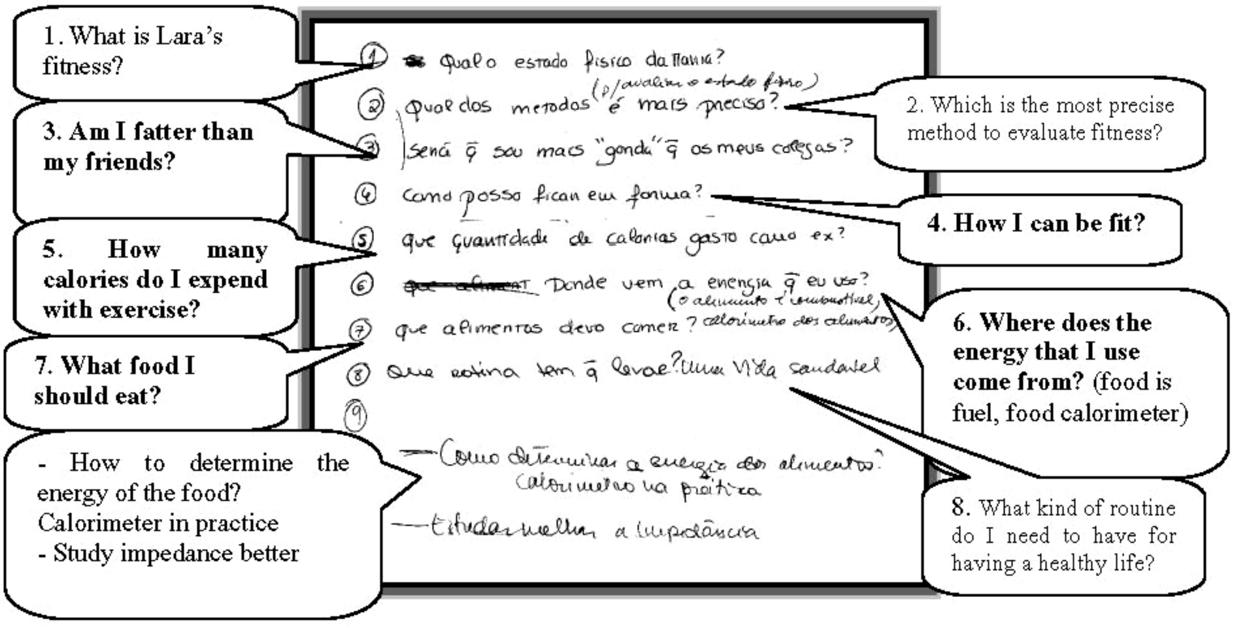

Figure 2. Some orientation questions formulated in the 4th phase

In Figure 2, we highlight in bold the questions asked in the character's voice. These questions formulated by Lara give the group three key sub-themes they wanted to develop. For example, the questions "What food should I eat?" and "Where does the energy that I use come from?" are opportunities to talk about the calorimetry of food. In this context, the questions became a tool for the elaboration, organization and presentation of ideas, and the importance of these and of other kinds of questions arose in Inês interview:

Inês: OK, we had a theme, right? This (showing a page of notes) was at the beginning and here (a second page) was for the meeting with the teacher. Then, we had this idea of Lara ... (leafing and placing pages of notes in order to give to the interviewer) …

Interviewer (I): Here, where you wrote 'Orientation questions'. Is that because I encouraged you to ask questions or because ...

Inês: It's useful ...

I: What do you mean "It's useful"? Do you mean that asking questions is useful? I know that you have already done some other work about asking questions, structuring ideas with questions.

Inês: No, I don't think so... (She continues leafing through her notes, talking about the notes.)

I: When you think about this work and other work you have done in the past, have questions facilitated you work, or not?

Inês: They are a useful way to guide. I don't know! I don't remember all my other work, but I know that questions worked really well here.

The two other students in this small group also saw that asking questions had advantages. For example, *Cidália* added at the end of her interview that she was now asking questions as an aid in studying for her final examinations in chemistry. To this extent, it is worth noting that all the advantages pointed out by Holcomb (1996) and Wlederhold & Kagan (1992), in a more systematic and structural way, were arrived at by these students through spontaneous processes. The use of questions in this phase prompted a greater convergence and a more systematic approach to the miniproject. For example, they experimented with a rudimentary calorimeter in the laboratory and, later, measured (with *Inês's* balance) the fat percentages in a sample of students.

In the **5th phase**, the group composed the poster and the slides for their presentation. This phase was accomplished in *Paula*'s absence, who only came back to join in the group's processes for the next parts of the work. In this phase the written work was eased by the use of the questions that served in organizing the sequence of the presentation, and in reflections on the text. The meetings with the researchers at this time were marked by the writing of the final prose that would embellish the poster and slides as part of the oral presentation of the project. The learning in this phase was more intense for *Inês* and *Cidália*. For example, in one interview *Inês* noted that she had developed skills in working with the software used to the make the poster and the slides for presentation, as shown in Figure 3. She noted, too, that the act of asking questions had served as a means to organize processes and procedures, and to connect their written ideas.

During the oral presentation (**6th phase**) each group had to present their work to the assembled class. Lemke (1993) argues that:

> *Learning sciences means learning to talk science. It also means learning to use this specialized conceptual language in reading and writing, in reasoning and problem solving, and in guiding practical action in the laboratory and in daily life. It means learning to communicate in the language of scientific and to act as member of the community of people who do so (p. 1).*

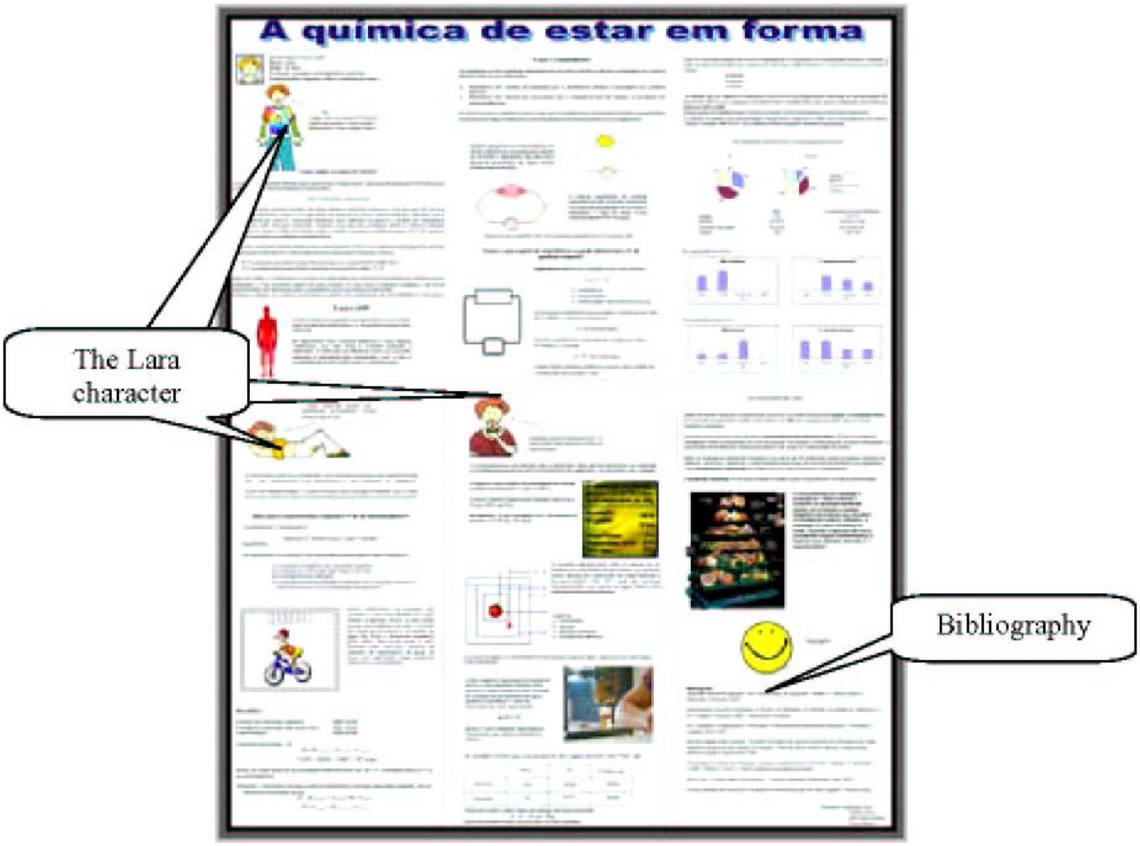

Figure 3. Poster to presentation of the mini-project ‘thermochemistry of fitness’

To Lemke (1993) ‘talking science’ means observing, describing, comparing, classifying, analysing, discussing, hypothesizing, theorizing, **questioning**[5], challenging and arguing. These oral presentations constituted such an opportunity for these first year students to do just this. Each group had 15 minutes of presentation and a further 5 minutes for questions and discussion.

While *Paula* had not taken part in the previous writing phase she returned to cooperate with *Inês* and *Cidália*, sharing the presentation into three parts and with the other two guiding and supporting *Paula* through the talk. Inês introduced the character ‘Lara’ and her questions. In the Figure 4 and 5, we show the two first slides she used.

[5] bold added to the original text

Figures 4 and 5. Two first slides used in the oral presentation

The first slide introduces the character and, in the second slide (Figure 5), shows Lara formulating the first question: “These trousers do not fit me!!! Am I so fat? How I can know how fit I am?” Questions like these were used during all the presentation as a means of introducing and connecting sub-themes to each other and serving as ‘organising’ sub-titles:

How can I know my fitness?

What is impedance? And ‘How can I determine the % fat of a body from its impedance?’

How many calories are in this cake?

How many calories are expended in different physical activities?

How can I calculate this?

Does the human body obey the 1st law of thermodynamics?

The class reacted extremely well to these presentations – not least to this one by the group of three. A swell of questions - and debate - arose at the end of the presentation.

After the oral presentation the posters were gathered in by the teachers for a more detailed assessment (**7th Phase**). The department have inaugurated a complex arrangement for adding the assessment of the group’s work to other, more theoretical parts of the overall programme. A score for each person’s participation in the mini-project was added to the average of the theoretical components, taking into account each student's involvement, not only in the presentation of the mini-project but in its full development. Using specified criteria related to the level of engagement of the students, the teacher’s assessment of the ‘Thermochemistry group’ placed *Inês* with the highest score, followed by *Cidália* and then *Paula*.

Summary questions

Finally, we ourselves ask two questions: *How well are we doing?* and *Where do we go from here?*

This particular strand of our work on organisational questions is in its infancy but has opened up a range of possible avenues for further exploration. The organisational questions asked by the students are very useful instruments in the self-management and processing of group work. For example, in this short study, Phases 1, 2 and 3 of the project development were characterised by questions geared to the initial exploration and organisation of the group’s theme. During the 4th phase, deeper questions were asked, such as: “What methods are the most precise for measuring physical states?” The 5th phase is characterised by the organisation of the final poster and oral outcomes.

We have seen that questions have contributed to students’ engagement in their study of the discipline, bringing an increase in interaction between teacher and students, and an increase in the confidence and trust of the students in asking questions. For example, creating the character called Lara allowed them to ask (sometimes naive) questions, then used to organise the remainder of the work and their reflections as the group. One of the questions ‘asked by Lara’, for example, was: “Am I fatter than my friends?” and was used later in the 6th phase.

The ‘function’ and ‘quality’ of these organisational questions have varied with the context in which they arose and were used, so that factual and conceptual questions are distinctive from organisational and reflective questions, and we see the flow as follows:

Organisational questions can → **Organize Reflection and** → **Promote small group learning**

The overall consensus of those who undertook mini-projects was that these were enormously valuable, enjoyable and very well worth the time and effort invested in them, and that the questions generated in-group, and by audience responses to the presentation, were highly formative of thinking and learning. In this sense, these organisational questions have been useful incentives to promote the active learning of chemistry. Designing inquiry-based-learning with, and for, university students has developed their problem-solving skills, logical reasoning as well as reflective thinking. It has involved working as a member of a team, questioning, being creative, and shaping the skills for continued intellectual development. For Light and Cox (2001), this is one of the most important learning experiences that a university can offer because it enables the exploration of theoretical ideas and conceptual change. This paper has presented some small ways in which students’ questions can be used to shape these processes.

Needless to say, some of the future research questions that flow from this study might be:

How typical are these organisational questions across other groups?

Are these organisational questions general or are there more generic questions that can be used to guide this kind of student investigative work?

How effective is it to organize work in this way – does it suit different kinds of students, different teachers and different kinds of working practices?

Is it worth teaching the use of organisational questions as a vehicle for promoting planning and strategic purposes?

What is the relationship between questions that organize thinking and those that organize practical tasks?

We plan further work in this field to provide some answers to these questions. As noted above, however, we are principally concerned with this last question, and will be presenting data and discussions on these issues in the near future.

Bibliography

Alfke, D. (1974) Asking operational questions. *Science and Children*, *1*(1), 18-19.

Barbosa, R., Jofili, Z. & Watts, D.M. (2004) Cooperating and constructing knowledge: Case studies from Chemistry and Citizenship. *International Journal of Science Education*, in press.

Biggs, J. (1999). *Teaching for quality learning at university*. Philadelphia: Open University Press.

Cohen, E. G. (1994). *Designing Groupwork. Strategies for the heterogeneous classroom* (Second ed.). New York: Teachers College Press.

Felder, R. M., & Brent, R. (2001). Effective strategies for cooperative learning. *Journal Cooperation & Collaboration in College Teaching, 10*(2), 69-72.

Graesser, A. C., & Olde, B. A. (2003). How does one know whether a person understands a device? The quality of the questions the person asks when the device breaks down. *Journal of Educational Psychology, 95*(3), 524-536.

Haller, C. R., Gallagher, V. J., Weldon, T. L., & Felder, R. M. (2000). Dynamics of peer education in cooperative Learning workgroups. *Journal Engineering Education, 89*(3), 285-293.

Holcomb, E. L. (1996). *Asking the right questions: Tools and techniques for teamwork*. Thousand Oaks: Corwin Press, INC.

Hodson, D. (1998) *Teaching and Learning Science. Towards a personalised approach.* Milton Keynes: Open University Press.

Johnson, D. W., & Johnson, R. T. (1987). *Learning together e alone. Cooperative, competitive e individualistic learning* (Second ed.). New Jersey: Prentice-Hall International.

Jones, A.T., Simon, S.A., Black, P.J., Fairbrother, R.W. and Watson J.R. (1992) *Open work in science. Development of investigations in schools.* Hatfield: Association for Science Education.

Lemke, J. L. (1993). *Talking Science: Language, Learning and Values*. New Jersey: Ablex Publishing Corporation Norwood.

Light, G., & Cox, R. (2001). *Learning and Teaching in Higher Education. The Reflective Professional* (1ª Edição ed.). London: Paul Chapman Publishing.

Marbach-AD, G., & Sokolove, P. G. (2000). Good science begins with good questions. *Journal of College Science Teaching, 30*(3), 192-195.

Maskill, R., & Pedrosa de Jesus, H. (1997). Pupils' questions, alternative frameworks and the design of science teaching. *International Journal of Science Education, 19*(7), 781-799.

Nelson, N. (2001). Writing to Learn. In P. Tynjälä (Ed.), *Writing as a learning tool* (1º Edição ed., Vol. 7, pp. 23-36). London: Kluwer Academic Publishers.

Otero, J., & Graesser, A. C. (2001). PREG: Elements of a model of question asking. *Cognition and Instruction, 19*(2), 143-175.

Pearson, G. (1999) *Strategy in action. Strategic understanding and practice*. Harlow: Pearson Education Limited.

Pedrosa de Jesus, H., Teixeira-Dias, J. J. C., & Watts, D. M. (2001, September, 2001). *Quality Questions in Undergraduate Chemistry.* Paper presented at the 6th European Conference on Research in Chemistry Education, Universidade de Aveiro, Portugal.

Pedrosa de Jesus, H., Neri de Souza, F., Teixeira-Dias, J. J. C., & Watts, M. (2001, September, 2001). *Questioning in Chemistry at the University.* Paper presented at the 6th European Conference on Research in Chemical Education, Universidade de Aveiro, Portugal.

Pedrosa de Jesus, H., Teixeira-Dias, J. J. C., & Watts, M. (2003). Question of Chemistry. *International Journal of Science Education, 25*(8), 1015-1034.

Pedrosa de Jesus, H., Neri de Souza, F., Teixeira-Dias, J. J. C., & Watts, M. (2003, April). *Teaching for Quality Learning in Chemistry.* Paper presented at the International Conference Teaching and Learning in Higher Education New Trends and Innovations, Universidade de Aveiro, Portugal.

Sisovic, D., & Bojovic, S. (2000). Approaching the concepts of acids and bases by cooperative learning. *Chemistry Education: Research and Practice in Europe, 1*(2), 263-275.

Slavin, R. E. (1995). *Cooperative Learning* (Second ed.). Massachusetts: Allyn & Bacon.

Tynjälä, P., Mason, L., & Lonka, K. (2001). *Writing as a learning tool* (1º Edição ed. Vol. 7). London: Kluwer Academic Publishers.

Walker, R. (1993) *Real world research.* Oxford: Blackwell Publishing.

Watts, M., Gould, G., & Alsop, S. (1997). Questions of understanding: categorising pupils, questions in science. *School Science Review, 79*(286), 57-63.

Wlederhold, C., & Kagan, S. (1992). Cooperative questioning and critical thinking. In N. Davidson & T. Worsham (Eds.), *Enhancing thinking through cooperative learning* (pp. 198-208). New York: Teachers College Press.

Using ICT within an Innovative Teaching Paradigm in Chemistry

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Introduction

Modelling activities using software rich in animated graphics were reported to be very successful in engaging students' commitment, building confidence in working independently and at their own pace. Many teachers were enthusiastic about modelling as an amplifier of understanding.

Many researchers agree that modelling should be at the center of teaching of sciences (Martinand 1992; Lemeignan & Weil-Barais, 1993 ; Bliss, 1994; Mellar et al., 1994; Tiberghien, 1994, etc.). For science education, it is especially important that students learn to develop models and explanations of natural phenomena (Coleman, 1998; Coleman, Brown, & Rivkin, 1997). Currently, various software tools support students' construction of models (Jackson, Stratford, Krajcik, & Soloway,1996; Dimitracopoulou et al., 1999; Komis et al., 2001), explanations (Sandoval & Reiser, 1997), and arguments (Linn, Bell, & Hsi, 1998) for natural phenomena.

Ogborn (1999) defends the idea that the use of computer modelling systems is a fundamental tool in the learning of Science.

