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THE PRACTICE OF CHEMISTRY EDUCATION (PAPER)
Chemical education in Europe: Curricula and policies

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AN INTEGRATED PHYSICAL-SCIENCE (PHYSICS AND CHEMISTRY) INTRODUCTION FOR LOWER-SECONDARY LEVEL (GRADE 7)

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ABSTRACT: The integration of physics and chemistry can not only be accomplished successfully, but it is useful for both subjects. In Greece, while general science is taught in the fifth and sixth grades, physics and chemistry are absent from the seventh grade. Here, we propose an integrated programme of physics and chemistry for a two-period per week course in the seventh grade. The relevant book (in Greek) includes experiments, theory, simple knowledge, and more demanding questions. The basic aims are: revision of basic primary physical science; preparation for the separate physics and chemistry courses that follow; and application of the theory and practice of science education. The programme is made of eight units that contain thirty-six lessons. The eight units are: matter and soil; motion and force; temperature and heat; water; air and atmospheric pressure; chemical reactions; energy; electricity. Basic features are: the spiral curriculum; qualitative treatment of concepts; taking into account of alternative conceptions; experimental-constructivist teaching and learning; simplicity of phenomena and principles; exclusion of atoms and molecules, of equations, and of graphs; and connection with everyday life. The programme is on trial during 1998-99 and 1999-2000 in eleven schools, involving 24 teachers and about 1500 students. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 281-294]

KEY WORDS: *integrated physics and chemistry; Greece; seventh grade; spiral curriculum; qualitative treatment of concepts; alternative conceptions; constructivist teaching and learning; simplicity of phenomena and concepts; atoms and molecules*

INTRODUCTION

In Greece, physical science (physics and chemistry) is absent from the first year of the lower-secondary level (seventh grade), while it is present in the final two years of primary school (fifth and sixth grades). This absence is surprising, if we take into account on the one hand the *sine qua non* for our modern technological society of the relevant knowledge, and on the other hand the important contribution of physical science for the cognitive development of students in the Piagetian sense. We therefore proposed an integrated programme of physics and chemistry for a two-period per week course in the seventh grade. The basic aims of the programme are:

1. repetition and revision of basic physical science taught in primary school, with some extensions and a more scientific approach;

2. preparation for the separate physics and chemistry courses that follow in the eighth and the ninth grades;
3. application of theory and practice that arises from research work in science education.

The repetition and revision of basic concepts and knowledge that were introduced in primary school is necessary because, for various reasons, students do not maintain much of this knowledge, as it was shown, at least for Greek students, in a recent study (Tsaparlis et al., 1997).

The programme has been approved as an experimental programme (*S.E.P.P.E.*) by the *Pedagogic Institute* (a department of the Greek Ministry of Education and Religious Affairs) and is on trial during the school years 1998-99 and 1999-2000 in eleven schools, involving 24 teachers, and about 1500 students. A textbook, suitable for the trial, has already been prepared, and includes experiments, theory, simple knowledge, and more demanding questions. The outline and excerpts from one sample lesson (without drawings or photos) can be seen in the Appendix.

RATIONALE: THE NEED FOR, AND VALUE OF, AN INTEGRATION OF PHYSICS AND CHEMISTRY

It is widely accepted that the various disciplines of science (physics, chemistry, biology, geology) are not independent of each other, as can be clearly seen by branches such as physical chemistry, molecular biology, biophysics, biochemistry, geophysics, and geochemistry. These interconnections have led internationally to many integrated science courses for the primary, lower secondary, and partly for upper secondary levels. In Greece, however, integrated science exists only at the primary level.

According to the conclusions of the Varna (Bulgaria) International Conference on the integrated teaching of science (Conseil International des Unions Scientifiques, 1968), the teaching of integrated science contributes to students' general education by emphasising the unity of science as well as its role in contemporary society.

Gadsen, Becht, and Dawson (1979) have provided an analysis of over 100 projects for integrated science teaching in various countries, and examined the motivations and the objectives of these projects. The main motivation was the conviction that the understanding of the separate subjects requires contributions from the other subjects.

