CHEMISTRY EDUCATION:
RESEARCH AND PRACTICE IN EUROPE
2001, Vol. 2, No. 3, pp. 241-252

RESEARCH REPORT
Methods and issues of teaching and learning

Constantinos KAMPOURAKIS, Kyriaki GEORGOUSI, and Georgios TSAPARLIS
University of Ioannina, Department of Chemistry

PHYSICAL-SCIENCE KNOWLEDGE AND PATTERNS OF ACHIEVEMENT AT THE PRIMARY-SECONDARY INTERFACE

PART 1. GENERAL STUDENT POPULATION

Received 2 July 2001; revised 30 September 2001; accepted 30 September 2001

ABSTRACT: In primary Greek schools, physics and chemistry are part of the integrated science programme which is taught in the final two grades, fifth and sixth. Nine hundred and seventy-six seventh and eighth-grade students (age 11.5-13.5), from nine urban and semi-urban Greek lower secondary schools, each answered one out of three similar tests, in an investigation of basic physics and chemistry knowledge and patterns of student achievement at the primary-secondary interface. The mean overall achievement in all three tests (17.2% for the seventh and 21.5% for the eighth grade) was low. The older students achieved higher than the younger ones in all three tests. This is surprising given that the knowledge tested was taught in fifth and sixth grades, and was less immediate for the eighth-grade students. Achievement on macroscopic physics topics was higher than macroscopic chemistry topics. Submicroscopic topics (referring to corpuscular matter) proved much more difficult than macroscopic topics. As expected critical-thinking questions were much harder than questions demanding simple recall or recognition of knowledge. In all cases, boys achieved higher than girls; however, there was a drop in the gender gap from the seventh to the eighth grade. The implications of the findings are discussed. [*Chem. Educ. Res. Pract. Eur.*: 2001, *2*, 241-252]

KEY WORDS: *Primary physical science; primary physics, primary chemistry; primary-secondary interface; submiscroscopic chemistry; gender and primary science*

INTRODUCTION

In primary school, science is usually taught as an integrated subject, with physics and chemistry occupying a central part, and at the same time posing the heaviest intellectual demand for students. This demand is due to the complex and usually abstract concepts, which become intangible when one turns to the submicroscopic level of matter. (Biology, the main other component of integrated science, is not hard to teach at the descriptive level, but becomes complicated when it comes to explanations - it needs also basic physics and chemistry knowledge.)

This study aimed at investigating the basic physics and chemistry knowledge and patterns of achievement that characterise students at the primary-secondary interface. In particular, in addition to an overall examination of knowledge retention of primary physics and chemistry, we were interested in comparing: (a) physics with chemistry; (b) submicroscopic (at the corpuscular molecular and atomic level) with macroscopic knowledge; and (c) conceptual understanding with recall and recognition of knowledge. Gender as well demographic (socio-economic-geographic) differences were also examined.

The investigation has been carried out in Greece, where physics and chemistry are part of the integrated science programme which is taught in the fifth and the sixth grades (primary school, age 9.5-12) under the title *Investigating the Natural World.* (In grades one through to four, science topics are part of a wider course, called *The World Around Us,* in which science topics - predominantly biological - are interspersed among sociology, geography and other topics.) In the fifth and the sixth grades, physics covers almost half of the course (51 and 41% respectively), followed by biology (25 and 23%), while chemistry has a much smaller share (around 12% in each grade).

RATIONALE

It has been argued that the great technological advancement that characterises our modern society makes the acquisition of basic science knowledge and understanding a *sine qua non* for contemporary citizens. This explains why the current trends and efforts in the science-education literature, policy and practice aim at the acquisition of both basic science knowledge and understanding, and higher-order cognitive skills by all contemporary citizens (National Research Council, 1996; Zoller & Tsaparlis, 1997). These trends were the result of the failure of the advanced science curricula of the sixties that proved to be targeted only at the very able students.