> *"1. We need computer modeling systems which express their models in terms of objects and their actions on one another. Given these, children as young as nine or ten years old can make interesting models and begin to theorize for themselves in a way that many would characterize as 'abstract' or 'mathematical'.*
> *2. We need computer modeling systems which allow one to express relationships between things which handle 'big' and 'small', 'increasing' and 'decreasing' but without requiring one to write algebra. Given these, many students can think effectively about quite complex systems, even involving feedback, and can learn much regular mathematics from them"* (J. Ogborn, 1999, p. 2).

In this article we discuss the process of modelling in the teaching of Sciences via the use of three different mediums: a video; objects from everyday life for the experiments; and the software "ModellingSpace". We are thinking of the advantages of these three pedagogic tools can contribute to the learning of concepts in Chemistry, taking into consideration the cognitive processes that are involved in the modelling.

Theoretical framework

Learning science requires an understanding of concepts and formal relationships, a process that has been proved difficult for students. The research questions that have been formulated for an experiment, as well as the actual practice of the experiment by the students, play an essential role for the transition from representations (descriptions of their manipulations, perceptions of events, etc.) to scientific concepts (Lemeignan & Weil-Barais, 1993).

Research in the field of cognitive psychology has shown that the process of translation among the various symbolic systems is essential for science learning (Vergnaud, 1987). Gerard Vergnaud (1987) has proposed a general theoretical framework (schema) which emphasises the relationships that the student has to construct in order to be able to understand and interpret situations, to communicate their purpose and to make predictions, inferences, etc. He emphasises the role of the student's actions and cognitive resources in the elaboration of knowledge, within a constructivist approach. He distinguishes three functioning registers: a) the register of actions on real objects (student's knowledge is dependent upon the reality: the student acts, manipulates and thus provokes changes and transformations in the world of objects); the register of mental representations (presented in Vergnaud's theory by the «invariants opératoires», or the "constant organisation of the activity associated to classes of problems"); the register of symbolic representations (maths, language, etc.).

In parallel, it has been proposed that the use of technology-based learning environments can facilitate the connection between the three registers: aspects of reality, their conceptualisation and their symbolic representations (Smyrnaiou & Weil-Barais, 2003), while students' understanding was better. However, students' understanding was significantly better when students carried out real experiments before using the software (Smyrnaiou, 2003).

The teaching paradigm

Based on the presented theoretical framework, we discuss an innovative paradigm in Chemistry teaching and specifically in the topic of acidity and alkalinity. The paradigm is designed within a socio-constructivist approach, where the student takes an active role in the construction of his/her knowledge, and it exploits three different mediums: a video in order to motivate students' interest; objects from everyday life for the experiments; the software "ModellingSpace[6]".

First, students look at a video on the changes of red cabbage colours, as a result of the addition of chemical substances. They describe and explain the video, expressing their first representations. Next, they carry-out the experiment using everyday objects. They observe that the vinaigrette of a red

[6] Acknowledgement :IST-Schoolof Tomorrow Project IST-2000-25385 "ModellingSpace", project manager A. Dimitracopoulou of the Aegean University. Participating in this project are: the University of the Aegean, (GR), the University of Patras (GR), the University of Mons-Hainaut (B), the New University of Lisbon (PT), the University of Angers (F) and SchlumbergerSema (SP).

cabbage salad is coloured in red, but when one cleans the salad bowl with a crockery product the container is coloured green. In the presence of lemonade, the cabbage water becomes red. They describe and try to explain the changes.

Finally, they design and virtually run the experiment using "ModellingSpace" (Dimitracopoulou et al., 1999; Komis et al., 2001), which is an open-ended learning environment that allows students to create models, work and reflect on entities (representing objects) and their properties (representing concepts),while they construct the model of the situation using the entities (concrete or abstract), the properties and their relations.

The Research

The research was set out to explore students' descriptions and manipulations while being exposed to the three different mediums: video; real objects; software. Furthermore, students'models while using "ModellingSpace" were explored. Finally, the extent to which the combination of the three mediums enhanced students' understaning was investigated.

The developed teaching paradigm was implemented with six groups of students. The paradigm was implemented separately with each group. Students in the first three groups attended sixth grade of primary school (11 - 12 years old), while students in the other three groups attended third grade of low-secondary school (14-15 years old). Each group consisted of three students. The duration of the implementation was 30 - 40 minutes for each group and students had volunteered to participate. The implementation of the paradigm with each of the six groups was video-recorded, while some of them were also interviewed afterwards.

Results

With the video

The majority of students answer that the change of the colour means the addition of some substances. Others students speak generally for a substance as an indicator, a humid, a solid, etc., and others concretely report an experiment.

The video mobilised the interest of students who participated in the research. Their expressions were positive when they watched the projection of the video several times. Moreover, they evaluated the video positively and they judged it as essential in the teaching when they were asked relatively. We have not observed remarkable differences between students' answers concerning the video in relation to their age.

With the objects

The students realise the experiment using simple daily materials. The fact that they work in teams seems to positively help almost all the teams. The interactions between the students as well as the role that each student plays in the team are very interesting.

The conclusions to which they come to are:

The indicator is "the red cabbage" which changes colour with the addition of a base or acid.

The addition of acid has as a result the change of colour of the indicator into rose.

The addition of base has as a result the change of colour of the indicator into green.

The " lemon", the "seven - up " are acids and with the addition of the indicator their colour becomes rose.

The "detergent for washing of dishes" is a base, and with the addition of the indicator their colour becomes green.

The acid's colour or base's colour does not change with the addition of an increased quantity of the indicator.

The experiments with the objects appeared easy for the majority of students who participated in the research. We did not observe particular differences in relation to students' age concerning their ability to experiment and formulate their conclusions.

With the educational software

Even if almost all the teams of students lead to proportional conclusions after the completion of experiments with the objects, nevertheless the models that they built in the modelling software are different. The representation of previous conclusions with symbolic form varies and is influenced by their age.

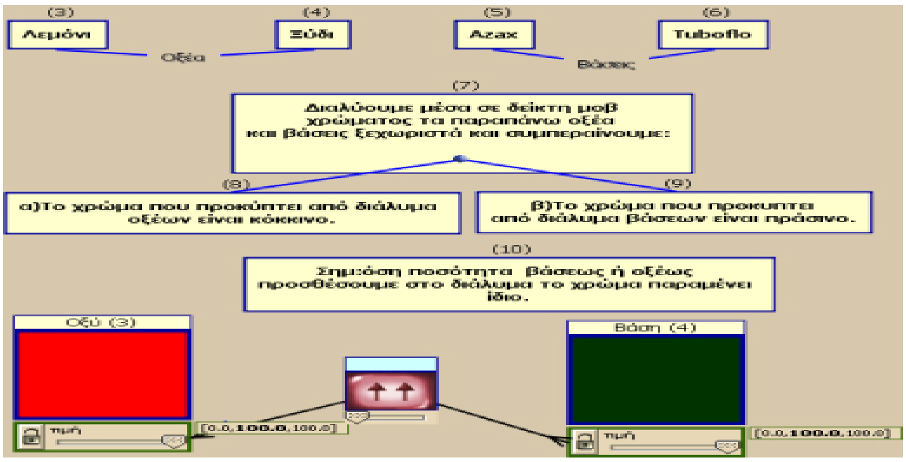

Figure 1. Model of students of low-secondary school (14-15 years old)

Concretely, the models differ as for the type of entities that they used. Thus some students use open-abstract entities, others use entities-text and the two types together, as can be seen from the models that we mention.

Another difference that is presented in their models concerns the entities' names that they use. More specifically, most students of sixth grade of primary school (11 - 12 years old) are influenced by phenomenological descriptions and they name the entities reported in the objects (for example lemon) or in the attributes of objects as the colour (for example rose). By contrast, most students of third grade of low-secondary school (14-15 years old) use the scientific concepts (for example acid, base).

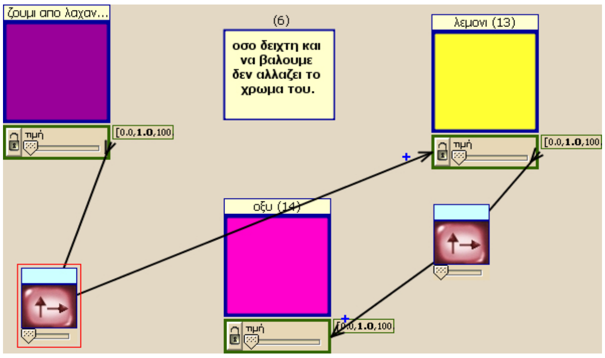

Figure 2. Model of students of low-secondary school (14-15 years old)

Another difference is presented for the semi-quantitative relations that they use in order to connect the entities. Thus enough students of sixth grade of primary school (11 - 12 years old), use two mathematical relations together, the one above in an other or a false relation, while most students of third grade of low-secondary school (14-15 years old) use the suitable semi-quantitave relation which is compatible with the linguistic expression that they use in their conclusion.

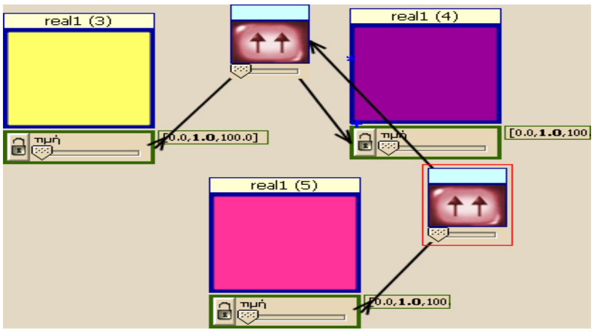

Figure 3. Model of students of sixth grade of primary school (11 - 12 years old)

Evaluation of process

All the students evaluate positively all the phases of the process. They believe that the use of three media helps them to understand better the chemical phenomenon. They do not want to remove from the process one of the three media (video, objects, software of modelling). But their answers differ in the order of the video's use.

Their professor also evaluates positively the use of video, objects and modelling software. Concretely, he says that "*it appears from the way that children functioned that the software is* *attractive and functionnal because in a very short time they have succeeded in accomplishing something that they had acquired as knowledge through the experiments they realised* ". He continues that he would use the same way "*because the particular thematic unit becomes very easily handled in the laboratory with materials of daily use, the thing that a teacher is obliged to direct his students to say that acids and bases can be substances closed in the containers that are found closed in the cupboards of laborator. However, there are also substances that are contained in materials of daily use… the software, then this is a good way, through the representation, to see what the students have understood ...* ".

The data that we have collected from the answers of students and professor allows us to consider that the combination of the advantages of each media leads the students to understand and learn better the chemical phenomenon.

Conclusions

Preliminary results show that students develop rich representations through their exposure to the three media: video; real objects and software. Is seems that when using the real objects, students' representations are influenced by their actions and by the phenomenology of physical objects, which some of the students express in the models they build using abstract entities in the software.

Even if almost all the teams of students reach the same results after the experiment with the daily materials, and formulate their conclusions with the use of almost the same linguistic expressions, nevertheless the representation of these conclusions with symbolic form via the modelling software leads to quite different results. The models are different not only between students of different ages but also between students of the same age. This means that all the students can realise the same experiment and formulate the same conclusions. However they conceive it differently, and focus their attention on different points (eg colour, objects, etc.).

Other difficulties that were observed are a) the students invent mathematical relationships or they use false ones, b) they confuse the colour with the intensity of colour. Thus they are led to the false conclusion that if we add an increased quantity of indicator in an acid solution its colour changes, c) the use of daily objects. For example the use of plastic glasses, the colour of certain substances, the fact that the red cabbage is an indicator that can change many colours as from yellow to green and in certain cases to brown.

Thus we can formulate at this point the proposal that it is essential to realize the experiments on the computer after the realisation of real experiments, in order to advance the reasoning of students in greater depth and pass on to formal thought. The symbolic experiments are not contrary to reality, but can supplement it.This proposal can be verified or denied with the continuity of experiments in the second phase of the program as well as from the reverse process.

References

Bliss, J. (1994), From Mental Models to Modelling in H. Mellar, J. Bliss, R. Boohan, J. Ogborn (Eds), *Learning with Artificial Worlds: Computer Based Modelling in the Curriculum,* The Falmer Press, London.

Coleman, E. B. (1998), Using explanatory knowledge during collaborative problem solving in science. *Journal of the Learning Sciences, 7*(3&4), 387-427.

Coleman, E. B., Brown, A. L., & Rivkin, I. D. (1997), The effect of instructional explanations on learning from scientific texts. *Journal of the Learning Sciences, 6*(4), 347-365.

Dimitracopoulou, A. & Komis, V. (2004), Design Principles for a modeling environment for learning, modelling & collaboration in sciences, In C. Constantinou, Z. Zacharia, P. Commers, (Guest Editors), *International Journal of Continuing Engineering Education and Life-Long Learning (IJCEELL),* Special issue on The Role of Information and Communication Technology in Science Teaching and Learning.

Jackson, S.L., Stratford, S.J., Krajcik, J., & Soloway, E. (1996), Making dynamic modeling accessible to pre-college science students. *Interactive Learning Environments, 4*(3), 233-257.

Komis, V., Dimitracopoulou, A., Politis, P., Avouris, N. (2001), Expérimentations sur l'utilisation d'un logiciel de modélisation par petits groupes d'élèves, *Sciences et techniques éducatives,* Hermes, Avril, vol. 8, n° 1-2, pp. 75-86.

Lemeignan, G. & Weil-Barais, A. (1993), *Construire des concepts en Physique*. Paris, Hachette éducation.

Linn, M. C., Bell, P., & Hsi, S. (1998), Using the internet to enhance student understanding of science: The knowledge integration environment. *Interactive Learning Environments, 6*(1-2), 4-38. Knowledge Representations for Epistemic Practices 42

Martinant, J.-L. (Coord.) (1992), *Enseignement et apprentissage de la modélisation en sciences* . Paris, INRP.

Mellar, H., Bliss, J., Boohan, R., Ogborn, J., Tompsett, (Eds), (1994), *Learning with Artificial Worlds: Computer Based Modelling in the Curriculum,* The Falmer Press, London.

Ogborn, J. (1999), Modeling clay for thinking and learning, In W. Feurzeig & N. Roberts (Eds.), Modeling and simulation in science and mathematics education (pp. 5-37). New York: Springer.

Sandoval, W. A., & Reiser, B. J. (1997), Evolving explanations in high school biology, *Paper presented at the Annual Meeting of the American Educational Research Assn.* . Chicago, IL, March 24-28.

Smyrnaiou, Z. & Weil-Barais, A. (2003), Cognitive evaluation of a technology based learning environment for scientific education . In (Ed) C. Constantinou & Z. Zacharia, "*Computer Based Learning in Sciences*, Proceedings of 6th International Conference CBLIS, 5-10 July, 2003, Nicosia, Cyprus, Vol 2, pp. 125-139.

Smyrnaiou, Z. (2003), *Modélisation: l'apport des logiciels éducatifs*. Thèse, Université Paris V,(http://www.tematice.fr.

Tiberghien, A. (1994), Modeling as a basis for analyzing teaching-learning situations, *Learning and Instruction*, vol. 4 pp. 71-87 .

Vergnaud, G. (1987), « La fonction de l'action et de la symbolisation dans la formation des connaissances chez l'enfant », In J. Piaget, P. Mounoud & J.P. Bronckart (Eds), *Psychologie*, pp. 821-844, Encyclopédie de la Pléiade, Paris, Gallimard.

The Eurobachelor and Euromaster Cometh – an Opportunity or a Threat?

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Introduction

Bologna Declaration

"Development of a coherent and cohesive European Higher Education Area by 2010"

The Bologna Declaration[1] and subsequent communiqués (Prague[2], Berlin[3]) have opened up the possibility of exciting developments in the field of Higher Education, particularly for those who are prepared to think outside of the constraints of what has gone before or of that with which they are immediately familiar. The key features of the original Bologna Declaration were:

- System of easily readable and comparable degrees and diplomas
- Two main cycles, undergraduate & graduate, access to second requires successful completion of first (minimum length 3 years)
- Establishment of an academic credit system (ECTS)
- Mobility
- Quality assurance
- European dimensions in higher education – curricular development, inter- institutional co-operation, mobility schemes and integrated programmes of study, training and research

To many the Bologna Declaration is seen as an opportunity, for instance enabling the development of types of programmes that have not run before and forging new collaborations and partnerships. To others it may be seen as a threat, bringing changes to the *status quo* or maybe leading to decreasing student numbers for existing programmes. This paper focuses attention on some crucial words within that Declaration, namely *graduate* and *integrated programmes of study and training* and addresses the issues that surround them.

Methods

Attention has focused mainly to date on the so-called first cycle, the three year Eurobachelor, where much harmonization may be possible since at this level we are concerned primarily with providing a firm grounding in a subject discipline post school. Much progress has been made in some subject areas through a project known as *Tuning*[4] . To date the disciplines chosen for Tuning have been Business Administration, Education Sciences, Geology, History, Mathematics, Physics, Chemistry and Nursing & European Studies, with Chemistry taking a leading role. The remit of the Project was to 'identify points of reference for generic and subject-specific competences of first and second cycle graduates.' A full discussion of Tuning is outside of the scope of this paper but a major outcome for chemists is that their community has taken Tuning a stage further:

- Producing through the European Chemistry Thematic Network (ECTN) a document[5] which sets out a framework for a Chemistry Eurobachelor
- Having this document approved and ratified by the ECTN governing body and the Federation of European Chemical Societies (FECS) General Assembly
- Electing a Eurobachelor Label Committee who will make recommendations to the Administrative Council of the ECTN Association concerning the award of the label

In the *Berlin Communiqué*[3] of 2003 European ministers further affirmed that, "....degrees should have different defined outcomes. First and second cycle degrees should have different orientations and various profiles in order to accommodate a diversity of individual, academic and labour needs." Thus we can anticipate that at the second cycle stage we might see different degree profiles emerging.

Concurrently there is much discussion of the make up and ultimately, harmonisation of Masters Degrees in general, in Europe. For example, a survey on Masters Degrees and Joint Degrees in Europe has been published[6] by Tauch & Rauhvargers. This survey gives a comprehensive description of the range and type of provision throughout Europe and discusses current trends. Additionally the European University Association[7] has published a paper on Developing Joint Masters Programmes for Europe. Conferences have taken place in Helsinki[8] (March 2003) on Master-level degrees in the context of the Bologna Process & Joint Masters Degrees in Cluj[9] (October 2003).

Thus **now** is the time where we ought to start thinking imaginatively at the Euromaster level about different kinds of courses which fit students for the different roles that they may wish to take in society.

Very recently Mitchell[10] has opened up discussion about a chemistry Euromaster where he identifies four types of Masters' programmes.