At his point, we must be careful to distinguish between integration and coordination: although integration is more desirable (especially for lower ages), this integration is not always possible or obvious. There are of course topics that truly cross the disciplines, such as matter and its states, water, air, environment. But there are equally, many other topics for which coordination is preferable. Apart from content and concepts, the methodology of science is, to a great extent, of an interdisciplinary nature.

The integration of physics and chemistry can not only be accomplished successfully, but it is useful for both subjects. At the outset, chemistry needs basic concepts from physics, such as mass, density, weight, atmospheric pressure, temperature, heat, energy. On the other hand, physics also benefits by an exposure to basic chemistry and physical chemistry topics, such as substances and mixtures, elements and compounds, metals and non-metals. It is not then surprising that a physics course may precede a chemistry one, as in Yugoslavia, where biology is taught first in grade five (age 11), physics follows in grade six, and chemistry comes third in grade seven (Sisovic & Bojovic, 2000). In their work, Sisovic and Bojovic provide maps with physics and chemistry concepts, in which they draw both intra- and inter-disciplinary connections of these concepts. Note also that there are numerous voices against the artificial separation of school chemistry from school physics (Van Berkel, de Vos, Verdonk, & Pilot, 2000, p. 148).

At higher levels, chemistry is further dependent on physics. Thus, according to research findings (Harris, 1983), a group of 40 students, who had completed high school chemistry and physics, achieved considerably higher in first-year college general chemistry (79.0% with standard deviation 9.2) than an equal number (40) who lacked prior physics preparation (63.2% with s.d.13.0); that is physics is deemed an important factor for success in college chemistry.

Although the practice in most countries seems to be the integration of all science subjects, we feel that biology presents certain difficulties, as biologists themselves admit: “The concepts of biology presuppose or include understanding of physics and chemistry” (Zogza, 1998). In addition “in biology, it is not feasible to lead the students by means of simple experiments to the discovery of a law. This can be done in physics or chemistry; for biology, this is difficult even for organised research laboratories” (*Pedagogic Institute*, 1998). Experiments in biology are more complicated, and so biology does not easily render itself to a constructivist approach to teaching and learning, at least at this level.

Finally, mention should be made of a physical science discovery course for elementary school teachers, consisting of 24 exercises, designed to lead students towards an understanding of 24 selected topics in chemistry and physics (Jasien, 1995). The topics were based on the guidelines of the *Science Framework for California Public Schools* (1990).

THE CONTENT OF THE PROGRAMME

The programme consists of eight units, which are composed of 36 lessons. The eight units are as follows: (a) matter and soil; (b) motion and force; (c) temperature and heat; (d) water; (e) air and atmospheric pressure; (f) chemical reactions; (g) energy; and (h) electricity. Table 1 has the titles of the 36 lessons. The Figure in the next page, shows a distinction of the topics and the concepts of the programme into purely physical, purely chemical, as well as into interdisciplinary ones. The main intra- and inter-disciplinary connections between various topics/concepts are also drawn; in addition, topics that are needed in both disciplines are shown in italics. Note that each unit is grouped separately, and that there is a top-down hierarchy, in accordance with the order of the topics in the programme (see Table 1).

Note that an earlier version of the programme had the thirty-six lessons distributed into ten units, with two extra units, one on pressure in solids and liquids, and another on compounds and elements (Tsaparlis & Kampourakis, 1999). In the earlier version, the unit on water was after the unit on air, which we think as pedagogically less sound.

The concepts of *energy* (especially chemical energy) and of *interaction* are very difficult for young students (Duit,1986; 1994). It is possible of course to do a lot of physics and chemistry without these concepts, that is, it is possible to leave energy entirely out of this course. We have opted not to do that; although energy formally appears late in the programme, the concept of energy is introduced and used from the introductory lesson. Here is how this lesson starts:

“Scientists, and especially physicists and chemists, basically are interested in two concepts of the

TABLE 1. The 36 lessons of the programme.

0. Physics, chemistry and science.

UNIT A. Matter and soil
1. 1.States of matter - Soil.
2. Substances and mixtures.
3. Separation of mixtures.
4. Measuring length.
5. Measuring surface and volume.
6. Mass.
7. Density.