The following two beliefs underlie the rationale of this study:

(a) A child's cognitive development is not a mere biological maturation, but is achieved by means of a dynamic interaction of the child with the environment and society; according to Piaget (1964) such an interaction leads to self-regulation or equilibration.
(b) The above interaction consists in direct experimentation, an activity that a child carries out continually from the very beginning of his/her life. In Piaget's own words (quoted in Duckworth, 1964), "a subject must be active, must transform things, and find the structure of his own actions on the objects". Further, "active is meant in two senses. One is acting on material things. The other means doing things in social collaboration, in a group effort".

If one couples the above views with the statement that 'lifelong scientific literacy begins with attitudes and values established in earlier years' (National Research Council, 1996, p.2), one is led to accept that the systematic exposure of children to scientific concepts should start as early as possible in the primary school (and even in kindergarten). Such a practice is followed in many developed countries: in England and Wales, for instance, primary science, along with English language and mathematics, constitute the three core subjects in primary school, and is taught as a separate subject from the first grade (Millar, 1996).

METHOD

Aiming at covering as much of the subject matter as possible, we constructed three different tests A, B and C, that shared the same philosophy. Tests A and B consisted solely of questions derived from the course material for the fifth grade, while test C consisted mainly of questions from the sixth grade. Each test consisted of ten major questions, with each such question being on a different thematic unit and made of a number of sub-questions (usually two or three). Each test was designed to be answered within 45 minutes. Before application, the tests were tried with a small number of students and revised. The content validity of the tests was judged by four persons, the three authors (of which two are teacher-physicists, and one university chemist) plus another teacher-physicist. Each student had to answer only one test. To reduce copying the answers, adjacent students were assigned different tests.

The tests were administered to seventh and eighth-grade students (lower secondary school, age 11.5-13.5) at the first week of the school year 1996-97. Seventh-grade students had a four-month to two-year distance from their exposure to the relevant material in their fifth and sixth grades of primary school. For the eighth-grade students one further year had elapsed. The reason for including the eighth-grade sample was that these students had not been taught physics or chemistry in the seventh grade (but they had been taught biology). Their inclusion provided the opportunity to check the effect of the elapsed time. The investigation was carried out in nine lower secondary schools, of which five were from an urban area, and three from neighbouring semi-urban regions, this reflecting, we believe, the Greek student population as a whole.

Most of the questions asked for a simple recall of knowledge (usually filling in of blanks), while, in a few cases, there were multiple (double or triple) choice items. Recall and recognition of knowledge demand the lowest level of cognitive objectives in the Bloom taxonomy (Bloom, 1956). In addition, there were a few questions that demanded understanding and application, while a smaller number required critical thinking.

Figure 1 provides samples of questions, together with the corresponding marking scheme. Total marks for each test were 100. Each knowledge element recalled was allocated two marks (or three in some cases). If it occurred in a multiple-choice item or as a group with similar knowledge elements, it was given one mark. Finally, each critical-thinking question was given four marks.

The questions were classified into four main categories: (a) macroscopic physics, (b) macroscopic chemistry, (c) questions on the structure of matter (submicro questions), and (d) questions that required critical thinking. Table 1 shows the corresponding weighting factors in the overall marking of each test.

The reliability of the tests, as well as the equivalence of the three samples that answered the three different tests, were judged through a number of common questions that were present in all tests, covering 11% of the total marks of each test. Statistical analysis of variance (one-way ANOVA) showed that almost all observed differences were not statistically significant. For that reason, we assumed the three samples as equivalent.

RESULTS AND DISCUSSION

Table 2 gives the total achievement as percentage mean scores on the three tests A, B, and C for the seventh and the eighth grades. It is seen that the three tests were not equivalent, but there was a scaling up in difficulty from A to C. For both grades, the differences are statistically significant at $p = 0.01$, as shown by one-way ANOVA. The greater difficulty of test C is due to the fact that it contained considerably higher submicroscopic questions, as well more difficult questions on macroscopic chemistry.