- Short programmes which are not intended to form a prerequisite to PhD training
- Standard programmes
- Transitional programmes
- Joint degree programmes

For the last three modes, the stated aim is that they will provide access to PhD training, whereas the first type, the short programme (common for instance in the UK), he suggests, will not normally achieve a European dimension, particularly as they may often not require the writing of a Master Thesis

Results

Linking Masters' programmes predominantly to PhD training would seem an opportunity lost. Understandably equating a 60 credit*, possibly one year Masters programme with a 90-120 credit point second cycle Bologna programme is not sustainable, but having *alternative* Masters' programmes of standard length (normally 2 years) and 90-120 credit points would be. These alternative Masters could fulfil **new European roles** for example.

- Training of school teachers who will have experience of the commercial applications of their discipline
- Producing graduates who were more attuned to employer needs
- Providing interdisciplinary scientists

These are just three examples. Expanding a little on these:

1. Teachers

Generally there are two types of teacher training in Europe – a concurrent model (teaching a subject discipline alongside pedagogy and practical experience) and a consecutive model (training and pedagogy subsequent to the subject discipline degree). A possible consecutive model for 24 month's Masters course could be:

- Mths 1-2 Introduction to, and skills for, industry
- Mths 3-12 Practical industrial training
- Mths13-19 Pedagogy and practical aspects of teacher training
- Mths 20-23 Practical experience in school
- Mth 24 Examinations

2. 'More Attuned Graduates'

- Mths 1-2 Introduction to, and skills for, industry
- Mths 3-6 Industrial chemistry & business
- Mths 7-18 Practical industrial training
- Mths 19-23 Completion of Masters Thesis started in industry
- Mth 24 Examinations

3. Interdisciplinary Scientists

- Mths 1-24 Traditional modular course including Masters Thesis, modules supportive of interdisciplinary theme
- Co-operation between at least two different country based European institutions
- University based with the possibility of the Masters Thesis being conducted in industry at the forefront of the particular technology
- Examples, Nanomagnetic Materials, Environmental Biotechnology & New Processing Technologies

There would be nothing to prevent these Masters degrees leading on to PhD study. Indeed you could argue that such graduates would be more 'well-rounded' and mature through either experience of industry or having studied the context of their scientific discipline. They should be equally, if not more able, to undertake a research programme compared to their *standard* European Masters counterparts. However we should look upon a Masters Degree not only leading to a PhD but as a means of producing:

- Better qualified teachers who will understand more about the importance of chemistry & where it leads
- Graduates who are more attuned to the industrial environment because they will have already experienced it
- Adaptable graduates who span a range of scientific disciplines and can easily move into new technologies

Conclusions

The purpose of this paper is not to lay down specifics but to start people thinking 'outside of the box'. Some people would argue that 3 years is too short a time to train a graduate, others that 8 years is too long. Maybe it is in this middle ground where we should be concentrating, taking 5 years to produce, to coin an commercial phrase, a graduate that is 'fit for purpose', where the *purpose* is in fact a number of *different purposes* dependant on focussed education/training during the last two years of what is in effect a five year course. Indeed in the Berlin communiqué[3], European ministers reaffirmed the adoption of a system essentially based on two main cycles, where for the time being at least, a third cycle is not seen as core.

* 60 credits represent the workload of an academic year of study, 30 credits are given for a semester, and 20 credits represent a term of study.

Implications for Education

As chemists, we have the opportunity to be at the vanguard in the development of new ideas in teaching and learning since we have organisations such as the European Chemistry Thematic Network[11] which provides an active forum for chemistry collaboration at university level. Witness the programme to date[5] on the development of a chemistry Eurobachelor degree, at a far advanced stage compared with many other subject disciplines. Such developments as the Eurobachelor and Euromaster, which will ultimately take place universally, can only be seen as a threat, not an opportunity, if we stand on the sidelines. Let the debate begin!

Bibliography

1 Bologna Declaration
http://www.bologna-berlin2003.de/pdf/bologna_declaration.pdf

2 Prague communiqué http://europa.eu.int/comm/education/prague.pdf

3 Berlin communiqué
http://www.minedu.fi/opm/koulutus/yliopistokoulutus/bologna/berliinikommunikea_en.pdf

4 Tuning http://europa.eu.int/comm/education/policies/educ/tuning/tuning_en.html; www.relint.deusto.es/TuningProject/index.htm; www.let.rug.nl/TuningProject/index.htm

5 Chemistry Eurobachelor http://www.cpe.fr/ectn/tuning%20eurobachelor.htm

6 Survey on Master Degrees and Joint Degrees in Europe, ***EUA thema***, 2002, C Tauch and A Rauhvargers, http://www.minedu.fi/julkaisut/pdf/Survey_Master_Joint_degrees.pdf

7 Developing Joint Masters Programmes for Europe, **EUA**, 2004
http://www.eua.be/eua/jsp/en/upload/Joint_Masters_report.1087219975578.pdf

8 Conference www.bologna-berlin2003.de/pdf/Results.pdf

9 Conference http://eua.ubbcluj.ro

10 The Chemistry "Euromaster": Fact or Fiction? Some Thoughts and Recommendations, T N Mitchell, ***ECTN Newsletter***, 2004, **5**, 2, http://www.cpe.fr/ect//arch/doc/2004/N02/ECTNNews04v05n02_EuroMaster.pdf

11 European Chemistry Thematic Network http://www.cpe.fr/ectn/

Industrial Placements Group

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Introduction

The value of a period of chemically related work experience during an undergraduate chemistry degree programme cannot be overemphasised. These periods or work experience are severally referred to as *Industrial Placement, Stage (France, IUTs), Praktikum (Germany & Austria, Fachhochschule), Co-op Education (USA), Industrial Training, Internship (USA) and Sandwich Degree.* Despite much anecdotal evidence (but unfortunately) a limited amount of published data, many European university chemistry departments have yet to embrace this adjunct to academic study, as a means to produce well-rounded chemistry graduates who have additional skills to offer employers on graduation.

For those not familiar with sandwich education, the following are some key points concerning the state of its adoption, particularly in Europe, its place in UK chemistry education and the types of placement that chemistry undergraduates are involved in.

Geographical spread

- Origins in North America
- Japan Institutes of Technological Sciences (Gijutsu Kagaku Daigaku) 5 months practical training periods
- Well established in UK, Ireland, France (IUTs), Germany/Austria (Fachhochschule), Finland (Technical Universities)
- Programmes funded by the European Union, Greece (Institutions of Technological Education), Hungary
- Being started Poland
- Limited amount Spain (Prácticas en la Industria), Sweden, Netherlands (HBO establishments –Hoger Beroepsonderwijs)

UK data

Industrial Training in UK Chemistry Degree Courses 1998-2001 – facts & figures

- 600 students per year involved (estimate)[1]
- 15% of graduating chemists have experienced some form of industrial training (nationally 11-14% of all subjects)[1]

- 81 Higher Education Institutions provide 1278 chemistry degree courses (figures for 2000)[1]
- 62 Higher Education Institutions offer courses with an element of industrial experience, survey identifying ~100 courses[1]
- (Association for Sandwich Education and Training web site suggests) there are possibly in total ~220, ie ~17% of courses

Typical work placements

Quality Control work
Analytical development work
Operation of state-of-the-art equipment
Research in any branch of chemistry
Pilot plant work
Full scale plant work, involving shift work
Technical sales and customer contacts
Taking a product from bench to production scale
Information Technology

A recently formed working group within the ECTN is looking at sandwich chemistry education with three key objectives. Firstly to spread the word about the benefits of sandwich education, secondly to help others develop programmes of their own and thirdly to gather data about sandwich education within the extended European Community, so that they can examine and document its benefits and ramifications.

Methods

The Working Group currently consists of members from universities in Hungary, Ireland, Portugal and the United Kingdom. Additionally expressions of interest have been received from the wider European Community. At present the group is being reconstituted to include members of the current Leonardo FACE project led by Leo Gros from the Europa Fachhochschule Fresenius, Idstein and others for when that project ceases at the end of this year (2004). Group meetings have been held in Budapest and Toulouse with other communications taking place electronically. A symposium[2] has been held in conjunction with several representatives of the Hungarian chemical industry, where various aspects of sandwich training have been explored.

Results

At their inaugural meeting the members of the group established that they all firmly believe in the importance of industrial placements and that their main goals were:

(i) to promote the benefits of sandwich education to the European chemical community.

(ii) to gather expertise to put systems in place to guide institutions wishing to set up chemistry programmes involving an industrial placement.

(iii) to collect, examine and analyse data about sandwich education within the extended European Community.

In connection with the first two goals a key issue is how such sandwich education can be delivered in the context of the Bologna Declaration. The group are particularly keen to bring on board other countries not yet represented in the membership of the group, especially where there is little or no tradition of sandwich courses.

To achieve the goals a series of activities were agreed upon, which include:

1. The organisation of workshops for industrialists, academics and representatives of the ministry of education of countries where there is no tradition of sandwich courses, to promote this type of educational scheme and develop industrial contacts.
2. Meeting regularly i.e. two or three times a year to monitor the group's activities and discuss new ones.
3. Collecting data regarding the effects industrial placements have on students' performance and careers and carry out adequate statistical analysis.
4. Sponsoring sandwich students on a pilot scheme in a country where there is no tradition of sandwich courses to promote the benefits of industrial placements.

These are ambitious goals and the group agreed that these could not be easily achieved without sufficient funding. Thus, currently, (the latent period) investigations are being undertaken into the feasibility of raising funds from various sources.

Industrial placement programmes as an educational tool for third level degree programmes offer real and quantifiable benefits to all participants, students, employers and universities. For the students it helps build self-confidence and put academic knowledge into practice. It allows them to develop key skills such as effective communication and team working and provides an opportunity to observe decision making processes which is particularly important for multi-national chemical companies. For employers it allows them input into the educational process where they can effect change and will allow them to identify future employees and to retain the best candidates for their industries. For the universities it strengthens their profile with industrial colleagues and can act as an effective lobby group with government. Industrial placement programmes offer significant rewards for all participants.

Conclusion

The group is of the opinion that industrial placements can, and must provide a key feature in the education of our young people. They are encouraged that there is interest from industrialists in this form of education. However they are realistic in the fact that little can be achieved by ‘a band of enthusiasts’ without financial support. Thus this hurdle has to be a priority in the short term if progress is to be made.

Implications for Education

A student who has benefited from an industrial placement is much more able to ‘hit the ground running’ when he/she graduates and moves into fulltime employment. Employers are very aware of this and this is reflected in the fact that such ‘sandwich graduates’ find employment more quickly on graduation and often receive a higher starting salary than their ‘non-sandwich’ peers.

However perhaps more importantly is the huge problem that chemists face in getting across the message concerning the important rôle played by chemistry in the well being of society (and producing its creature comforts) to the population as a whole. How can many of them do that if they have no first hand experience of what the chemical industry does and how it does it? This is a major reason why industrial placements are so important. Since if you further imagine those same chemists without industrial experience going on to teach the next generation of young people in school, how can we hope to enthuse and present a balanced view to pupils of the products and benefits of chemistry in particular, and science in general, to society at large? Pupils in schools must understand the context of chemistry within science and the world and their need to study it.

Many things are possible through sandwich degree programmes which you might not have thought about if you teach in an institute where only full-time degree programmes are offered. For instance academics can be brought up-to-date with new developments in industrial chemistry. Students can earn money to help support their studies. Industry can obtain access to academic research expertise (which it might be prepared to pay for!). New vocational degree programmes can be developed. For industry it is an opportunity to have someone undertake a project that otherwise might not be achieved and so on.

Finally for those already wedded to the idea of sandwich education, we face real challenges (but positively have real opportunities) post Bologna with the standardisation of degree programmes. Sandwich provision must not become a casualty of reorganisation simply because it is too difficult to accommodate!

Bibliography

1 Internal Report by the Royal Society of Chemistry, 2001 (please contact this author for further details)

2 Sandwich Courses, Faculty of Science, Eötvös Loránd University, Budapest, Hungary, 29 August 2003

Posters

A Teachers Training Course on the History of Chemistry

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Abstract

The history of science constitutes a powerful teaching aid, above all for the secondary school level. Its contribution to the learning of scientific contents is a fact that has been recognized for a long time. There are many reasons that can reinforce this idea: among them that, in relation to the students, the history of science fosters their capacity for reasoning, enhances their interest in science, humanises science and helps towards comprehension of the scientific method. In sum, the motivation and the achievement of students would be increased, allowing them to understand how the scientific thought and the scientific theories have been built. Besides, it also permits students to acquire values and attitudes in order to become responsible citizens in the future.

Nevertheless, generally science teachers do not have the training needed to teach sciences with this approach. First, because they do not have an organized and systematic knowledge about the basic contents on the history of science and, second, because they do not know adequate teaching strategies in order to use the history of science as a teaching resource in the classroom. It is true that current science textbooks do include many notes and references about the history of science, but these are clearly insufficient to help teachers in that direction. Thus, in many cases to train teachers becomes a necessity, so that they would be able to accomplish this teaching approach.

The objective of this communication is to present and discuss a program on the history of chemistry developed through a distance education system, with the aim of training science teachers in this direction. In this program the evolution of chemistry is shown by discussing the main facts, scientists, theories and discoveries, with a special emphasis on the evolution of the ideas and on the relationships between science and the social events.

Introduction

The quick changes produced in all areas of social life demand from the corresponding professionals an adaptation to these changes, so that they must constantly update. This is also the case of the professionals devoted to teaching. So, teacher staff must be trained in order to be able to know the latest innovations in knowledge and in new teaching strategies. Continuing training constitutes a good solution to this necessity, becoming in consequence an important issue in the educational policies of all the countries.

On the other hand, the changes in scientific and technological fields might be the ones that have a deeper influence on our daily life. The improvement in the quality of nowadays´ way of living is due, to a great extent, to this fact. But the advances in science and technology have also been the origin of many negative aspects of our world (pollution, global warming, chemical weapons, etc..). Thus, all the citizens and, especially, young students from secondary -and even primary- school should become aware of the benefits and problems of science.

In consequence, special attention to science teaching and science education must be paid. And this attention involves taking into account two aspects: how science is taught in the school and how teachers are prepared for this issue.

Regarding science teaching

A great improvement in science teaching has taken place mainly since the sixties of the last century (Lazarowitz and Tamir, 1994). Thus, new pedagogical approaches have been employed, from the increase of experimental teaching (Tamir, 1990; Kirschner, 1992; Jong, 1998) to the use of many and different teaching aids or specific strategies for sciences. Concerning this last point, one of the most interesting and original perspectives is the science-technological-society (STS) approach, which allows the students to understand the inter-relations between science and technology and the social aspects (SATIS, 1986; Salter, 1996). The evolution of science takes place in a non-isolated context and, therefore, many factors (culture, economy, politics, religion…) have a strong influence on this evolution. And science, in turn, exerts an influence on all these factors. As a result, not only will the learning of the scientific contents be easier, but this will also help the students to perceive the involvement of science in daily life (Solomon, 1988, 1993; Fleming, 1989; Fensham, 1990; Acevedo, 1995; Martins, 2002, among many others). So, those young citizens will become responsible and conscious of the social values of science and technology, as well as of all the problems that can arrive.

Regarding teachers training

To achieve these goals, science teacher staff must be trained in these approaches and strategies. In this respect, continuing training has a significant role. Consequently, universities and institutions offer many and varied courses focussed on this direction.

Distance teaching systems present many advantages for the continuing training of professionals because of its flexibility in time, space and rate of study. In this way, the Spanish Distance University (UNED) has a program for the continuing training of secondary school teachers, that includes many courses devoted to science teachers, regarding different aspects of the teaching task (new pedagogical approaches, teaching aids, strategies, etc.).

The history of science as a teaching aid

The *history of science* constitutes a rich source of examples of STS relationships. Besides, in relation to the learning of students it can have multiple effects, due to the fact that the history of science:

- fosters the capacity of reasoning
- enhances the interest in science
- humanises science and helps the comprehension of the scientific method

- permits the acquisition of values and attitudes.

In sum, on the one hand, the motivation and the achievement of students could be increased, allowing them to understand how scientific thought and scientific theories have been built. On the other hand, the students could become responsible citizens in the future.

For all these reasons (and very probably more reasons can be found) the history of science can be a powerful teaching aid, above all for the secondary school level. This fact has long been recognized, and has been the subject of many researches (Hodson, 1988; Dana, 1990; Duschl, 1994; Matthews, 1994; Gil, 1996; Monk and Osborne, 1997; Scerri and McIntyre, 1997; Moore, 1998; Paixão and Cachapuz, 2000; Tsaparlis, 2000; among many others).

Teacher Training in the History of Science

Generally speaking, science teachers do not have an adequate training to teach sciences with this approach. First, because many of them do not have an organized and systematic knowledge about the basic contents on the history of science (normally history of science is not included in the science university curricula). Second, because they do not know appropriate teaching strategies in order to use the history of science as a teaching resource in the classroom. It is true that current science textbooks do include many notes and references about the history of science, but these are clearly insufficient to help teachers in that direction. As a result, it is very often essential to train teachers, so that they would be able to accomplish this teaching approach.

With all this in mind, a *Course on the history of chemistry for secondary school teachers of sciences* was designed, so that the most significant steps of the history of chemistry were treated, as well as some adequate strategies to be employed in the classroom.

The main aspects of this design and the results of this course will be discussed here.

A course on the history of chemistry through distance education

Structure and methodology

This course belongs to the program of UNED for teachers continuing training and, as a consequence, it is developed through distance teaching methodology. The specific study materials and a tutorial system to guide the teachers registered are, essentially, the methodological guidelines.

Study material

This consists of two written materials, especially designed for this course:

- The basic course material is a textbook entitled “Introduction to the History of Chemistry”, where the students could acquire basic ideas about the evolution of chemistry (Esteban, 2002).

- A didactic guide is also included. It helps and orientates the students about when and how to read and learn the contents of the basic textbook, and where and how to search wider information about those contents. So, this guide shows the objectives of the course; instructions for integrating all the study materials; suggestions about how to focus the contents; requirements for completing the course successfully; literature references for further study, as well as some suitable strategies to be employed in the classroom by teachers.

Assessment

Each student has to prepare a small research study about a topic related to the history of chemistry, accompanied by a discussion about how to incorporate some of these data as a teaching support in the classroom. In this way, the assessment constitutes another element of the training process, because it involves a good teaching exercise.

Tutorials

The tutorials are carried out by the teaching team of the course, constituted by a professor of the university and a collaborator (a secondary school teacher with experience in distance teaching).

In general, it is important to keep regular communication with the teachers (students of the course), so that they would not feel alone in their learning. This communication between teaching team-students (in both directions) takes place:

- By *mail* and *telephone*.
- By *e-mail*, which is a quick and easy way to inform and counsel the students in a personal way.