UNIT B. Motion and force
8. Introduction to motion.
9. Forces.
10. Displacement, velocity, and force are vectors.
11. Weight, gravity, and gravity field.
12. Relation between weight and mass.
13. Pressure exerted by solids.

UNIT C. Temperature and heat
14. Temperature and heat.
15. Thermal equilibrium.
16. Expansion and contraction of solids on heating
17. Thermal expansion and contraction of liquids.

UNIT D. Water
18. Water.
19. Solutions.
20. Crystallisation, recrystal-lisation, and crystals.
21. Hydrostatic pressure.
22. Flow of liquids and communicating vessels.

UNIT E. Air
23. Air and the atmosphere.
24. Atmospheric pressure.
25. Behaviour of gases on heating, cooling, compressing and decompressing.

UNIT F. Chemical reactions
26. The concept of chemical reaction.
27. Chemical reactions in aqueous solutions.
28. Compounds and elements.
29. Getting to know more about elements.

UNIT G. Energy
30. Combustion and fuels
31. Energy.
32. Forms of energy - Energy transfer and conversions.

UNIT H. Electricity
33. Electrocharging and electric charges.
34. Electrical conductors and insulators.
35. Electric current.

universe: **matter** and **energy**. … All materials that are close to us or far away consist of matter; all materials contain energy. A large piece of iron contains more iron than a small piece of iron. This we express by saying that the larger piece has larger **mass**. Mass is a basic property of matter…. Another property of matter is that it occupies some space, it has **volume**. A third property of matter is that it contains energy that we call **chemical energy**. For instance, food, fuels, batteries and dry cells contain chemical energy. Actually, everything contains energy, for instance wood and stone; even our bodies contain chemical energy that has been and is taken from food.

Take a stone from the ground, raise it, and then let it fall. In this action, first you did something to the stone: you took it and raised it; this we call an **interaction** between yourself and the stone. We *accept* that during this interaction, an amount of energy moved (was *transferred*) from you to the stone where it was deposited in some way (but as we will understand later NOT as chemical energy). When you let the stone fall, the stone *interacted* with the earth: the earth attracted it. Again, we *accept* that there occurred an *interaction* between the stone and the earth during which the stone transferred to the earth the amount of energy that it previously had taken from you; part of this energy was transferred to the air during the fall, and the rest to the earth on touching it.

We *agree* then that during every change there is an interaction between materials that is always