The fact that the three tests were found to be not equivalent in difficulty, suggests that a combination of the three tests provides a more realistic/accurate picture of students' knowledge. Table 3 provides a summary of results for the overall study ($N = 976$), that is for the union (the average) of the three tests (A + B + C). For the total scores, achievement on the union of the three tests is simply their average. On the other hand, for the various categories (macro, submicro, physics, chemistry, critical-thinking questions) the scores for each test participated in the total score with specified weights, depending on their assigned marks. Finally, for the same union it has been taken that we had equal numbers of students for each separate test A, B and C.

Macroscopic physics

a1) The instrument we use to measure forces is called………….. *(2 marks)*

a2) If we push a body which is still on the ground, it will move for a while, and after a while it will stop. The force that makes the body stop is called ………….. *(3 marks)*

b) The energy of a raised body is called .... energy. The energy of a moving body is called .... energy. The energy of a deformed spring is called .... energy. *(2+1+2=5 marks)*

c) Are temperature and heat the same thing or different? ……………………… Is heat a form of energy? ……………….. If we mix hot water with cold water, energy is transferred from hot water to cold water. This energy is called ………… *(1+1+2=4 marks)*

Macroscopic chemistry

a) The large variety of materials that exist in nature derive from the combination of a few simple materials that are called …………….. *(2 marks)*

b) Quote the names of five chemical compounds that you may know. *(5 marks)*

c) Which is the product of the incomplete combustion (burning) of carbon? Which is the product*)* of the complete combustion (burning) of carbon? *(4 marks*)

Submicroscopic science

a) Which are the particles making up the atom of a chemical element? *(1 mark for each particle plus 1 mark if all three particles are mentioned)*

b) Show with a drawing how you think are the molecules of (I) water, (ii) hydrogen, (iii) carbon dioxide. *(2+2+3=7 marks, plus 1 mark if all three are correct)*

b) Which is the term used for the union (joining) of nuclei that leads to the making of the nucleus of another element? *(2 marks)*

Critical-thinking questions

a) Suggest an experiment to show air is trapped inside a sponge or inside a rusk. *(4 marks)*

b) You will have noticed in winter that cold glass becomes often 'cloudy', with water droplets appearing on it. The same happens on the outside surface of a bottle that you take out of the fridge. Can you explain this phenomenon? *(4 marks)*

c) Why atmospheric pressure does not cause crumpling of an inflated balloon? *(4 marks)*

FIGURE 1. *Examples of questions, with corresponding marks, from the written tests used in the investigation.*

TABLE 1. *The four main categories of questions, with weighting factors.**

Category	**Test A** (%)	**Test B** (%)	**Test C** (%)	**Average of the three tests** (%)
Macroscopic physics	66	57	42	55
Macroscopic chemistry	22	29	18	23
Structure of matter	12	14	40	22
Critical thinking	12	12	6	10

*Critical-thinking questions were also part of macroscopic-physics/chemistry questions. For this reason, weighting factors do not add up to 100%.

TABLE 2. *Mean percentage scores*[a] *on the three tests A, B, and C, for the seventh and the eighth grades.*

	Test A	Test B	Test C
Seventh grade	22.6 (15.1) *N* = 162	17.4 (15.1) *N* = 158	11.6 (10.6) *N* = 186
Eighth grade	27.3 (14.5) *N* = 148	22.8 (11.6) *N* = 151	14.4 (11.5) *N* = 171

[a] Standard deviations in parentheses.

TABLE 3. *Summary of results*[a] *of the overall study (N = 976), for the seventh grade and the eighth grade.*

	Total	Total macro	Total submicro	Physics macro	Chemistry macro	Critical thinking
Seventh grade (*N* = 506)	17.2 (13.0)	19.3 (15.0)	9.8 (15.9)	21.4 (16.9)	14.2 (16.9)	9.3 (17.8)
eighth grade (*N* = 470)	21.5 (13.7)	24.1 (15.6)	12.3 (17.0)	25.2 (16.7)	21.6 (21.0)	12.0 (18.9)

[a] Mean percentage scores, with standard deviations in parentheses. The various categories (macro + submicro or physics + chemistry) participated in the total mark with specified weights, depending on their assigned marks (see Table 1). The three tests, A, B, and C, contribute equally, that is, it was assumed that we had equal numbers of students from each sample (both for the total mean mark and the separate category marks).