And besides:

- *Radio* has also been employed in order to discuss some general aspects of the history of chemistry.
- *A web page* has been elaborated (http://www.uned.es/pfp-introduccion-historia-quimica) with wide information (methodology, aims, contents, programme, images, bibliography…); thus, more people would be able to find out many details about this course before registration.

Contents

The main chapters of the history of chemistry -from prehistory up till today- have been developed, attending essentially to the *building process* of the scientific knowledge and the *evolution* of ideas, theories and techniques. The relation of that evolution with the social, economic and political aspects is especially stressed.

These contents have been distributed along 14 themes, grouped in turn *in three blocks*:

Block I. The first steps of chemistry:

1. Chemists facing their history. 2. Primitive chemistry. 3. First theories in chemistry. 4. Alchemy.

Block II. The steps towards science:

5. Medical chemistry in the Renaissance. 6. The chemistry of Boyle. 7. Phlogiston and pneumatic chemistry. 8. Lavoisier and the new chemistry.

Block III. The steps of the new chemistry:

9. Dalton and the atomic theory. 10. Development of physical chemistry. 11. Classification of the elements. 12. Resurgence of organic chemistry. 13. Evolution of inorganic chemistry and analytical chemistry. 14. The chemical industry and the science/technology/society relationships.

Results and conclusions

This course began in 2001, and is still ongoing. About the type of students – with the exception of some physicians and a biologist (and even a psychologist) – all were chemists: 64% men and 36% women.

However, in spite of our good expectations, the number of students has always been low. In principle, this fact may be due to the increasing amount of training courses for science teachers offered by our university, as well as by other institutions. So, our course on history of chemistry has to compete with many other courses, with very varied contents, objectives and subjects.

On the other hand, we also can argue that science teachers are not greatly interested in the history of chemistry, at least no so much as might be thought at first sight. Yet, by contrast, they may find other topics (such as didactic guidelines in chemistry, experimental work or even more specific ones, such as cosmetics or plastics) more “adequate” for sciences and, as a result, this type of course might become more attractive for teachers.

In consequence, we pose some questions:

- *Do science teachers really appreciate the importance of the history of science in relation to their education and training as scientists?*
- *Do science teachers really feel the usefulness of the history of science as a teaching aid in the classroom?*

And – although the importance of the history and philosophy of science is increasing among educators and scientists – unfortunately, the answer to both questions could perhaps be "*No*".

References

Acevedo, J.A. (1995). Educación tecnológica desde una perspectiva CTS. Una breve revisión del tema. *Alambique,* 3, 75-84.

Dana, T.M. (1990). The history and philosophy of science: what does it mean for science classrooms? *The Australian Science Teachers Journal*, 36, 21-26.

Duschl, R.A. (1994). Research on the history and philosophy of science. In Gabel, D.L. (Ed.), *Handbook of Research on Science Teaching*, pp. 443-465. New York: McMillan Publishing Co.

Esteban, S. (2001). *Introducción a la Historia de la Química*. Madrid: UNED (Colección Cuadernos de la UNED)

Fensham, P.J. (1990). What will science education do about technology? *The Australian Science Teachers Journal*, 36, 8-21.

Fleming, R. (1989). Literacy for the technological age. *Science Education*, 73, 391-404.

Gil, D. (1996). New trends in science education. *International Journal of Science Education*, 18, 889-901.

Hodson, D. (1988). Towards a philosophically more valid science curriculum. *Science Education*, 72, 19-40.

Jong, O. (1998). Los experimentos que plantean problemas en las aulas de química: dilemas y soluciones. *Enseñanza de las Ciencias*, 16(2), 305-314.

Kirschner, P.A. (1992). Epistemology, practical work and academic skills in science education. *Science and Education*, 1, 273-299.

Lazarowitz, R. and Tamir, P. (1994). Research on using laboratory instruction in science. In Gabel, D. (Ed.), *Handbook of research on science teaching and learning* (pp. 94-128). New York: McMillan Publishing Co.

Martins, I.P. (2002). Problemas e perspectivas sobre a integraçao CTS no sistema educativo portuguès. *Revista Electrónica de Enseñanza de las Ciencias*, 1(1). On line in [http://www.saum.uvigo.es/reec].

Matthews, M.R. (1994). *Science teaching: The role of history and philosophy of science*. New York: Routledge.

Monk, M. and Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education*, 82, 527-552.

Moore, J.W. (1998). Editorial: History, chemistry and a longer view. *Journal of Chemical Education*, 75, 1199.

Paixão, M.F. and Cachapuz, A. (2000). Mass conservation in chemical reactions: the development of an innovative teaching strategy based on the history and philosophy of science. *Chemistry Education: Research and Practice in Europe*, 1, 201-215. O line in [http://www.uoi.gr/conf_sem/cerapie].

Salter Science (1996). *The Salters´ Approach*. ASE, Association for Science Education. University of York. (UK).

SATIS, Science and Technology in Society (1986). ASE, Association for Science Education. University of York. (UK).

Scerri, E.R. and McIntyre, L. (1997). The case for the philosophy of chemistry. *Synthese*, 111, 213-232.

Solomon, J. (1988). Science society course: tools for thinking about social issues. *International Journal of Science Education*, 14, 397-401.

Solomon, J. (1993). *Teaching science, technology and society.* Walton Halls: Open University Press.

Tamir, P. (1990). Evaluation of student laboratory work and its role in developing policy. In Hegarty-Hazel, E. (Ed.), *The student laboratory and the science curriculum* (pp. 242-267). London: Routledge.

Tsaparlis, G. (2000). Chemistry and science education versus education: a top-down and bottom-up relation. *Chemistry Education: Research and Practice in Europe*, 1, 5-7. On line in [http://www.uoi.gr/conf_sem/cerapie].

What can Students Learn in the Chemistry Laboratory?

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Introduction

Practical work (PW) has had, since long ago, a fundamental role in the education of Chemistry students (Woolnough, 1991; Miguéns & Garrett, 1991). However, doubts have sometimes been raised about its importance as a means for promoting significant learning of Chemistry (Hodson, 1990; 1993).

In order to make PW relevant, it is necessary that it can motivate the students and contribute to the development of a set of skills and competencies that are fundamental in tertiary education (Figueiredo, Viana & Maia, 2001).

The work here presented, developed in that context, is the result of a research project carried out at the University of Évora (Portugal), on the use of PW as an investigative activity of problem solving. This project also had a didactic purpose. It aimed at contributing to the increase in the success of students in chemistry courses included in non-chemistry science degrees, as well as to a revalorization of PW as a privileged strategy for the teaching of chemistry.

Methodology

An initial characterization of students of different courses according to their success in examinations (fig. 1) and also concerning their former preparation (fig.2), done through a questionnaire, including a diagnostic test, gave the basis for the choice of the course in which the experimental intervention should be implemented (Geological Resources Engineering – ERG, the one with lowest results), and of the course used as control group (Hydrologic Resources Engineering – ERH).

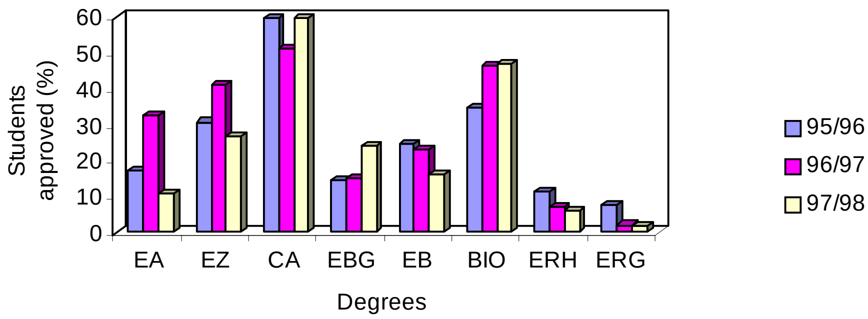


Fig 1. Percentage of students approved in Chemistry I from 95/96 to 97/98

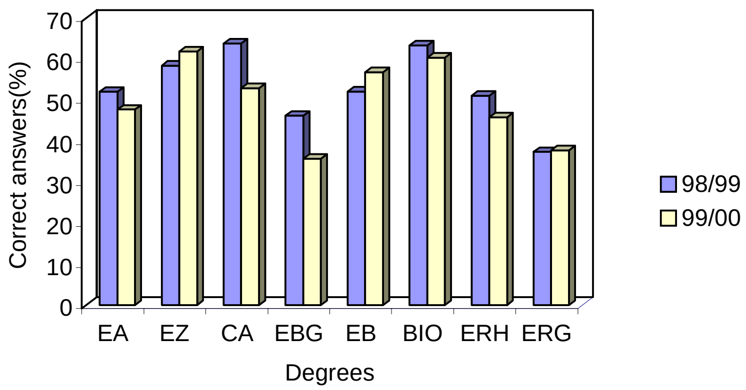


Fig 2. Percentage of correct answers in 98/99 and 99/00

In the graphs: EA – Agronomic Engineering; EZ – Zootechnical Engineering; CA – Environmental Sciences; BG – Biology and Geology; EB – Biophysical Engineering; BIO – Biology; ERH – Hydrological Resources Engineering; ERG – Geological Resources Engineering

The experimental intervention (during the two first semesters of 1998/99 and 1999/2000) consisted in the substitution of the traditional practical work, following "recipes", by practical problems related to areas of interest of the students. The solution of the problems required information research for the design of the experiments that the students had to plan, perform and report.

All the problems were, in a way or another, related to some materials identified by the students:

Fig 3. Sample of marble

Fig 4. Sample of quick lime

Fig 5. Sample of iron ore

The problems proposed to the students and the related topics were:

Problem I - Can we measure the amount of heat associated with the production of calcium hydroxide from calcium oxide?

Related topics

- Specific heat
- 1st Principle of Thermodynamics
- Heat
- Temperature
- Calorific capacity
- Enthalpy variation

Problem II - Can we simulate the mechanism of formation of a plate of limestone?

Related topics

- Le Chatelier's Principle
- Identification of carbonates
- Production of CO_2
- **Precipitation equilibrium**
- Acid-Base equilibrium

Problem III - Can we evaluate the "need for acidity correction" of a soil?

Related topics

- Acid
- Base
- pH
- Titration curve
- Acid – base Titration
- Buffer capacity

Problem IV - Can we determine the amount of iron existing in an iron ore?

Related topics

- Oxidizing agent
- Reducing agent
- Dichromatometry
- Redox Titration
- Redox Indicators

Results

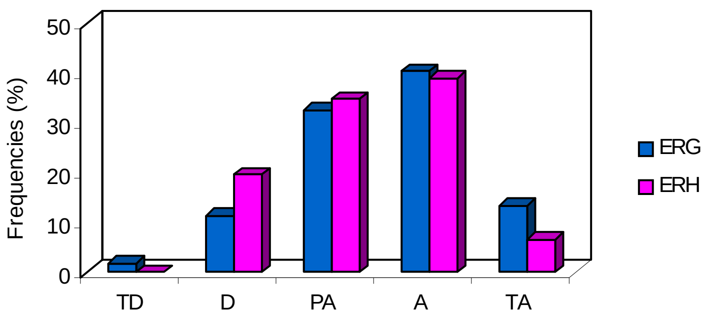
The evaluation of the new approach was done through a questionnaire applied to the students of both courses two years later.

The comparison between the answers given by the two groups of students is illustrated below for some items of the questionnaire. The items were grouped in five categories:

- Type of Approach to Practical Work
- Motivation
- Learning Outcomes
- Usefulness of the Learning Outcomes in Other Contexts
- Scientific Training

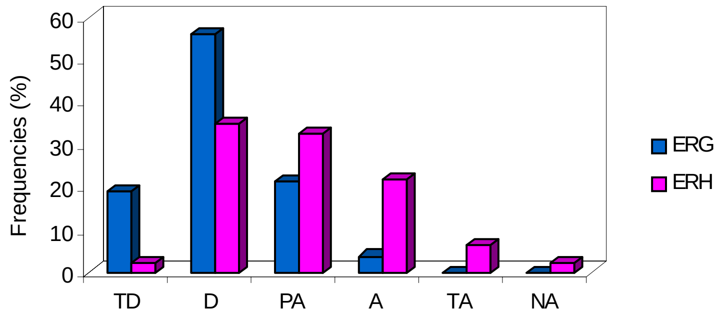
Type of approach to Practical Work

"Giving students an experimental protocol of the recipe type prevents them from attaining important learning outcomes"



Student's t Test (Sig > 0,05)

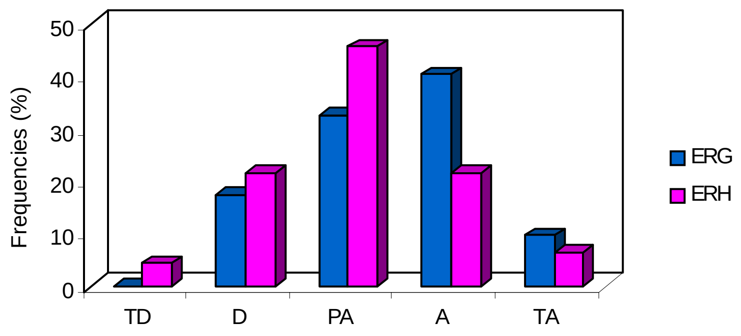
"Practical work should aim only at learning some procedures used in the laboratory"



Student's t Test (Sig < 0,05)

Motivation

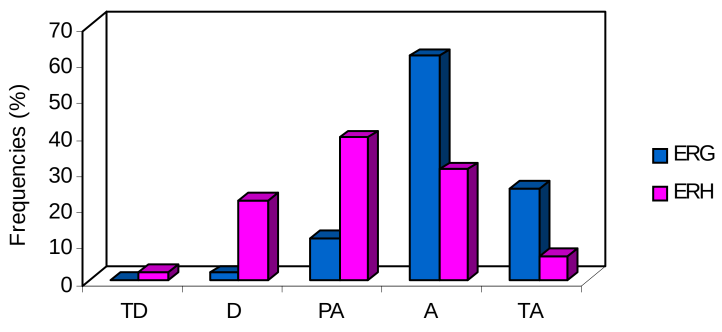
"Without laboratory classes it would have been more difficult to be motivated to study Chemistry"



Student's t Test (Sig < 0,05)

Learning Outcomes

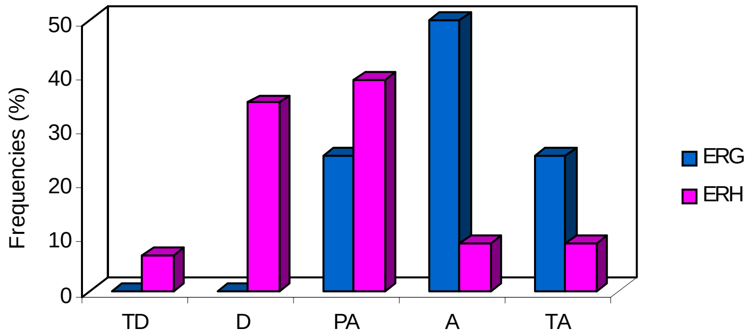
"Laboratory classes were essential to learn some topics in Chemistry"



Student's t Test (Sig < 0,05)

Usefulness of the learning outcomes in other contexts

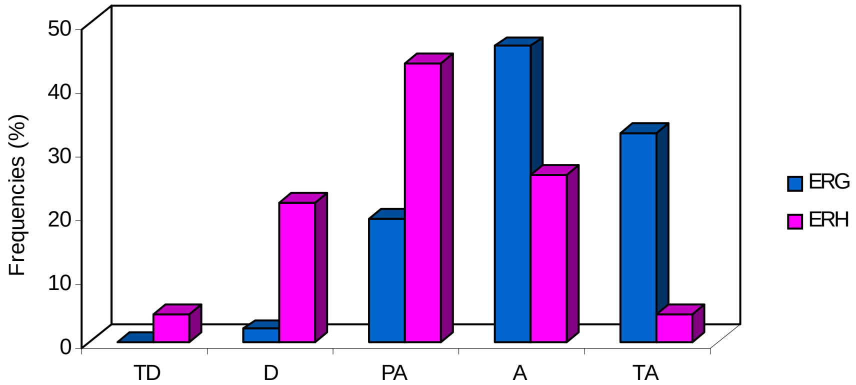
"What I learned on this course was useful for other areas of study in my degree"



Student's t Test (Sig < 0,05)

Scientific Training

"The laboratory classes were important for my scientific training"



Student's t Test (Sig < 0,05)

In the graphs: TD – I Totally Disagree
D – I Disagree
A – I Agree
PA – I Agree in Part
CA – I Agree Completely
NA – No answer
ERG – Geological Resources Engineering
ERH – Hydrological Resources Engineering

Discussion of results

The analysis and comparison of answers with the experimental group (ERG) and control group (ERH) showed that the new approach to the Practical Work:

- Has a greater acceptance from students than the traditional approach based on following recipe type protocols
- Influenced positively the motivation of ERG students
- Influenced positively the success of these students in the Chemistry I course
- Promoted the development of positive attitudes towards learning Chemistry
- Contributed to the development of fundamental competencies for the training of tertiary level students

Bibliography

Miguéns, M. & Garrett, R. M.(1991). Prácticas en la enseñanza de las Ciencias. Problemas y posibilidades. *Enseñanza de las Ciencias*, 9 (3), 229-236.

Woolnough, B. (1991). Setting the scene. *In* Woolnough, B. Ed., *Practical Science*, Milton Keynes: Open University Press.

Hodson, D. (1990). A Critical Look at Practical Work in School Science. *School Science Review*, 70 (256), 33-40.

Hodson, D. (1993). Re-thinking Old Ways: Towards a More Critical Approach to Practical work in School Science. *Studies in Science Education*, 22, 85-142.

Figueiredo, M. R. D. T.; Viana C. A. N.; Maia, M. E. (2001a). Experimental work and the teaching of Chemistry at University. *Proceedings of 6th ECRICE/2nd ECCE*. Cachapuz, A. CD-ROM ed. Aveiro.

Hungarian Students' Misconceptions in Basic Chemistry Concepts

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Introduction

We can speak about research in the field of misconceptions nearly for four decades. In spite of this, in Hungary this research tendency is still in its infancy. In our country, there were only attempts in the natural sciences. It is understandable why. In this field, misconceptions get in the way of new learning.

A misconception is an idea which is inconsistent with scientific theories. These concepts are useful for the individual in daily life, that's why it is difficult to eliminate them. In our research we consider the misconception to be a concept strongly attached to the structure of knowledge and formed during instruction.

Although, many subjects have been investigated, in Hungary there is not yet a wide and comprehensive examination. Such topics are for example: structure of matter, chemical calculation, burning, chemical balancing and the particle model of matter.