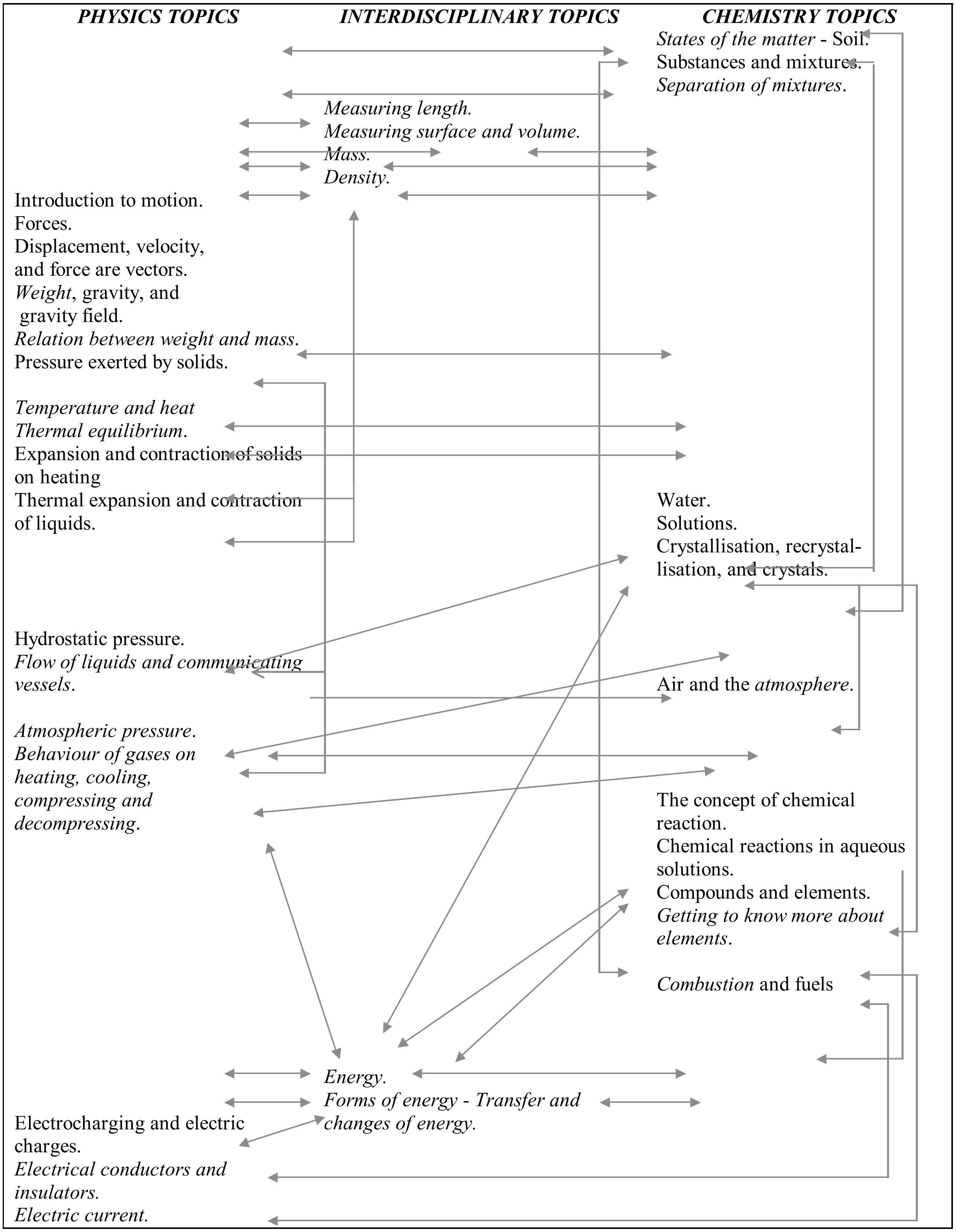

FIGURE *Distinction of the topics of the programme into physical, chemical, and interdisciplinary and main intra- and inter-disciplinary connections. For further explanations see text.*

accompanied by a *transfer of energy*. Thus, when we eat, we '*interact with food*', taking energy from it. Unlike matter, energy has no mass, occupies no volume, yet it can be measured. The ability of matter to interact with other matter, giving or taking energy from it, is a fourth property of it….."

GUIDING PRINCIPLES FOR THE PROGRAMME AND THE BOOK

Ten guiding principles, that follow from the current science-education literature, have been observed in the writing of the book. Table 2 lists these principles, while a more detailed discussion about them follows.

TABLE 2. *The ten guiding principles in the writing of the textbook.*

1. The spiral curriculum.
2. Use of experiments, especially experiments that will be carried out by groups of pupils.
3. Focus on meaningful learning - Discouragement of rote learning.
4. Emphasis on simplicity of phenomena and concepts - Priority given to concrete examples - Avoidance of the abstract concepts of molecules and atoms.
5. Preference for qualitative descriptions and simple relations. Avoidance of representations with symbols, equations, or graphs.
6. Scientific rigour - Correct use of language.
7. Connection of science with everyday life and applications - Development of environmental conscience.
8. Taking into account of students' alternative frameworks - Avoiding the development of misconceptions.
9. Constructivist teaching and learning.
10. Contribution to students' cognitive development, as well as encouragement of critical thinking.

1. The spiral curriculum. The programme should constitute part of a *spiral curriculum* (a term coined by Bruner) that should start in primary school and continue into higher school levels, in such a way as to ensure both an overlap with previous material (repetition and revision) and a progression in complexity (the spiral effect). In addition to providing the chance for students to return to the same topic, thus reinforcing learning, the spiral curriculum is also useful for developing fuller knowledge and understanding, because it is not possible to exhaust a topic in one grade, mainly because of the difficulties associated with many concepts.