The mean overall achievement in all three tests (17.2% for the seventh, and 21.5% for the eighth grade) was low. This finding is in agreement with the views of primary teachers that "most of their students assimilate very few things from the physics topics taught in science lessons" (Chalkia & Kostopoulos, 1997). There are a number of reasons associated with the low scores - see below.

A problem may arise from the fact that we do not know how representative of the Greek student population was our sample. A more reasonable calculation of mean achievement scores was made in which a weight of two was assigned to the union of all urban schools and a weight of one to the union of all semi-urban schools [with equal weight to each participated school (or to the union of two schools in the case of small schools)]. The mean values that resulted were 16.7% for the seventh grade and 20.6% for the eighth grade; that is, not very different from the earlier reported values.

Tables 4 and 5 give detailed results for the separate tests A, B, and C.

Comparison between the seventh and the eighth grades

It is remarkable that in all three tests, older students (eighth grade) performed higher than younger students (seventh grade). The differences were 4.7% ($t = 2.79$, $p < 0.01$) in test A, 5.4% in test B ($t = 4.33$, $p < 0.01$), and 2.8% in test C ($t = 2.39$, $p < 0.02$). The difference in the union of the three tests was 4.3%. ($t = 5.03$, $p < 0.01$). All the differences are statistically significant. Although it is known that forgetting is rapid soon after learning but quickly slows down (Ebbinghaus, 1913), this finding was somehow surprising, if one takes

TABLE 4. *Detailed results[a] on the three tests A, B, and C, for seventh grade.*

	Total	Total macro	Total submicro	Physics macro	Chemistry macro	Critical thinking
Test A	22.6	23.4	16.9	27.3	11.6	8.2
(*N* = 162)	(15.1)	(14.8)	(24.2)	(16.3)	(14.9)	(16.2)
Test B	17.4	19.4	5.0	18.2	21.6	10.0
(*N* = 158)	(10.3)	(11.1)	(10.6)	(11.5)	(14.3)	(16.8)
Test C	11.6	13.1	9.3	16.4	5.5	10.2
(*N* = 186)	(10.6)	(13.4)	(11.6)	(14.4)	(9.6)	(20.3)

[a] Percentage mean scores, with standard deviations in parentheses.

TABLE 5. *Detailed results[a] on the three tests A, B, and C, for eighth grade.*

	Total	Total macro	Total submicro	Physics macro	Chemistry macro	Critical thinking
Test A	27.3	28.3	19.6	31.3	19.6	13.5
(*N* = 148)	(14.5)	(13.9)	(25.5)	(14.5)	(17.3)	(17.6)
Test B	22.8	25.0	8.8	22.4	30.3	11.1
(*N* = 151)	(11.6)	(12.4)	(13.2)	(11.9)	(17.3)	(17.8)
Test C	14.4	16.5	11.3	19.4	9.9	11.0
(*N* = 171)	(11.5)	(12.4)	(12.2)	(14.0)	(12.5)	(19.0)

[a] Percentage mean scores, with standard deviations in parentheses.

into account the one year period that had elapsed for the eighth-grade students without them having been exposed to further formal instruction in physics or chemistry. The difference may be due to: (a) social and environmental effects; (b) the cognitive development of the students; (c) some effect from the biology course that students took in the seventh grade; and (c) possible advance preparation of some eighth-grade students during their summer vacation. (Recall that neither physics nor chemistry had been taught in the seventh grade.)