The method

We attempt to reveal misconceptions in basic chemical ideas in a PhD work. We wonder whether we can find similar concepts to them in the literature. There can be different results from a different culture or syllabus. For this purpose we prepared four written tests with the following themes:

A) Physical change, chemical change
B) Mole
C) Atom, molecule, ion
D) Element, compound, mixture

The sample

2954 Hungarian secondary school students (grade 7 to 11, aged 13-17) from 17 schools participated in our survey.

Table 1. The sample

Grade/age	7./13	8./14	9./15	10./16	11./17	Sum total
A	174	168	148	150	136	**776**
B	171	166	142	144	127	**750**
C	171	166	136	136	117	**726**
D	163	161	135	127	116	**702**
Sum total	**679**	**661**	**561**	**557**	**496**	**2954**

Results

In preparing the tests, we aimed at selecting tasks found in the literature, thus we can compare the results. Here the most interesting achievements will be seen. Now we present only test D.

In the first task we asked students to define the concepts of element, compound and mixture. This was an open-end question.

Obviously the answers were different, and so their assessment was difficult. We used a known method found in the literature (Abraham, Grzybowski, Renner and Marek (1992).

Table 2. Method used in the classification of pupils' answers - used by Abraham et al. (1992)

Level of understanding	Criteria for scoring	Score
No response	Blank I don't know I don't understand	**0**
No understanding	Repetition of the question Irrelevant or unclear response	**1**
Specific misconception	Responses that include illogical or incorrect information	**2**
Partial understanding with specific misconception	Responses that show understanding of the concept but also make statements which demonstrate a misunderstanding	**3**
Partial understanding	Responses that include at least one of the components of the valid response, but not all the components	**4**
Sound understanding	Responses that include all components of the valid response	**5**

You can see some examples here for students' answers in defining an element. In brackets the percentages can be found noting the proportion of pupils who had that result.

The majority of students didn't answer, or had misconceptions in their responses.

Examples of different scores:

0 : No response. **(23%)**

1 : "Battery that is used for electricity."

Note: In HU there is one word (elem) with two meanings: battery vs. element. **(3%)**

2 : "Neutral chemical particle." **(24%)**

3 : "A simple substance that consists of the same molecules." **(29%)**

4 : "A substance that is made up of the same atoms." **(18%)**

5 : "The sum of atoms with the same atomic number."

"The simplest substance which cannot be separated into simpler substances by chemical method."

(3%)

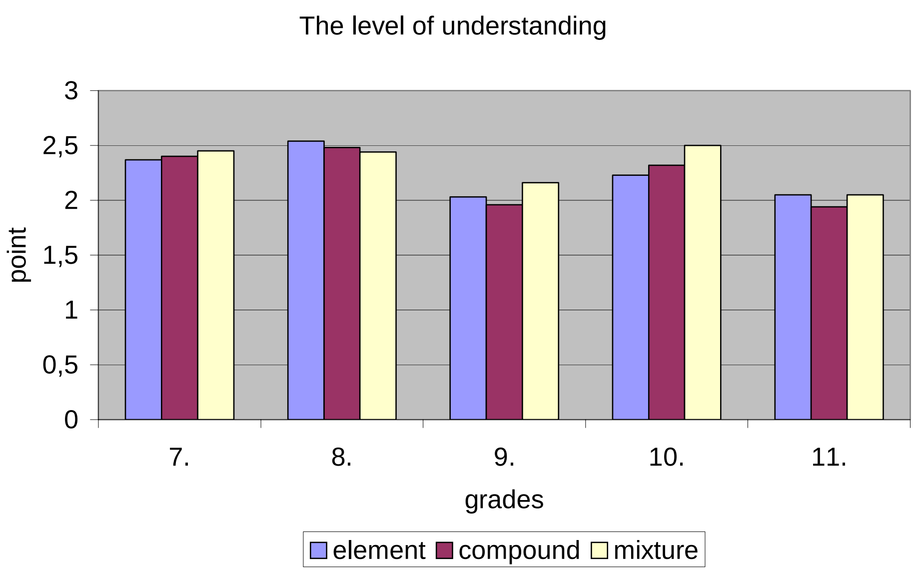

Diagram 1

Diagram 1 shows the level of understanding in different grades. The level is low generally (max. value is 5). Pupils learn about these ideas at 7th grade. We can observe that at 8th and 10th grades the level is higher. In our hypothesis, at these grades students' comprehension of these concepts is higher, because macroscopic knowledge is taught. They learn about inorganic chemistry at 8th grade, and organic chemistry at 10th grade. At the 9th grade the atomic structure is taught on microscopic level and usually pupils have difficulties in moving between these levels.

Further we can see many misconceptions because of these difficulties. In many cases it is true that at 11th grade we can find the lowest level. At this grade only a minority of pupils learn chemistry and only for a career.

After the classification of responses we categorised the answers with the same content. 14 per cent of students believe that an element is a particle. This is a common misconception.

Categories of responses (element)

V_2: substance made up of the same atoms - 11%

V_1: made up of the same atoms - 10%

V_4: element is a chemical particle - 6%

V_{11}: substances in the periodic table - 6%

V_7: element is the smallest part of a substance - 4%

Total 14% : element is a particle (atom, molecule, unit, other)

In task 2 we had some statements from a) to m). Students had to choose the appropriate category/categories for each statement. We wanted to know that they can distinguish between compound and mixture, and that they know which kind of properties the element has.

Task 2: Choose among the following five categories that match the statements below.

E: element	C: compound	M: mixture
N: neither	D: I don’t know	

Which of these substances

a) is made from different atoms
b) can be split into something simpler by chemical means
c) is liquid (25˚C, 0,1 MPa)
d) is made from the same atoms
e) is made from different molecules
f) cannot be split into something simpler by chemical means
g) can be produced only artificially
h) can be separated in a physical way
i) is made from molecules containing many different kinds of atom
j) is made from the same molecules
k) is like a solution
l) the ratio of components is constant in
m) has components that hold their original properties

In diagram 2 we can see misconceptions about the compound. The yellow columns indicate these kinds of statements. If we pay attention thoughtfully, we can observe that these sentences are about the mixture. Pupils mix these concepts.

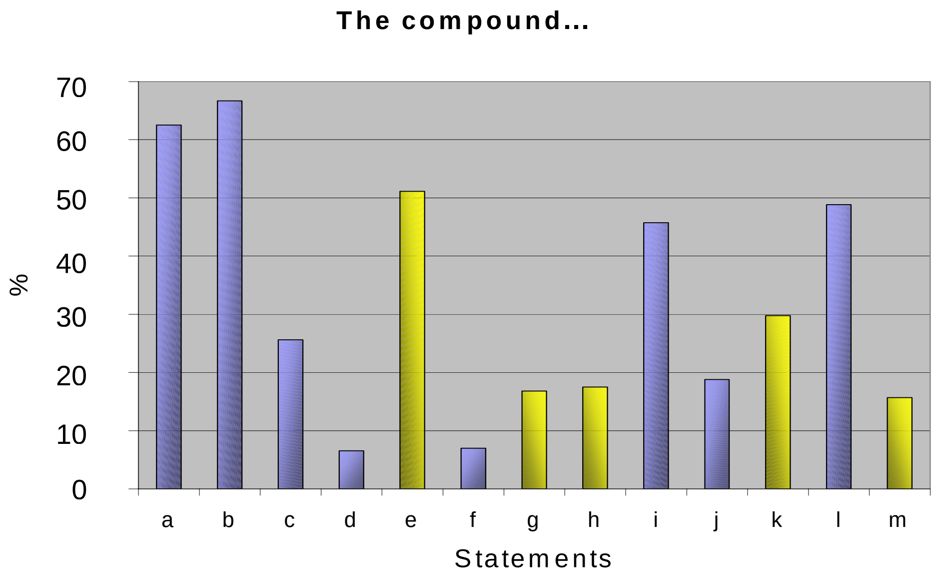

Diagram 2

e) is made from different molecules

k) is like a solution

h) can be separated by physical change

g) can be made only in an artificial way

m) has components that hold original properties

In task 3 pupils had to classify different matters into the next categories:

pure substance: element, pure substance: compound, homogeneous mixture, heterogeneous mixture

These matters were: air, salt, sparkling mineral water, hydrochloric acid, carbon dioxide, bromine, oxygen, petrol, brass, ice cube in water, ozone, ammonium chloride, water, copper, yoghurt with pieces of fruit, steel, tablet of iron (for anaemia).

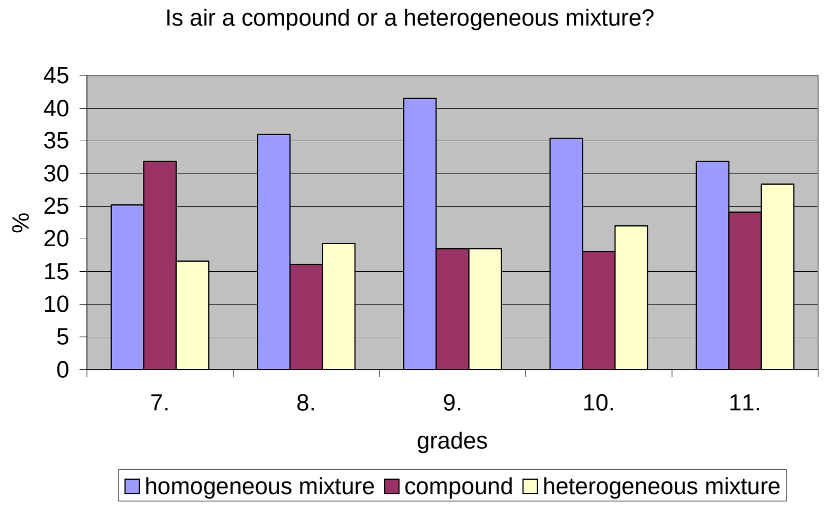

Diagram 3

Air is an example in the textbooks when students learn about mixture. The concept of mixture is difficult to understand for children at an early age (7th grade). But to distinguish between homogeneous and a heterogeneous mixture is more difficult later too.

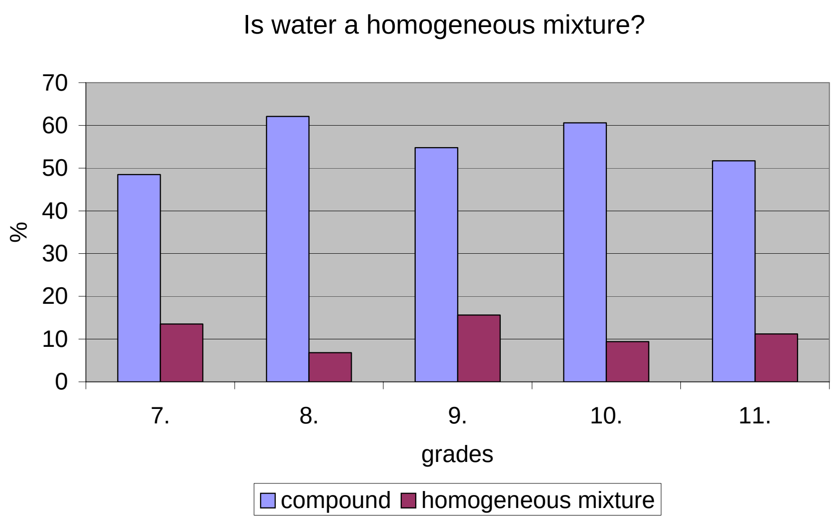

Diagram 4

Water is also an example of learning about a compound. On the whole, ten per cent of pupils said that water is a homogeneous mixture.

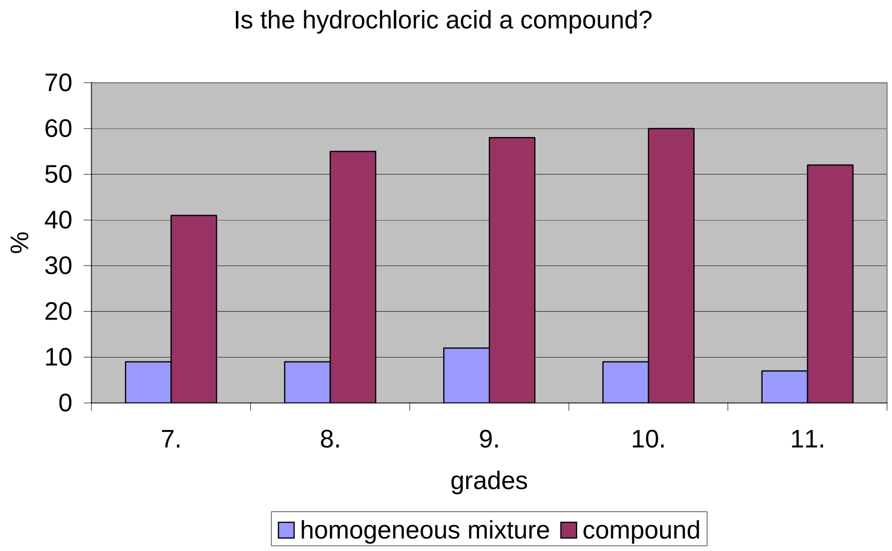

Diagram 5

Hydrochloric acid is a compound in many students' opinion (more than 40 per cent). We can look for the reason in the textbooks and at the symbolic level in the lessons. If we are speaking about hydrochloric acid in a chemical reaction, we write hydrogen chloride on the board. Of course, because the hydrogen chloride reacts in the process. But in this case our student will believe that hydrochloric acid is a compound.

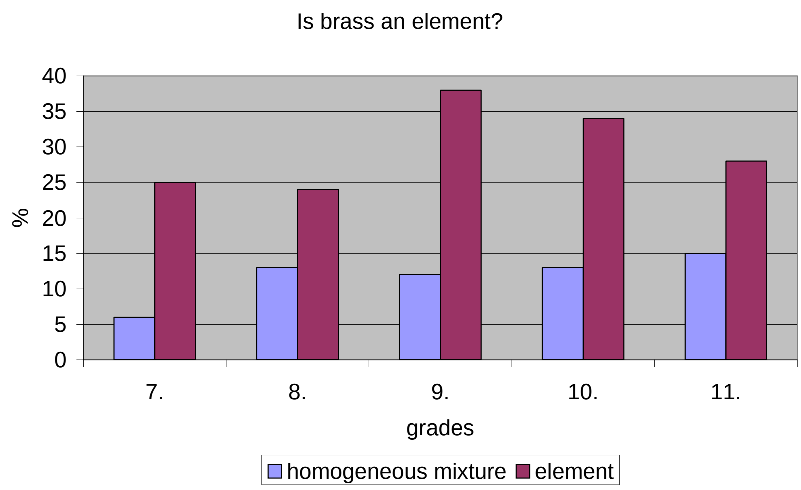

Diagram 6

The problem of brass is very interesting and we may understand it only in Hungarian. In Hungarian, brass is yellow copper, and copper is red copper, if I make a loan translation. So, the difference between the two coppers is only in the colour. Many students think that brass is a species of copper. Why?

Our hypothesis:

1. This case is like the case of phosphorus. There are two species of phosphorus, the yellow one and the red one.
2. Children get in touch with brass in everyday life, and we usually mention this kind of copper.

In task 5 pupils had to fill in incomplete sentences.

Answers that can be chosen by pupils:
atom, atoms, element, elements, molecule, molecules, compound, compounds,
not to be filled in, I don't know

For example:
The form of ammonia …………….. is a triangular pyramid where all the hydrogen …………… are univalent.
The …………… is a composite matter.
When we are heating solid iodine, a vapour is formed and in this vapour iodine ……………… are there. …. and so on.

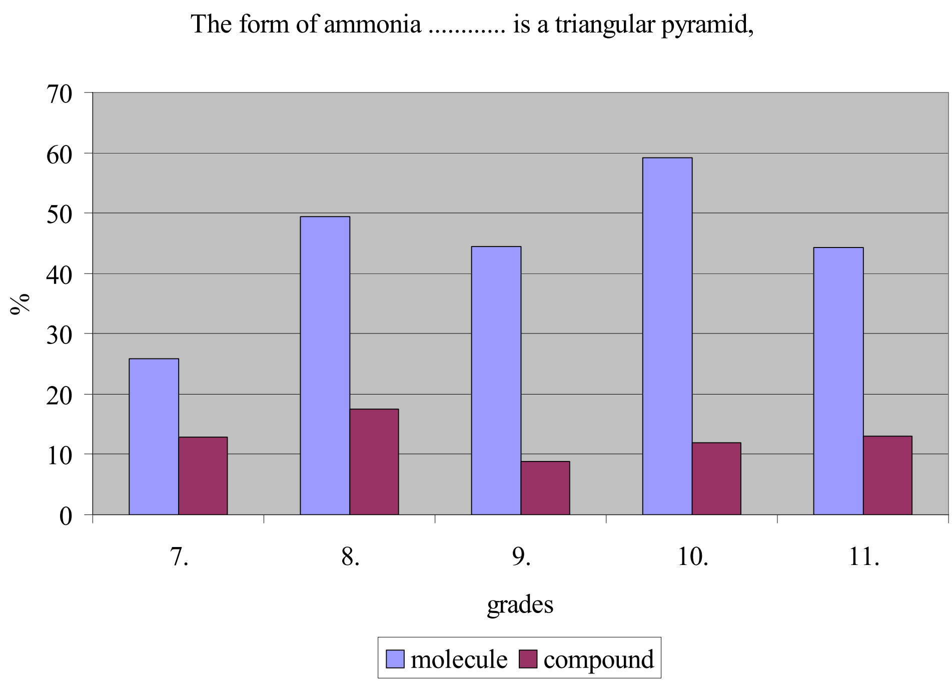

Diagram 7

where all the hydrogen .... are univalent.

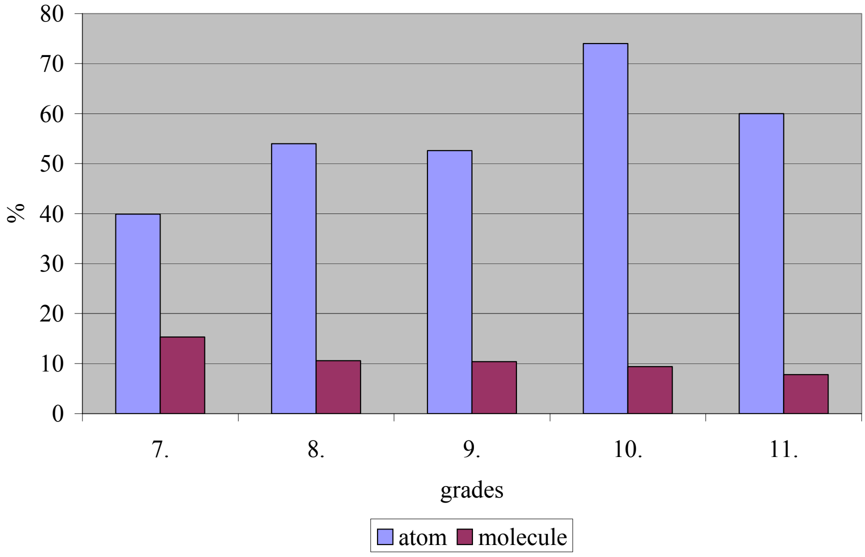

Diagram 8

More than 10 % of students think that in this sentence the ammonia is a compound and this compound has the form of a triangular pyramid. It is a common problem that, in students' opinion, macroscopic thing has microscopic properties. They don't understand the relation between the property of compound and its structure, its particles. Students at 8th and 10th grade have better results.