2. Teaching with experiments. Teaching physical science without using experiments is a practice that is the rule in many countries, including Greece. We must accept that physical science taught without experiments is highly unsatisfactory. It makes every other effort on the part of the teacher (study from books, questions, exercises) almost useless. It is also very important that students work together in groups of two, three or four (Alexopoulou & Driver, 1996), both for learning and for the development of communication skills. Whenever it is not feasible for students themselves to carry out the experiments, the teacher should use demonstrations, where the experiment is carried out in front of the class by a pair of students under the guidance of the teacher. Note that in the book, the outcome of an experiment is not, as a rule, shown in drawings or in pictures. In this way, the book acts as a laboratory guide, with blank spaces for students to fill in their own observations and conclusions.

3. Meaningful learning - No rote learning. The emphasis on meaningful learning (Ausubel, 1968) is a must for a programme with the stated objectives. Rote learning should be restricted to a few necessary facts. For this purpose, each lesson starts with the section '*The lesson in questions*'. These questions serve three purposes: (a) as a statement of the objectives of the lesson; (b) as an overview/summary of the lesson; and (c) as a source of sufficient information to guarantee that the student has a good knowledge of the content of the lesson, once these questions are answered correctly.

4. Simplicity of phenomena and concepts - No molecules or atoms. Each phenomenon or concept is treated at the simplest possible level. Thus, we introduce the concept of instant and mean velocity, but not that of acceleration; we speak about forces, but not about friction or moments; the concept of vector is used for displacement, velocity, and force, but no addition of vectors is made. According to Piaget's theory of cognitive development, 50% of children at the age of 12 are in the stage of concrete operations, while only 10% of them have developed formal abilities (Shayer, 1991). It is natural then that students find difficulty with abstract concepts. The concepts of molecular and atomic structure are exceptionally abstract. It is no surprise then that the early use of structural concepts in science classes can be criticised both from the Piagetian (Herron, 1978), and other perspectives (e.g. Johnstone, 1991). Tsaparlis (1997) has made a critical analysis of structural concepts from various perspectives of science education, and in all cases he found these concepts difficult for pupils. For this reason, we have opted not to use (as a rule) the concepts of molecules and atoms in this programme. (For a very carefully designed approach to these concepts, see Nussbaum, 1998.)

5. Qualitative approach - Simple quantitative relations - No symbol equations - No graphs. We believe that a qualitative treatment should proceed a quantitative one, and where necessary, all quantitative relations used should be simple. Emphasis is given to the four operations of arithmetic, in particular to division. The meaning of the ratio of two quantities described by Arons (1983-1984) is in our opinion a powerful tool for grasping simple mathematical relations between various physical quantities. We only go as far as direct and inverse proportion. All mathematical relations are expressed in words, not with symbols. Finally, we have avoided altogether the use of graphs, which are known to cause difficulties to students both in constructing and interpreting them (Leinhardt, Zaslavsky, & Stein, 1990; *Association of Greek Physicists*, 1995).

6. Scientific rigour - Use of correct language. We maintain that scientific rigour must be an end in itself in the teaching of science. For instance, when quoting the boiling point of a substance, we also quote the corresponding pressure value. Loose and incomplete phrasing, not only establishes wrong concepts in students, but also develops in them a lack of respect for scientific rigour. Needless to say that an integral part of scientific rigour is the correct and proper use of language, because language and thought interact and interconnect (Vygotsky, 1962).

7. Connection with everyday life. The many applications and uses of physics and chemistry in everyday life should be given a dominant place in teaching. In this programme, such applications appear in: (a) the normal flow of the course material; (b) special inserts (e.g. 'how to deal with a fire', 'electric voltage: a matter of life or death'); and (c) in the final part of each *lesson 'Learn more, think, and find out why'*.

8. Misconceptions - Alternative frameworks. It is well known that students construct their own explanations for physical phenomena by means of everyday experiences, before they receive systematic science instruction. These so called misconceptions or alternative frameworks (which can be also caused by wrong or inadequate teaching), have been the subject of a vast bibliography in science education during the past fifteen years and more. In our programme, we pay attention to misconceptions both implicitly and explicitly. The special small inserts '*Take into account*' aim frequently to prevent misconceptions.

9. Constructivist-active teaching and learning. We subscribe fervently to constructivist methods of teaching and learning, and consequently we give emphasis to such an approach. We consider that this is the most important innovation of this programme. Along the same lines, we also apply Aron' s recommendations (1983-1984) that "*first should come the idea, and then the name*", and so we use functional definitions stated first by the students with guidance and assistance from the teacher. Carrying out experiments by the students themselves also contributes to active learning. Of course, in principle, constructivist teaching is the responsibility primarily of the teacher; the textbook comes second to this. However, to help the teacher, we have made the textbook into a teaching guide.

10. Cognitive development - Critical and creative thinking. It is not possible to avoid formal concepts altogether in such a course. Indeed, it is necessary to deal with such concepts, for only when students deal with such concepts will they develop formal capabilities. By frequent use of proper techniques and interventions, we aim to develop formal-operations capacity in students. Control of variables, and analogies, are two such capabilities that are treated with care. For this purpose, we have also made very limited use of the *CASE* programme (*Cognitive Acceleration through Science Education*: Adey, Shayer, & Yates, 1989). With the final section of each lesson '*Know more, think, and find out why'*, students are encouraged to try more demanding questions that call for higher-order cognitive skills (*HOCS*) (Zoller & Tsaparlis, 1997, and references therein). In addition, students are asked to suggest experimental methodologies, thus cultivating their creative thinking.

CONCLUDING REMARKS

The programme is original, and does not copy another programme or book. It has taken into account general principles and recommendations from the science-education literature. Some examples will demonstrate this:

- A whole lesson has been given for the introduction of the concept of density. Compare this with the usual definition of density as the ratio of mass over volume, just in a couple of lines.

- In introducing the concepts of force, weight, and mass, the epistemological views of Thomas S. Kuhn were taken into account (Kuhn, 1990).
- The concept of chemical reaction follows the method of de Vos and Verdonk (1985).
- Energy is presented according to the recommendations by researchers, mostly by *Reinders Duit* (1986; 1994).

The guiding principles that were applied for the selection of content and the method of the produced textbook, incorporate most of the scientific procedures that have been described by the *American Association for the Advancement of Science* (AAAS): observation, classification, numerical relationships, measurements, time-space relationships, communication (oral, pictorial, and written), inference, prevision ('what would happen if …'), hypothesis formulation, production of operative definitions, identification and control of variables, experiment, and data interpretation.

The use of various and different theoretical perspectives, such as the spiral curriculum (from Bruner' s theory of learning), Ausubel' s theory of meaningful learning, the application of Piagetian theory to education, and constructivist methods of teaching and learning, are all utilised with the purpose of achieving the highest possible positive cognitive and affective outcome. In other words, we have tried to exploit as much as possible from the 'arsenal' that is open to us through the science education literature. It is our opinion that the use (sometimes separately, sometimes together) of different - even for some researchers conflicting - perspectives leads to complementary positive results (Niaz, 1993; Tsaparlis, 1997).

In its present form, this programme is but a product of the mind. The approval by the *Greek Pedagogic Institute* of its experimental trial will undoubtedly lead to practical refinements and improvements. A follow-up, experimental-control group study of the impact of the programme on student performance in subsequent physics and chemistry courses is planned.

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APPENDIX: OUTLINE AND EXCERPTS FROM A LESSON

31st Lesson

COMPOUNDS AND ELEMENTS
A difference we cannot see

In the previous lessons, we referred to and used various substances many times, for instance oxygen, sulphur, iron, water, salt, copper, spirit, carbon. If you were asked to classify these substances into two groups on the basis of a common feature, you might put on one side iron and copper (two metals), and on the other side all the other substances that obviously are not metals. We, however, have in our mind a different grouping. From the chemical point of view, these substances, and all pure substances, can be grouped into two large groups. The distinction we are after cannot be seen with naked eye, nor with the most perfect microscope. It is, as we call it, a submicro difference, very important for chemistry. In this lesson, we are going to study that distinction.