Some development can be observed with the progress of age, but of course at 11th grade the good result decreased. Numerous students think that this part is about the hydrogen molecule. Maybe those who chose the unsuitable answer think that hydrogen is not in atomic form, it is in a molecule.

Task 6 is after M. J. Sanger (2000)

The following drawings contain representations of atoms and molecules. Classify each of these drawings (labelled 1-5) according to the three characteristics listed below. You should classify all five drawings for each category.

This task was found in the literature. Pupils had to classify five drawings. The three categories were:

1. State of the matter: solid, liquid or gas
2. Physical composition of the matter: pure substance, homogeneous mixture or heterogeneous mixture
3. Chemical composition of the matter: element, compound or both

The drawings in Figure 1 were classified by the students.

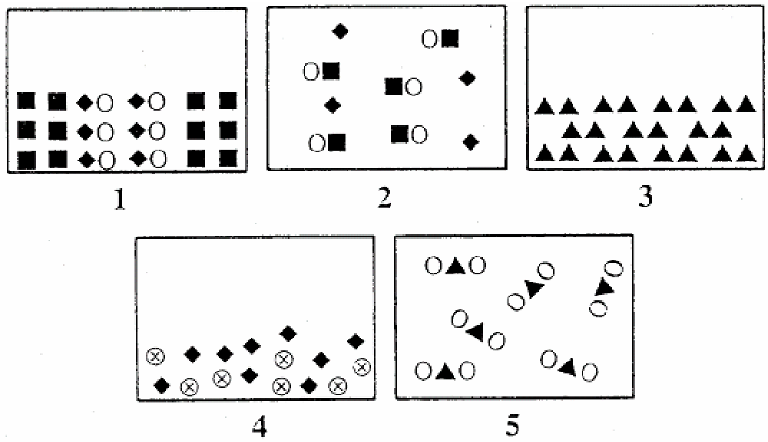

Figure 1

The first one is a solid, heterogeneous mixture. Mixture of element and compound.

The second one is a gas, homogeneous mixture of an element and a compound.

The third one is a solid, pure substance, an element.

The fourth one is a liquid, homogeneous mixture of elements.

The fifth one is a gas, pure substance, a compound.

The next diagrams show the percentage of students who chose each answer given in the exercise. In diagram 9 we can see that pupils were the most successful in choosing the appropriate state of matter. The correct answers are noted by the percentage at the top of the columns.

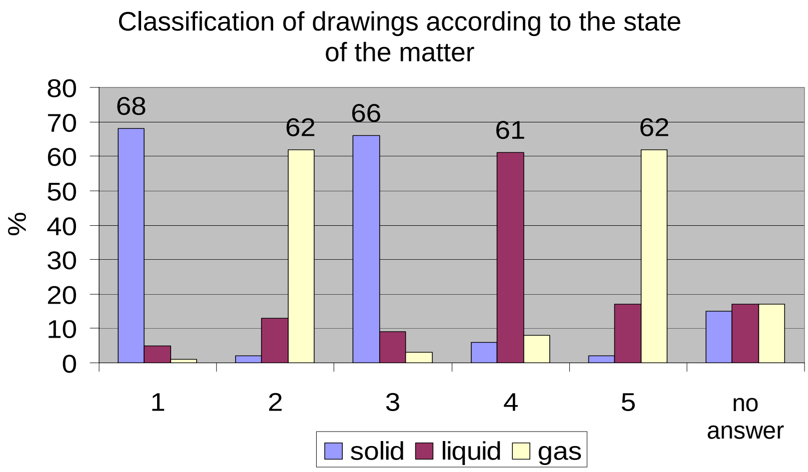

Diagram 9

The greatest problem was to classify the fifth drawing (diagram 10). In the literature we can read that students choose a mixture because they see two kind of particles on the picture, and the mixture is at least composed of two things in their opinion. That is to say, they classified a microscopic drawing based on macroscopic property.

Many students thought that on the fourth picture a compound can be seen in a liquid state (diagram 11). But they didn't count the number of particles in the picture. If it were a compound, the numbers of two kinds of particles would have an appropriate ratio.

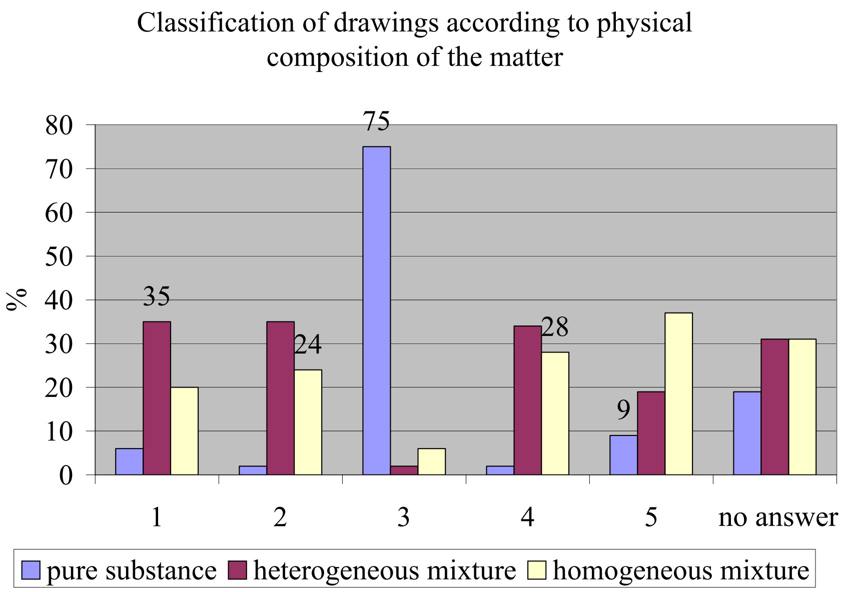

Diagram 10

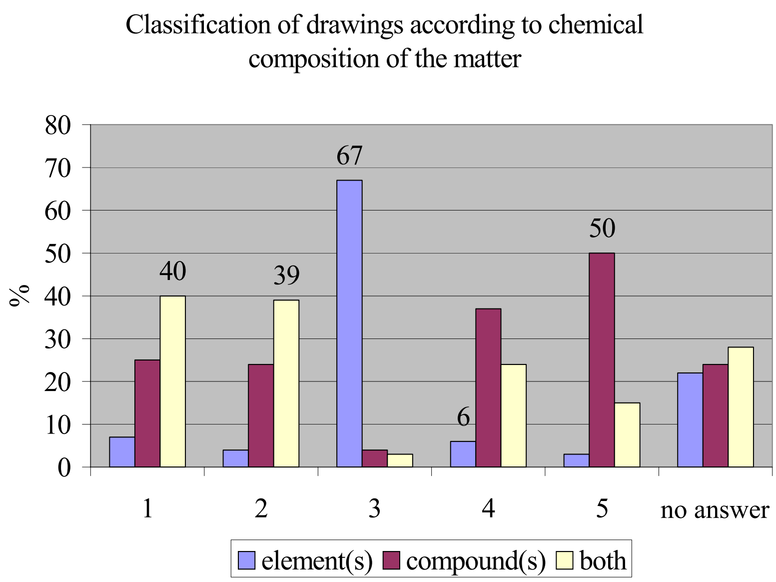

Diagram 11

Conclusions

Here we can see the most common misconceptions detected by us.

1. Very often students identify element with atom.
2. Students distinguish between compound and mixture with difficulty.
3. Some students believe that air is a compound or heterogeneous mixture.
4. Other students think that water is a homogeneous mixture.
5. In the majority of students' opinion, HCl means hydrochloric acid.
6. Brass is a species of copper, it is an element.
7. They confuse the molecule with the compound...
8. … and atom with the molecule.
9. They give macroscopic properties to the particles.

References

ABRAHAM, M. R., GRZYBOWSKI, E. B., RENNER, J. W., and MAREK, E. A. (1992). Understandings and Misunderstandings of Eighth Graders of Five Chemistry Concepts Found in Textbooks. *Journal of Research in Science Teaching 29* (2), 105-120.

SANGER, M. J. (2000) Using Particulate Drawings to Determine and Improve Students' Conceptions of Pure Substances and Mixtures. *Journal of Chemical Education 77* (6) 762-766.

Together We will be Able to Do More. Cooperation between the Faculty of Chemistry of Jagiellonian University and Schools

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Recently, the quality of chemistry teaching has attracted great interest. Nowadays, there are many discussions about it. It is commonly known that there are two basic assumptions – teaching "how to learn", and teaching "how to think" as keys in the didactic process.

It is obvious that a former student is a present teacher, a future teacher is an actual student, and a future student is a pupil now. Thus, both very qualified teacher and very qualified or gifted pupil or student are important. What can we do? How do we act? Why do we collaborate? Why do we assist? In which way can we attract our pupils to chemistry? How to encourage pupils towards chemistry learning? In which proper way we can show that the chemical world is very fascinating? One of the solutions, which would help to be better teachers and students, is co-operation.

Co-operation between higher education institutions and schools is done in many different ways. So it is far from being a new idea. A variety of activities takes place all over the Europe. They are: not always as effective as they are expected to be. Taking this into account, a new ECTN workgroup "Links with Schools" has been created. The Faculty of Chemistry has a representative in this group. The "Links with schools" group will survey what has currently been done in each of the partner countries, analyse the impact of these activities, and hence, create a collection of examples of good practice. We can read about this in the special informal report from the first meeting of this group [1].

The Faculty of Chemistry has a lot of experience in co-operation with schools undertaken by different departments and units. The objectives of these activities are: improving the image of chemistry in the region and in society, developing talents and increasing the quality of chemistry teaching at schools, as well as promoting of the Faculty of Chemistry – encouraging students to study chemistry or environment studies. The brief description of these activities is presented below.

Co-operation is focused on three different groups:

a) students of secondary level of education (pupils),

b) teachers,

c) schools as organisations

The commonly comprehended co-operation with schools is realised through a number of methods.

a) **FOR PUPILS -** working with particularly gifted young people

The Faculty organises a chemistry competition for students of upper secondary schools (syllabus covering only) [2], workshops preparing the pupils for enrolling in the International Chemistry Olympiad, giving content-related support to chemistry competition for secondary level's pupils (organised by NGO) [3], lectures and laboratory classes of the Kraków Youth Association of Science and Art Friends. Selected activities are presented below:

The **chemistry competition** is open to anyone who wants to check and refresh the existing chemistry knowledge. During this competition theoretical problems should be solved in a proper way. We hope that preparing pupils' minds in this way will improve understanding and motivation. It can also encourage pupils to think about planning their future, about chemistry study.

Second proposal- **workshop** is a new way of working with pupils who have a gift for chemistry. The aim of those meetings is to promote the ability to solve problems in chemistry in a complex and multidisciplinary way, to provide pupils with the ability to communicate effectively in a chemistry context, and to improve logical thinking and knowledge construction. This course is so popular, that every year there are about 100 candidates, among whom there are a few future winners of the Chemistry Olympics. It should be noted that there is a preliminary test.

All exercises are divided into the following sections:
1. Reactions in aqueous solutions (the pH of solution, the Equilibrium constant K_c, buffers)
2. Electrochemistry
3.Kinetics
4. Basics of biochemistry
5. Spectroscopy
6. Thermochemistry
7. Complex compounds
8. Inorganic chemistry
9. Quantitative and qualitative analysis

This activity started in the academic year 2000/01.

Table I shows the number of candidates:

Year	Number of candidates
2001/02	80
2002/03	150
2003/04	200
2004/05	300

Since 1993 **The Kraków Youth Society of Friends of Sciences and Arts**, working under the auspices of the Jagiellonian University, has organised special activities for secondary school pupils. These activities give the young people an opportunity to broaden their knowledge and increase their interests within the wide range of sciences and humanities. Thanks to these activities, young people may become acquainted with the university life even before they become students. The Faculty of Chemistry also offers such activities. A number of candidates depends on the number of places in laboratory. Pupils were involved in a large variety of activities, which improved their knowledge of chemistry concepts and processes, and enhanced their intellectual abilities. Chemical activities are carried out experimentally, with pupils working in pairs. One of the most important aspects of the teacher's role during this meeting is to stimulate curiosity and discovery.

The first semester contains following parts:

1. Preparation of crystalline substances: Mohr's salt, chromium potassium sulphate.
2. Preparation of crystals: $CuSO_4$, $K_3Fe(CN)_6$
3. Precipitation reactions of coloured precipitates: salts and hydroxides of Ni(II), Fe(III), Cu(II), Fe(II), Ag(I)
4. Precipitation reactions of precipitates and tests of chemical properties (e.g. amphoteric)
5. Reactivity of metals
6. Oxidation-reduction reactions
7. Basics of complex compounds – aquo-complex, amino-complex, complex stability
8. Qualitative analysis
9. Acid-base titration

The second semester:

1. Purification of organic compounds – crystallisation, distillation, thin-layer chromatography
2. Analysis – identification reactions, group reactions of carbonyl compounds, IR spectroscopy, detection of functional groups
3. Synthesis – laboratory preparation of aspirin, p-nitroaniline, iodoform, methyl orange

The co-operation serves also to improve the image of chemistry as a branch of science combined with promotion of the Faculty. This is realised through:

Open Days - lectures and presentations of laboratories for the pupils (pre-university level of education) organised by the Department of Chemical Education in co-operation with other departments, where the researchers present modern equipment and subjects of investigations.

Here are some of the main lectures at those meetings:

1. Non-ideal solid state
2. Some words about contemporary alchemy
3. A three-dimensional chemistry
4. Liquid crystals
5. Searching for new proteins
6. Chemistry of colours

Educational Fairs - presentation of the education offer of the Faculty for secondary school students prepared by the Office of Career and Promotion.

The displays of experiments with cryogenic liquids – **meetings with cryogenic liquids** are very popular. Because cryogenic liquids are very cold, things that are normally soft are changed in surprising and amusing ways. A lot of interesting experiments with cryogenic liquids are generally known. Others are less known, but there are also some, about which not many people have heard, although they are worth knowing. This meeting is divided into 2 sections:

1. Lecture: Low temperatures - preparation and practical applications
2. Experimental part - Properties of liquid nitrogen, liquid air and liquid and solid argon and properties of substances at low temperatures.

The number of participants and the number of cryogenic displays is given in Table II:

Year	Number of participants	Number of cryogenic displays
2000	3600	44
2001	2500	32
2002	2000	30
2003	3000	38

Jagiellonian University Science Festival – a display of interesting experiments prepared by: Students Union, Organic Chemistry Department, Forensic Chemistry Department, Cryogenics Group, Department of Chemical Education.

The Faculty of Chemistry, Jagiellonian University, as a co-ordinator of CHLASTS project was an organiser of the **International competition for a poster for the school laboratory** "Chemistry is wonderful – make it safe!" [4]. The main aim of the competition was to increase the awareness of secondary school students about the need to adhere to safety procedures while conducting chemical and science experiments. The main causes of accidents that happen in the school/chemistry lab are not the properties of the substances, but human mistakes and errors (lack of caution, disregard of safety rules). All secondary schools students from the countries and regions - members of CHLAST project (Catalonia, Cyprus, Germany, Poland, Portugal) were invited to take part in the competition. The competition was held in two age groups: students of lower secondary school (age approximately 13-16) and students of upper secondary school/high school (age approximately 16-19). The content and idea of a poster referred either to the general idea of safety at school laboratories or to detailed safety procedures.

The jury of the competition were representatives of partner institution of the CHLASTS project. Criteria of assessment were as follows: close link to the subject of the competition, correctness from the point of view of safety, innovation and originality, artistic quality.

The best posters – winners of the international competition will be published in the journal '*Science Education International'*. In Poland more than 800 posters were presented during the competition.

b) **FOR TEACHERS**

The co-operation with teachers is chiefly undertaken by the Department of Chemical Education - ZMNCH (co-ordinators: Z.Kluz, M.M.Poźniczek). This activity involves:
Arrangement of postgraduate studies [5,6], providing the participants with the certificates for chemistry, or natural sciences teaching. Twice a year, scientific sessions are prepared and held, comprising lectures regarding the contemporary chemical knowledge, as well as presentation of works of teachers (poster session), or discussions regarding the achievements and problems of Polish schools (voice messages). The didactic aids are designed at ZMNCH, and in some cases, within students' master theses. The Department also manufactures the aids in question, such as handbooks, workbooks, guides for the teachers, teaching syllabuses, games, software, transparencies, etc. Some selected lectures are presented below:

1. Hydrocarbons' chemistry
2. Salts
3. H_2O_2 – preparation and practical application
4. Organic compounds containing nitrogen
5. Polysaccharides
6. Light and matter

7. Power engineering of chemistry reactions
8. Nomenclature of chemical compounds
9. Bioactive natural combinations
10. Role of complex compounds in the environment

Extra meetings and workshops are also organised by others:

– **workshops** improving professional skills of the teachers e.g. „Methods of interdisciplinary education – workshop for teachers "in the framework of „Interdisciplinary education – challenge of XXI century", Kraków 13-17 December 2000 [7]
– **lectures** by well-known foreign specialists in the area of chemistry education or other nature-based subjects (invited within the frame work of Tempus JEP 12224 STEP „Science Teachers Education Program", and Socrates programmes)
– **presentation of new techniques** such as Microscience experiments [8]
– "*ready for using*" materials such as scenarios of chemistry lessons, teaching materials for teachers and materials for teachers regarding safety issues (in the framework of the CHLASTS project) are prepared and published.

These include:

– Regulations for the chemistry classroom (co-ordinator J. Wilamowski), including:
– Safety regulations for conducting experiments
– Rules of good laboratory practice at basic operations
– Guidelines for teachers conducting chemical experiments
– Cards of Chemical Substances used in schools etc.

c) **FOR SCHOOLS** as organisation

If possible, the Faculty realizes the mission of the "older brother", through **making available specialized equipment** for classes of the Vocational Secondary School of Chemistry.

The campaign of **collecting used or outdated chemical agents from schools**, was introduced this year. As far as we know, this is the first such action in Europe. It was included in the Leonardo da Vinci Project – Chemical Laboratory Safety Training System. Let us give some examples of this activity:

1. Environment Protection – introduction of the low level in schools
   – information action
   – preparation of instructions: How to manage with chemicals and chemical waste in schools

2. Organization of disposal of the old chemical waste – action: “Clear Your School Chemical Laboratory”.
3. Introduction of chemical waste collection.
4. Organization of chemicals storage – common for all schools in the area – free exchange of chemicals – idea “Give and Take for Free”
   – organization of storage room (within the Faculty of Chemistry, Jagiellonian University),
   – organization of transport of chemicals
   – chemical waste recycling organization (collecting, classification and removal by specialized firms)

Taking this into account, all these activities allow different **results** to be achieved:
– The Faculty of Chemistry teaches more than 300 new students every year (three subjects: chemistry, environmental studies, material engineering);
– According to the superior educational authorities, chemistry teaching in the area of the Małopolska Province is at the highest level possible;
– The teachers achieve high degrees of professional development;
– Students reach high places in the International Chemistry Olympiad and other chemistry competitions.

In brief, the Faculty of Chemistry offers a variety of activities, materials and topics meeting the real needs of pupils/students and teachers. Pupils and teachers, students and teachers, schools and our Faculty are taken seriously as partners with interests and competencies. It is obvious that we all can learn from each other.

Bibliography

1. http://www.cpe.fr/ectn/Wkgrp/wkg.ectn_links_with_schools.htm
2. M. Poźniczek: Konkurs Wiedzy Chemicznej jako forma popularyzacji chemii, Niedziałki **3**, 2002
3. A. Warchoł, D. Lewandowska and L. Wasyłyszyn, I Małopolski Konkurs Chemii dla Gimnazjalistów – refleksje organizatorów, XII Szkoła Problemów Dydaktyki Chemii, Kraków, Sucha Beskidzka 4-7 czerwca 2003, Materiały Zjazdowe p.151
4. www.chlasts.org
5. Z. Kluz: Po co Studia Podyplomowe dla nauczycieli, Niedziałki **5**, 1995
6. M. Poźniczek, Z. Kluz, E. Odrowąż: Curriculum of the Interfaculty Postgraduate study for science teachers, TEMPUS SEMINAR – *Interdisciplinary education – challenge of the 21st century*, p. 87-88.
7. *Interdisciplinary education – challenge of the 21st century*, ed. I. Maciejowska, G. Stochel, Kraków 2002,
8. I. Maciejowska: Eksperymenty w skali mikro, Sesja Plakatowa dla Nauczycieli Chemii i Przyrody, Wydział Chemii UJ, Kraków, 2004

Teacher Training for the School of Tomorrow

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Introduction

The responsibility is strictly connected with the teachers' job. Teachers are expected to apply the best methods which can encourage their students to act, to find themselves in a modern community [1].

In 1999, reform of the Polish Educational System was introduced. Changes include organizational and essential aspects: new syllabus, external examination, stress on problem solving, development of transferable skills, new level of education (gymnasium – 3 years lower secondary school) [2]. The scope of the content of teaching in lower secondary school coincides with the previous material realised within primary school (stages 7-8).

Teaching chemistry in upper secondary school is conducted on two levels: the basic one and the broadened one (for the students in chemical profile classes). The basic profile involves 3 hours in the teaching cycle, and the broadened 6 – 8 hours. In accordance with the shortening of the teaching period in upper secondary school from four years to three years, in practice the number of hours assigned for chemistry teaching in profile decreased thus reducing the scope of the content of programme.

The kind of tasks which the students in lower secondary school have to solve during the internal examination has greatly changed. Stress is mainly put on the interpretation of data, e.g. figures or solving the problems, and not on playing back the information from memory [3].

The success of that reform greatly depends on the teachers, and this should be taken into consideration in their training [4].

We decided to make sure whether students intending to work as teachers in future are qualified for the new educational system, and also what mostly causes the difficulties they experience in meeting the challenges of pre-service teachers' training.

In order to obtain teacher qualifications in Poland it is necessary to:

- receive a Bachelor or MSc degree in a specific subject, e.g. chemistry,

- get a credit in a block of pedagogical subjects: 210 hours of psychology + pedagogy, 120 hours of particular didactics, e.g. the methodology of chemical education
- complete 150 hours of teaching practice in schools (practical placement).

As a rule, each teacher-training college (e.g. university department) has a somewhat different approach to and programme of the didactic syllabus. In the Department of Chemical Education at Jagiellonian University the syllabus consists of lectures – 30 hours and 2 practice blocks, each of 45 hours (methodology of chemical education in lower and upper secondary school). During the classes students get acquainted in more detail with: the Syllabus Basis, didactic materials such as: textbook, exercise-book, teacher's guide book, a set of tests and experiments, popular science literature, models, board games ("You can be a chemist", "Chemical memo", "Chemical domino"), computer programmes and multimedia. They acquire the skill of writing the scenarios of current and review lesson as well as of formulating one in upper secondary school, which is then evaluated and commented upon by group colleagues, the teacher of a particular class and the assistant (academic teacher who is a teacher trainer) leading a given student group [5,6].

Methods

The main sources of data come from:

- conspectus prepared by the students,
- observation sheets (observations of lessons led by students were done by academic teachers and group of colleagues),
- test sheets prepared by students (for secondary educational level),
- questionnaires on students' opinions about the course "methodology of chemical education".

Results

Results based on students' scenario

Students prefer to set for the pupils goals from the lowest taxonomic categories. They can not state operation aims. In their works, changeability and variety of work methods is something which is lacking. The logical chain of the lesson is often missing or disturbed. Students have also problems with creating observations and with drawing suitable conclusions from the experiments. The conspectus often consists of a schedule of content but they lack a plan for teacher's and students' acting. Difficulties are also created by the plenary part of the lesson and recapitulation. The suggested part is not interesting enough to get students involved in the topic and to maintain their interest for 45 minutes. Moreover, recapitulation is often based on repeating previously discussed items instead of using exercises to check their application.

Results based on observation

Students have problems with explaining basic knowledge, or else they use too sophisticated terminology and too complicated notions, not adequate to the given level of education. It may be observed that in lower secondary school, instead of the notion valency number being given in the programme, they use the notion oxidation number anticipated in the upper secondary programme, or else they do not perceive the difficulties which students may encounter, having seen the given notion, e.g. methods of writing equations of the reactions. They may also have problems with teaching especially difficult subjects, with which they also have problems and to which they have not given deep thought, e.g. thermodynamics.

What is more, they do not often wait long enough to hear students' answers: the shortest time of waiting is two seconds, and they answer they questions they have passed themselves on their own, as if they are afraid of not finishing the lesson within the given time.

Students give priority to display of experiments at the expense of pupils' own independent work.

The next problem is the fact that they often work with a few of the most active students in the class, "neglecting" the rest. This happens because they do not know the students they are supposed to work with (during training one student conducts only one 'show' lesson at each level of education).

Results based on questionnaires of students' opinions, linked to the course and the first experience in schools, bring the following observations:

- the most useful but also most difficult part of the classes was leading a "show" lesson in school and the following assessment along with discussing the positive elements and the errors;
- formulating questions which would encourage students towards independent thinking proved to be particularly challenging.

Results based on analysis of the test sheets prepared by students (for secondary educational level).

Students prepare a test of knowledge for secondary school pupils. Recurring difficulties are connected with choosing the right number of exercises adequate for the time of test (approx 45 minutes). What is more, they are also connected with formulating precise text exercises (order to be followed) and also selecting the right problems based on the whole knowledge that students should have acquired. Problems also occur if we take into consideration the precise way of evaluating exercises: this means a model of answers with score (points). Students also within classes correct original pupils' test papers (every student is obliged to correct the same works). The tasks of the students are to establish the grading scale and to mark the class works.

Taking into consideration the fact that one ability is connected with one point, students describe pointing abilities in a different way, e.g.

Student **A**	– for a fully correct notation of chemical equation gives	**1** point
Student **B**	– for a fully correct notation of substratum	1 point
	for the correct notation of products	1 point
	balancing of equation	1 point
	Together	**3** points

Different evaluation of the difficulty level also appears, for example some students give higher points for closed rather than open (problem) exercises. A frequent problem is also caused by transporting of the number of acquired points and comparing them with school grades with the lack of formal standards, for example *student A* – for 35% of correct answers gives a positive mark, but *student B* gives a positive mark for 60%. We observed that students are not able to use the Bloom taxonomy to construct a test.

Conclusions

It is observed that students duplicate the way of acting, which they used to observe in their secondary school teachers' method of teaching. However, taking into consideration the changes introduced by the reform, it does not give good results nowadays.

Some problems partly result from experiences acquired during university classes: rare appealing to problem solving methods (lecturing), patterns of chemical reactions notation (according to the university demands) instead of the full notations (required at Polish school). Difficulties are also created by transition from the university laboratory – where chemical substances, solutions and equipment are mainly acquired and prepared by technicians – and where, in Poland, a teacher is left on his/her own.

What is more, some problems while preparing the lessons are connected with being based on intuition and only on school textbooks, instead of conscientious effort and knowledge being used in following the problems, with explanation of difficult and sometimes basic topics. The students also do not use the variety of didactic materials meant for the teachers (only blackboard and chalk or, on the contrary, only computer); furthermore, they do not make use of the outcomes of research with regard to chemical education (they do not know them).

The implication for teachers' training to fit the course to the changed school situation is worth introducing.

Firstly, changes in curricula of the course – pre-service teachers training – are needed. The changes should include:

- more problem solving methods used by teacher trainers themselves,
- stress on conceptual change at primary, secondary and tertiary level of education,
- much more time for teaching principles and methods of assessment.

In addition, the course planners should include selecting as topics of the exercises conspectus those topics which in previous years created special difficulties for the students.

The next step is getting to know the available didactic tools for teachers and publications connected with the methodology of chemical education and pedagogy.

Investigation of the quality of teaching done by our alumni allows for a good course evaluation.

More effective co-operation between the teachers' trainers employed by University and students' supervisors (teachers in schools), allows for more effective use of time spent by students at school. Better communication between an academic teacher and a teacher at school will lead to the situation in which lecturers will know what is going on in a new school, and teachers will be informed about what the students are taught at university.

The last, also very important point is introducing assessment in school reality (during practical placement) to the programme of students' trainings, as a compulsory element to pass.

Literature

1. Richard I. Arends, Uczymy się nauczać, WSiP, Warszawa 1994
2. Ministerstwo Edukacji Narodowej –Podstawa programowa kształcenia ogólnego, Dz.U. Nr 14 z 23.02.99, Reforma Systemu Edukacji, Szkolnictwo Ponadgimnazjlne, Warszawa 2000
3. Bolesław Niemierko, Ocenianie szkolne bez tajemnic, WSiP, Warszawa 2002
4. Kazimierz Denek, O nowy kształt edukacji, Wydawnictwo Edukacyjne AKAPIT, Toruń 1998
5. Informator ECTS chemia, Uniwersytet Jagielloński Wydział Chemii, Kraków 2001
6. Dydaktyka chemii, red. Andrzej Burewicz, Hanna Gulińska, Wydawnictwo UAM, Poznań 2002

Pursuing Sustainability: A Waste Management Pedagogical Approach

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Abstract
A horizontal education of sustainability and chemistry gave birth to a waste management program that is being implemented in Portugal at Instituto Superior de Engenharia do Porto - ISEP. Aiming to enhance the conscientiousness of the decision maker next generation of saving resources managing wastes, and at the same time developing applied chemistry understanding, this program is responsible for the management and fate of all wastes generated in all chemical laboratories where the experimental classes of the Chemical Engineering degree take place, requiring the involvement of all working there: students, teachers plus laboratory technicians. Its main activities regard the establishment of proper strategies for generated disposals and their practical implementation. After alterations in experimental procedures aiming an immediate reduction of generated wastes, a proper selective disposal/collection of wastes was implemented. All gathered wastes entered a reutilization/recycling process after a proper chemical treatment followed by an analytical quality control under the lemma waste treats waste.

Key words: *sustainability; resources; waste management; education of applied chemistry, treatment, chemical laboratory inorganic waste.*

Introduction

The principle of sustainability states that, as we strive for economic prosperity and social enhanced conditions, we must not compromise the quality of life of future generations (Fiksel, 2002). In seeking for a sustainable development, policies and practices around the world are being continuously reshaped to upcoming needs and knowledge. For academic, industrial and research corporations, seeking sustainability involves designing environmentally and socially responsible technologies, products and processes with a full awareness of their life cycle in a cost-benefits perspective.

Learning how to balance natural resource savings, waste reduction and pollution prevention with economic and social development, green chemistry is becoming the central science of sustainability (Ghosh *et al.*, 2001) promoting the quality of life of humankind with the triple bottom line reference of economic, ethic and environmental values.

Over the course of the past decade, green chemistry has demonstrated how fundamental scientific methodologies are to protect human health and the environment in an economically beneficial manner (Anastas *et al.*, 2002). Discussion of green chemistry materials leads today's students to the concepts associated with developing environmental friend processes and products, and reducing the amounts of chemicals during laboratory work. Coherently, current and future chemists and engineers are now being trained to design, develop, and apply chemical processes and products to eliminate or, at least, to reduce the use and generation of hazardous substances to human health and the environment. Significant progress is being made in several key research areas, such as catalysis, the design of safer chemicals and environmental benign solvents, etc (Anastas *et al.*, 2002).

Although this "greening" of chemistry has brought many advantages, it still has no satisfactory answer from the chemical analytical laboratory workers and researchers and other educational staff in our institutions to the wastes generated in their work. The places where green chemistry and environmental subjects are extensively explored are turned by their inherent experimental activities into small quantity generators of hazardous wastes. If these wastes are mismanaged, no matter what the quantity may be, they have the same potential for harm as does fully regulated waste from larger sources.

Due to the noble activity of educating, chemistry schools still today pursue a well-accepted way of polluting (Carvalho, 1998). With several thousands of students in each country executing repeatedly the same experiences along the same week, and several during that year, several thousands of litres of highly toxic hazardous wastes are continuously produced by the end of each year. Depending on the school policy, the fate of these hazardous wastes is often to be disposed of in municipal landfills, in sanitary sewers or in other ways not intended for hazardous waste disposal.

The *in situ* chemical treatment of wastewater generated in school laboratories is another possibility, here explored. This new strategy may turn out excellent teaching material for improving the apprehension of fundamental chemistry knowledge through a transversal learning perspective, combining some typically important chemical reactions (precipitation, neutralisation, etc,) with classic and instrumental analytical methods, and may promote the social and environmental awareness of the future decision-makers of human society.

Thus, a waste management program (WMP) was created for supporting the laboratory activities of the Chemical Engineering department at the Instituto Superior de Engenharia do Porto (ISEP). A new research group called TRELAB (*Tratamento de REsíduos de LABoratório*, Laboratory Waste Treatment) assists the practical implementation of this WMP.

Scope of the waste management program

The WMP is responsible for liquid wastes generated by students of the Chemical (CEng) and Instrumentation and Industrial Quality (IIQEng) Engineering degrees at ISEP. Subjects concerning experimental classes taught in the laboratories of the Chemical Engineering department are listed in table 1. The WMP is responsible for the waste separation strategy, disposal and collection, characterisation, proper chemical treatment, and definition of an adequate fate.

The WMP deals specifically with inorganic liquid toxic wastes. While the organic solvents may be more or less easily separated by means of convenient distillation procedures, inorganic compounds – the majority of wastes generated at ISEP – are still without general detoxification procedures in the literature.

Table 1. Subjects lectured at the Chemical Engineering department including experimental classes.

Subject	Abbreviation	Course	Year / Semester	No. Exp. Works.	No. collected wastes
General Chemistry I	GC I	CEng	1/1	8	17
General Chemistry II	GC II	CEng	1/2	8	30
Instrumental Methods of Analysis	IMA	IIQEng	3/1	3	3
Instrumental Methods of Analysis I	IMA I	CEng	2/1	14	15
Instrumental Methods of Analysis II	IMA II	CEng	2/2	9	10
Chemical Analysis	CA	IIQEng	3/2	4	4
Quantitative Analysis	QnA	CEng	1/2	16	36
Electrochemistry and Corrosion	EC	CEng	2/2	5	35
Quality Control Laboratories	QCL	CEng	1/2	6	23
Residues and Effluents Characterisation	REC	CEng	4/2	1	13
Organic Chemistry laboratories	OCL	CEng	2/2	4	7
Qualitative Analysis	QlA	CEng	1/1	9	9
			TOTAL	87	202

Method

Before the WMP was fully established and able to fulfil the needs of the chemical engineering department in terms of environment and education, several tasks were first performed back in 1999, namely a theoretical characterisation of wastes and awareness campaigns, having students, teachers and technicians as the target population.

A. Theoretical characterisation of wastes

To have an idea about the wastes generated during the laboratory classes, all experimental procedures performed within each subject and throughout one semester were gathered. For each experiment, it was now possible to estimate the diversity of wastes concerned, to have their qualitative characterisation, and to approach their quantitative composition as well as their overall volume.

B. Awareness campaigns

The awareness of students and of school staff for the need of a WMP was also fundamental, for which brief dissertations and seminars were organised. Students attending lectures also filled in a questionnaire at the end of the first year of implementation of the WMP. Several classes were interrupted for this purpose after authorisation by the professors concerned. Professors and technicians were also asked to fill in the same questionnaire, having in mind the target population of students.

C. Selective disposal/collection of wastes

In order to ease subsequent tasks, a selective disposal/collection that enabled an extensive separation of wastes generated in each experiment was defined. The necessary storage containers were left in an accessible place by the WMP staff, inside the laboratory where the corresponding experiment was taking place. To distinguish waste storage containers from others placed in the same laboratory a new label was created.

D. Management, eventual treatment and final destination of stored wastes

Adequate chemical treatment processes are pondered and, as a principle, the elected is that one that employs as treatment agents other wastes, those stored already handled or those that are waiting for treatment. The adoption of this policy is patent in our lemma: *waste treats waste.*

Usually the treatment process consists of the separation of one chemical in a mixture; the formation of a second phase, and the different partition of the constituents between them, allows the recuperation of the chemical ready now to be submitted to a purification process. After evaluation of their final purity the products of the separation are stored in a proper container with a specific label quite distinct from the commercial ones and with similarities to the waste storage container label.

Rendering advantages both in economical and environmental perspectives, the possibility of reusing stored products of waste treatments is the first approach taken by the WMP. Two possibilities of utilisation were looked for, namely teaching experiments and/or chemical treatments of other collected wastes.