THE LESSON IN QUESTIONS

1. Do the various materials that we encounter in nature consist of a single pure substance or are they mixtures of substances?
2. What is water, a pure substance or a mixture? What about sugar?

....

5. What is the difference between a sugar-water mixture and a pure substance?

....

9. What happens to sugar when we heat it strongly? Which are the reactants and which are the products in that reaction?

....

Substances and mixtures

We know that most materials that we encounter in nature do not consist of only one substance, but are mixtures of many substances. How can we decide whether a material consists of one pure substance or if it is a mixture of many substances? Take for instance *water* … Take another example, that of *sugar*. Sugar that we buy in food shops is nearly pure. Like water, sugar has various characteristic properties, such as sweet taste, a definite value of density, it dissolves easily in water with a definite value of solubility at a specified temperature, etc. If, however, we take an aqueous solution of sugar, …

Composite substances and simple substances

Experiment 1
(Electrolysis of water)

....

Experiment 2

(Decomposition of mercury (I) oxide on heating)
....

....

Experiment 3

Your teacher will put into a dry Pyrex test tube a small amount of sugar. (S)he will then heat carefully the outside lower part of the tube with the flame from a burner, shaking continuously the tube.

As soon as a white 'smoke' is observed to come out of the sugar, the teacher will bring close to the 'smoke' a cold piece of glass.

Observe what happens to sugar, as it is heated, and what happens on the surface of the glass.
....
....
....

....

Take into account
Water DOES NOT exist inside sugar, as water exists, for instance, inside a potato or in bread or in a leaf. Remember also that sugar is a pure substance, not a mixture of substances with water among them. On the contrary, a potato, a slice of bread, a leaf are each a mixture with water being one of their constituents.

With experiment 3, we were able to **break** sugar into two other substances, carbon and water. With experiment 1 we **broke** water into two other substances, hydrogen and oxygen. For these reasons, water and sugar are termed composite substances. On the contrary, substances like hydrogen, oxygen, or carbon, which cannot be broken into other substances, are called simple substances.

Elements and compounds

Experiment 4

(Sulphur heated with iron dust)
....
....

Know more, think, and find out why

3. Can you suggest various methods that will help you find out if de-ionised water we buy in the supermarkets is really de-ionised, or is it tap water?

6. We saw that when sugar is strongly heated it breaks into two products, carbon and water.

- Give arguments to show that sugar is a compound and not a mixture of carbon and water.
- Taking into account that nothing happens to sugar if it is heated gently (for instance around $50^{o}C$), suggest a method which will help you confirm that sugar really does not contain water.

REFERENCES

Adey, P., Shayer, M., & Yates, C. (1989). *Thinking science* (Teacher's pack). Walton-on-Thames, Surrey: Nelson.

Alexopoulou, E. & Driver, R. (1996). Small-group discussion in physics: Peer interaction modes in pairs and fours. *Journal of Research in Science Teaching*, 33, 1099-1114.

Arons, A.(1983-1984). Students' patterns of thinking and reasoning. *The Physics Teacher*, *21*, 576; *22*, 211; *22*, 88.

Association of Greek Physicists (AFP) (1995) *Physical phenomena, physics, and pupils in eighth grade* (in Greek). Agrinion, Greece: AFP Branch of Agrinion.

Ausubel, D. P. (1968). *Educational psychology - A cognitive view*. New York: Holt, Reinhart, & Winston.

Conseil International des Unions Scientifiques (*CIES*) (1968). Congres sur l' integration des ensegnements scientifiques. Drujba (Bulgaria), 11-19 September 1968. CIES, Boulevard Pasteur 3, Paris XV.

De Vos & Verdonk, A.H. (1985). A new way to reactions. *Journal of Chemical Education*, 62, 238 & 648.