Results and discussion

The implementation of a wide WMP made sense only when the existence of wastes was completely recognised and accepted by those who produced them, including here students and staff supporting experimental classes. Only with their co-operation would it be thinkable to identify generated wastes and to perform their separation, both of vital importance for the success of subsequent tasks.

The theoretical characterisation of wastes was feasible after gathering all experimental protocols followed by students. All principles and reactions giving support to these experiments were then studied by TRELAB in order to establish both qualitative and quantitative information regarding all generated liquid wastes.

This action also gave rise to the first ground intervention of the WMP. Changes in some experimental procedures were proposed to professors, having in mind a reduction in the overall volume of generated wastes. Of course a significant decrease, up to a *micro*-scale, was in most cases unthinkable. As an example, analytical experiments based on classic techniques require a visual identification of the end point, for which a significant volume for reactions to occur is always necessary. Another difficulty concerned the already existing glass material, with high volume capacities; a significant reduction of generated wastes would require a high capital investment. Yet, an overall decrease of about 20% in collected liquid wastes was attainable.

Another ground intervention of the WMP concerned the replacement of a certain experiment by a similar one, emanating wastes of less toxicity. For example, in Quantitative Analysis students prepared a $KMnO_4$ solution, and its concentration was accurately established by subsequent titration with As_2O_3. Due to the recognised toxicity of arsenic, and with the agreement of the responsible professor, students are presently using sodium oxalate as a standardising reagent.

The selective disposal/disposal/collection of the generated wastes starts the practical implementation of the WMP. The more extensive the separation was the easier it would be to find out a practical solution for each waste. Hence, from 87 experiments compiled at the theoretical characterisation, around 200 wastes were separately collected (table 1). The strategy taken here can be easily demonstrated with the new work for standardisation of a $KMnO_4$ solution. This gives rise to three distinct wastes: leftovers of $KMnO_4$ with an approximate concentration of 0.02 mol/L, excesses of the $Na_2C_2O_4$ titrant solution with a concentration of approximately 0.0500 mol/L and the solution where the analytical reaction takes place. The capacity of the waste storage containers was also important. This depended not only on the experiment itself but also in the number of students, working individually or in small groups, and in the number of trials that were expected to occur for each experiment.

After selection, appropriate storage containers with capacities ranging from 1 to 5 L were conveniently labelled (Figure 1) and left in the laboratory by the WMP staff, also responsible for replacing the filled containers by an empty one whenever necessary. In case this last task failed, there were always blank labels and empty containers left in each laboratory so that the students could perform this operation and place their wastes properly. The label (Figure 1) needs to be easy to fill, having an additional code number (attributed by the WMP staff) that enables every collected waste to be tracked.

Considering that the practical selective separation of wastes was performed by the students, all of them should be aware of, and in agreement with, the WMP. To ensure this, several campaigns were established inside ISEP immediately after TRELAB's foundation. After one year of existence of the WMP, a questionnaire was passed by 195 students (of a population of 517) at the end of the second semester. The main targets here were students attending the 1st, 2nd and 3rd year of the Chemical Engineering degree, which is the period concerning the majority of the experimental classes covered by the WMP. It was interesting to verify that around 55% of the students had no idea about the average volume of waste that they generate in a General Chemistry II class (question 22 of questionnaire 1), taught at the second semester of the 1st year. Above all, this questionnaire was able to enhance their curiosity about their surrounding reality and to motivate them to actively participate with the WMP.

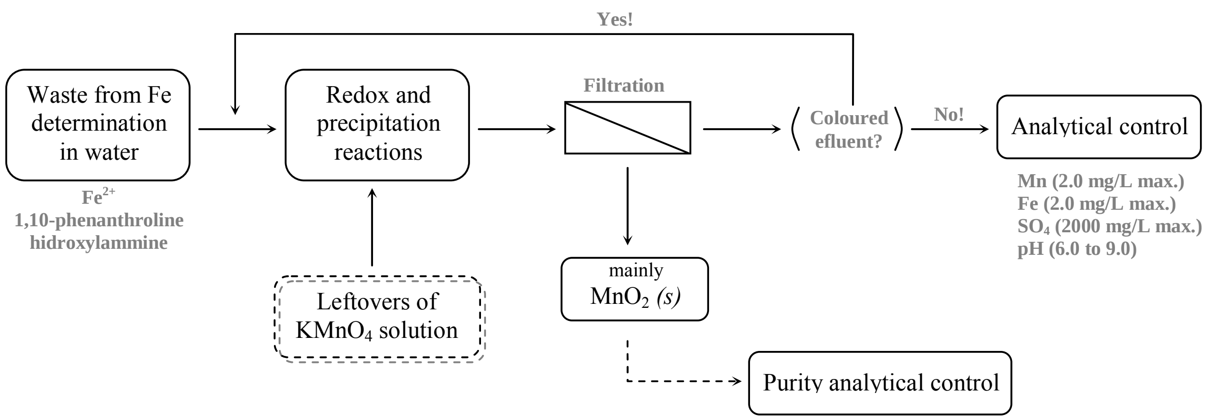
Presently, the motivation of the "old" students and the awareness of the coming ones are performed by several strategies. Students are invited by teachers to follow and/or find the circuit of a certain waste inside the WMP. Several students have also been active participants in the WMP, joining TRELAB and developing research work to find out what to do with the wastes whose fate was not yet defined. Before the end of the second semester, all students of the second year are supposed to treat a certain waste.

After disposal/collection , every waste is stored inside the laboratory where the WMP personnel develop their activities. The first approach here was, and still is, to look for the possibility of reusing a collected waste in another laboratory experiment or in the chemical treatment of other wastes. These are two distinct strategies that allow the automatic "elimination" of wastes, with significant economic and environmental advantages. Of course, some wastes require extensive research regarding the establishment of a proper chemical treatment. Parameters such as environment and costs must be carefully pondered so that the final balance of the WMP comes out positive.

The general approach taken by the WMP is easier to understand with an example, such as the previously indicated wastes generated by the $KMnO_4$ solution standardisation: solutions of $KMnO_4$, of $Na_2C_2O_4$ and of the analytical reaction involved.

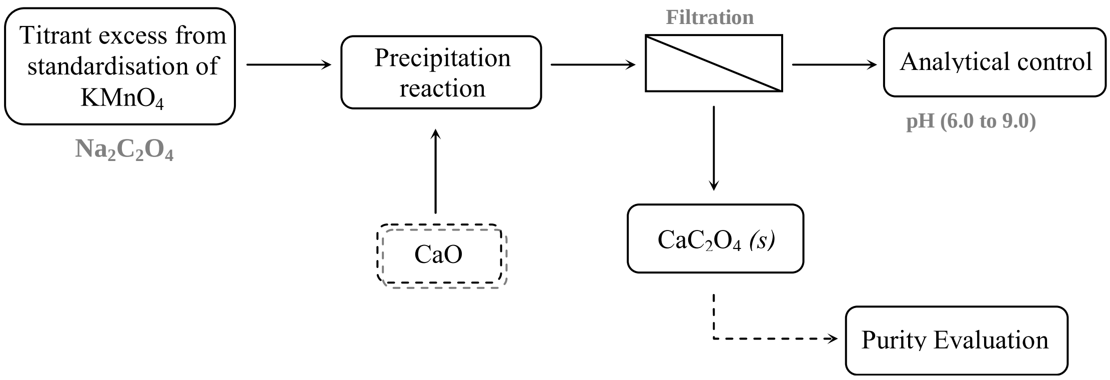
The collected leftovers of $KMnO_4$ solution, when not necessary within laboratory classes, are used to perform the treatment of several other wastes coming from other experimental classes. For example, the quality control of water is performed in the QCL subject (Table 1) and includes the determination of iron. This is performed by measuring the absorbency of the orange Fe (II)·1,10-phenanthroline complex at 510 nm. The mixture of the coloured complex, sulphuric acid and hydroxylamine, composes one of the wastes provided by this experiment. This waste certainly does not respect legislation imposition on manganese ions content, while the levels of iron and sulphate ions do respect it since they are expected to be lower than 2.0 and 2000 mg/L, respectively, the maximum concentrations permitted by Portuguese law (Decreto-Lei 236/98, 1st August). Additionally, its pH is also controlled and must be within 6.0 to 9.0. The treatment applied to this waste is based on the oxidative cleavage by of the organic compounds. The products of this typical reaction are usually not identified, though the overall cleavage is expected to decrease the inherent toxicity (Lunn *et al.*, 1994) of the original compound. To ensure this, eco toxicity tests are now being carried out over the treated waste solution. This oxidative procedure also makes it possible to eliminate the intrinsic colour of the solution, a logical requisite in legislation (Decreto-Lei 236/98, 1st August). The sequence of reactions applied to this case is represented in diagram 1. The effluent generated by filtration is controlled in terms of manganese, iron and sulphate ions concentrations, as well as in terms of pH. It is important to say that two of the experiments performed in IMA I (Table 1) regard the determination of iron and sulphate in waters, for which the students may use the filtrated solution as a sample to perform the experiment and give back the results to the WMP staff. The remaining solid, mostly composed of MnO_2, must be controlled as well, which is firstly performed by thermogravimetry (TG) and differential scanning calorimetry (DSC); these require only a few micrograms of sample, thus avoiding generation of secondary wastes. If TG/DSC analyses are not effective, others can be established from research information given in the literature. When purification is not necessary, depending on its further application, the solid is stored and properly labelled (Figure 2) with its % of Mn. As an example, after proper dissolution (The Index Merck, 1989), it may be used in analytical laboratories to prepare Mn solutions for a UV/Vis determination of Mn by means of its reaction with sodium diethyldithiocarbamate (Fernandezalba *et al.*, 1992). Overall, the $KMnO_4$ leftovers were simply "eliminated" by using them to treat another waste. Due to the strong oxidising properties of this reagent, other ways of reusing it upon the WMP have been already implemented.

Diagram 1. Reuse of $KMnO_4$ leftovers at the treatment of a waste collected from the determination of Fe in water.



The excess of $Na_2C_2O_4$ titrant left by the students may be chemically treated by precipitation reaction that enables $C_2O_4^{2-}$ to be removed from the waste (this anion is not regulated by Portuguese legislation, but it may be withdrawn from solution for other future analytical applications). In order to avoid the addition of unwanted ions to the collected solution, for instance chloride that requires posterior analytical control (maximum value of 150 mg/L at municipal drains), CaO was selected for this purpose (diagram 2). After filtration, the remaining liquid requires only pH control. The CaC_2O_4 solid is submitted to proper analytical control and then stored and accurately labelled (Figure 2). After proper dissolution in diluted HCl or HNO_3, the calcium oxalate solid can be used for the determination of calcium by UV/Vis (Wrobel *et al.*, 1997) or Atomic Absorption (Schron *et al.*, 1998) spectra.

Diagram 2. Treatment for the excess of titrant ($Na_2C_2O_4$) collected from the standardisation of a $KMnO_4$ solution.



The third generate waste, resulting from the analytical reaction for standardisation of the $KMnO_4$ solution (equation 1), seemed far more complex. This solution was expected to have mainly Mn^{2+}. The reaction concerned is self-indicated, since $KMnO_4$ is used in the burette and a drop of its excess gives rise to a rose colour. This is a non-persistent coloration due to the reaction of $KMnO_4$ with the already present Mn^{2+} and subsequent formation of the black solid MnO_2 (equation 2).

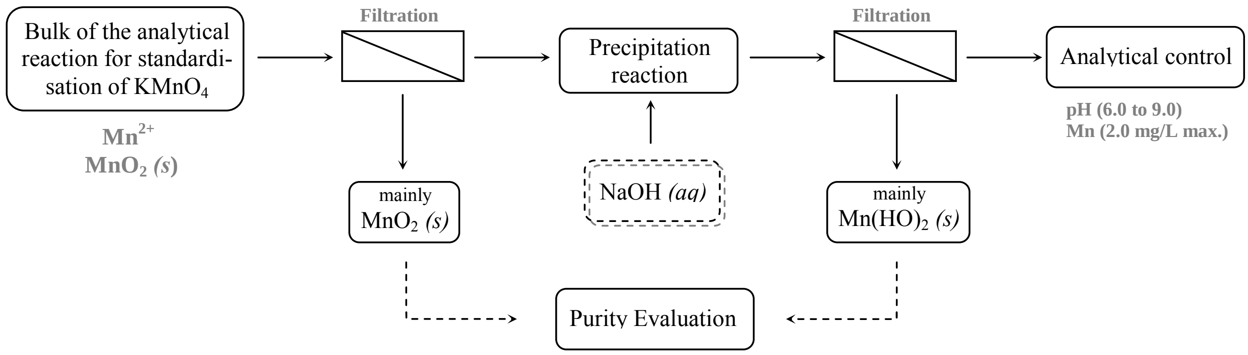
$$2\,MnO_4^- \,(aq) + 5H_2C_2O_4\,(aq) + 6H_3O^+ \rightleftharpoons 2Mn^{2+}\,(aq) + 10CO_2\,(g) + 14H_2O\,(l) \qquad \text{(eq. 1)}$$

$$2\,MnO_4^-\,(aq) + 3Mn^{2+}\,(aq) + 6H_2O \rightleftharpoons 4H_3O^+\,(aq) + 5MnO_2\,(s) \qquad \text{(eq. 2)}$$

The presence of a solid implies that the first approach would be to isolate it by filtration (Diagram 3). This solid might be perceptible within time and if students accidentally proceeded with a great excess of $KMnO_4$. After gathering a significant amount of solid that is expected to have mainly MnO_2, its purity was evaluated and added to the label. After convenient purification, this solid may have several practical applications, being used as a pigment for browning gun barrels, as a drier for paints and varnishes, and for printing and dyeing textiles (The Index Merck, 1989).

The main inorganic component of the waste was then isolated from the solution as a hydroxide precipitate, $Mn(HO)_2$ (Diagram 3). For this purpose, leftovers of a sodium hydroxide solution coming from another experiment performed at the QlA subject (table 1) were used. The liquid phase collected at the filtration procedure was controlled in terms of its Mn content and pH. The solid was stored and properly labelled (Figure 2) after purity evaluation, having a major expected composition of $Mn(HO)_2$. It may be used after in other experiments, for example at the Atomic Absorption determination of Mn (Bhattacharyya *et al.*, 1996) when the stock standard solution is conveniently acidified.

Diagram 3. Treatment for the waste generated by the analytical reaction for standardisation of the $KMnO_4$ solution.



Basically, all waste solutions collected by the WMP are being managed under the above described strategy. Solutions are reused, recycled or chemically treated, following further analytical control to fulfil requirements in legislation. When solids are formed, several practical applications may be looked for to enable their future utilisation, pursuing a sustainable perspective. Some of these are used today in teaching laboratories and others are still under purification processes. One new possibility brought out by this *in side* generation of solids is the replacement of some teaching experiments, thus enabling their consumption inside the Chemical Engineering department.

Until now, several dozens of other practical and simple solutions have been found. Of course, there is a long road to be travelled until solutions for all collected wastes are known. Some of the attained solids are also waiting for a practical application. If it proves impossible to use them inside the laboratories, the probability of sending them out to a specific waste treatment industry may always be considered. If so, the costs involved at the waste treatment will be significantly lowered, since the weight of the overall liquid waste (of several Kg) is reduced to a few grams of solid. Generally, the industries dedicated to the waste treatment charge for this operation in terms of weight (waste plus container).

Overall, since the WMP was implemented, more than 2000 L of hazard wastes have been eliminated from municipal drains, contributing both to preserving the environment and to improving the chemistry education practised at ISEP. Besides, the theoretical principles taught in the chemistry school of today are sustained by the practical experiments. In the future, the main goal searched by the WMP is to approach the desired sustainability within this educational institution.

Main conclusions

Combining environmental protection and sustainability, a WMP was implemented at ISEP. It starts with the student’s co-operation at the selective disposal/collection of wastes and ends up with their motivation to actively participate in the program. To defy them to take “care” of a stored waste or to look for it at the “circuit” established by the WMP are tempting challenges.

Besides the economic and environmental advantages, this program contributes to a transversal and integrated learning system, and thus to the development of student's skills promoting their self confidence is solving the actual problems of our society, thus – on a small, and then more manageable scale – stimulating them towards public participation in larger scale problems.

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References

Anastas PT and Kirchhoff MM (2002). Origins, current status, and future challenges of green chemistry. *Accounts of chemical research*, 35, 686-694.

Bhattacharyya SS, Mandal B, Das AK (1996). Determination of manganese in environmental samples (eg coal fly ash) by electrothermal AAS after its separation with a liquid chelating ion exchanger. *Fresenius J. Anal. Chem.*, 355, 180-182.

Carvalho, MFNN (1998). Segurança em Laboratórios de Ensino ou Investigação em Química: Considerações Gerais. *Boletim da Sociedade Portuguesa de Química*, 69, 7-13.

Decreto-Lei nº 236/98 de 1 de Agosto (1998). Estabelece normas, critérios e objectivos de qualidade com a finalidade de proteger o meio aquático e melhorar a qualidade das águas em função dos seus principais usos. Ministério do Ambiente, *Diário da República, I Série-A*, 176, 3676-3722.

Fernandezalba AR, Martinezvidal JL, Aguilera P, Freniche F, Aguera A (1992). Simultaneous 2nd-derivative spectrophotometric determination of manganese and copper. *Anal. Lett.*, 25, 1581-1593.

Fiksel, J (2002). Sustainable development through industrial ecology. *Advanced Sustainability through green chemistry and engineering*, 823, 13-29.

Ghosh A, Gupta SS, Bartos MJ, Hangun Y, Vuocolo LD, Steinhoff BA, Noser CA, Horner D, Mayer S, Inderhees K, Horwitz CP, Spatz J; Ryabov AD, Mondal S and Collins TJ (2001). Green Chemistry. Sustaining a high technology civilization. *Pure and Applied Chemistry*, 73, 113-118.

Lunn,G and Sansone, EB (1994). Polycyclic Heterocyclic Hydrocarbons *in* Destruction of Hazardous Chemicals in the Laboratory. 2nd Edition. Wiley, Interscience, pp. 357-374.

The Index Merck (1989). An encyclopedia of chemicals, drugs and biologicals. Budavari, S., Ed., 11th Edition, Merck & Co, Inc., Rahway, N. J., USA.

Schron W, Detcheva A, Dressler B, Danzer K (1998). Determination of copper, lead, cadmium, zinc, and iron in calcium fluoride and other fluoride-containing samples by means of direct solid sampling GF-AAS. *Fresenius J. Anal. Chem.*, 361, 106-109.

Wrobel K, Wrobel K, Lopez de Alba PL, Lopez Martinez L (1997). The application of the partial least squares method (PLS) for simultaneous spectrophotometric determination of calcium and magnesium in human serum. *Anal. Lett.*, 30, 717-737.

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