Duit, R. (1986). In search of an energy concept. In Driver, R. & Millar, R. (eds.), *Energy matters*, pp. 67-101. Leeds: University of Leeds.

Duit, R. (1994). Learning and teaching energy. In Fensham, P.J., Gunstone, R.F., & White, R.T. (eds.), *The content of science: A constructivist approach to its teaching and learning.* Ch. 14. London & Washington, DD.C.: The Falmer Press.

Gadsen, T., Becht, P., & Dawson, G. (1979). The design and content of integrated science courses. In: *New trends in integrated science teaching*, vol. V, p. 41. Paris: Unesco.

Harris, S.P. (1983). Physics, an important factor in the success of general college chemistry students. *Journal of Chemical Education, 60,* 739-740.

Herron, J.D. (1978). Piaget in the classroom. *Journal of Chemical Education, 55,* 165-170.

Jasien, P.G. (1995). A physical science discovery course for elementary school teachers. *Journal of Chemical Education, 72,* 48-48.

Johnstone, A.H. (1991). Thinking about thinking. *International Newsletter on Chemical Education.* (36), 7-10.

Kuhn, S.T. (1990). Dubbing and redubbing: The vulnerability of rigid designation. In C.W. Savage (ed.), *Scientific theories*, pp. 302-308. Minneapolis: University of Minnesota Press. (Reprinted in *Science & Education*, 2000, *9*, 11-19, under the title "On learning physics".)

Leinhardt, G., Zaslavsky, O., & Stein, M.K. (1990). Functions, graphs, and graphing: Tasks, learning, and teaching. *Review of Educational Research*, *60*, 1-64.

Niaz, M. (1993). 'Progressive problemshifts' between different research programs in science education: A Lakatosian perspective. *Journal of Research in Science Teaching*, *30*, 757-765.

Nussbaum, (1998). History and philosophy of science and the preparation for constructivist teaching: The case of particle theory. In Mintzes, J.J., Wandersee, J.H., & Novak, J.D. (eds.), *Teaching science for understanding - A human constructivist view*, Ch. 2. London: Academic Press.

Pedagogic Institute (1998). *Unified Upper Secondary School: Unified Framewok for the Programme of Studies*, p. 190 (in Greek). Athens: Pedagogic Institute - OEDB.

Shayer, M. (1991). Improving standards and the National Curriculum. *School Science Review*, *No. 72*, 17-24.

Science Framework for California Public Schools (1990). Sacramento: California Department of Education.

Sisovic, D. & Bojovic, S. (2000). On the use of concept maps at different stages of chemistry teaching. *Chemistry Education: Research and Practice in Europe, 1*, 135-144.

Tsaparlis, G (1997). Atomic and molecular structure in chemical education: A critical analysis from various perspectives of science education. *Journal of Chemical Education, 74,* 922-925.

Tsaparlis, G., Georgousi, K., Kampourakis, K., Lolas, T., Kontogeorgiou A. (1997). Pupils' knowledge of physical science at the primary-secondary interface (in Greek). Proceedings of a symposium: *Science and technology in primary education* (G. T. Kalkanis, ed.) pp 35-39. Athens: University of Athens, Department of Primary Education.

Tsaparlis, G. & Kampourakis, (1999). An integrated physical-science (physics and chemistry) introduction for lower-secondary level (grade 7). *5th ECRICE, Programme and Book of Abstracts*, p. 103. Ioannina: University of Ioannina.

Van Berkel, B., de Vos, W., Verdonk, A.H., & Pilot, A. (2000). Normal science education and its dangers: The case of school chemistry. *Science & Education*, *9*, 123-159.

Vygotsky, L.S. (1962). *Thought and language*. Haufmann & Vakar, C. (translators). Cambridge, Massachusetts: MIT Press.

Zogza, V. (1998). Symposium on biology education (in Greek). In *1st Panhellenic Conference on Science Education and New Educational Technologies*, Book of Abstracts, p. 91. Thessaloniki, Greece: Christodoulides Publications.

Zoller, U., & Tsaparlis, G. (1997). Higher and lower-order cognitive skills: The case of chemistry. *Research in Science Education*, *27*, 117-130.