The socio-environmental effects can be very important: through increased experience of life by means of TV, books, home influences and so on, the older students make more sense of the questions and respond more meaningfully. This would seem to be confirmed by the larger improvement of the achievement of girls relative to boys at the older stage (see below), which may be attributed to the faster maturation (which arises from biological development) of girls at the corresponding age. The effect from the biology course must have been minimal, since the biology course taught was mainly descriptive, giving little attention to physical and chemical explanations. On the other hand, we must take into account the cognitive development that occurs. In point of fact, the proportion of students who lack formal reasoning abilities (in the Piagetian sense) is about 86% in the age of 12 and 82% in the age of 13 (Shayer, 1991); the difference (about 4%) is just below the observed difference in achievement (4.3%) between seventh and eighth graders.

As far as advance preparation is concerned, it is reasonable to assume that only a relatively small proportion of students (as a rule ‘able’ students) was likely to have done some advance preparation. The values of standard deviations for the union of the three tests, as well for tests B and C, were higher for the eighth-grade students; however, all differences are not statistically significant: the F statistic takes values from 1.08 to 1.27. On the other hand, by deleting a number of best eighth-grade papers, we managed to make almost identical the standard deviations. The resulting mean achievement scores for the eighth grade were still considerably higher than the seventh grade; for example, by deleting the four top papers (scores 66, 60, 50, 49%) for test B, the standard deviation for the eighth grade became identical (10.3) to that for the seventh grade, with the achievement falling from 22.8 to 21.8, but yet remaining higher than that of the seventh grade (17.4) (t = 3.57, p < 0.01). We conclude that the most important effect that can explain the superiority of the older students might have been socio-environmental effects and the developmental factor.

Physics versus chemistry

Overall, achievement on macroscopic physics topics was higher than on macroscopic chemistry topics: 21.4% versus 14.2 for the seventh grade; 25.2 versus 21.6 for the eighth grade. The superiority on physics topics was quite large in tests A and C, while in test B achivement on chemistry topics was superior. [Test B contained some very basic chemical concepts (elements, compounds, mixtures) and examples of them.] In all cases, the differences are statistically significant. Note that there was trend of decrease in the gap between physics and chemistry as one moved from the seventh to the eighth grade.

According to Shayer and Adey (1981), chemistry is more difficult than physics and descriptive biology to be taught at lower level because most of its concepts are abstract and require formal-operations ability. Herron (1978) pointed out, for instance, that the concepts of chemical element and compound may have tangible examples but their attributes are abstract. Johnstone (1991) maintained that these two concepts cannot be grasped, unless the concepts of atom and molecule exist in the learner's long-term memory. In general, we may assume that chemistry macroscopic topics have an added difficulty, which might be due partly to the more abstract character of chemistry and partly to the lack of experiment from instruction.

A very important factor is the teacher. Research has shown (e.g. Harlen & Holroyd, 1997) that there is lack of confidence of primary teachers in the physical sciences. For such teachers, the conceptual nature of chemistry makes it least easy to grasp and then to transmit confidently to the students.

Macroscopic versus submicroscopic topics

In all three tests, achievement on macroscopic topics was higher than on submicroscopic topics, despite the fact that all submicroscopic questions required knowledge only, while some macroscopic questions required higher abilities. Overall, the former achievement was about double. The largest difference in favour of the macroscopic topics was in test B (14.4% in seventh grade, 16.2% in eighth grade), and the smallest in test C (3.8% in seventh grade, 5.2% in eighth grade). In all cases, the differences are statistically significant (p < 0.01).

This finding confirms various researchers findings and positions (e.g. Herron, 1978; Sequeira & Leite, 1990; Johnstone, 1991; Fensham, 1994; Tsaparlis, 1997) that the submicroscopic physical world is very difficult for students to grasp. Hence, its inclusion in the early introductions to science should better be avoided or treated with great care. This issue is further discussed in the "Conclusions and Implications" section.

Critical-thinking questions

Achievement on critical-thinking questions was considerably higher: about half of that for recall and recognition questions, and almost the same with achivement on submicroscopic topics. This result was not surprising taking into account that current school practice (at least in Greece) is far from addressing critical thinking and other higher-order cognitive skills (Zoller & Tsaparlis, 1997).

The effect of gender

It is well documented in the literature that boys have higher achievement than girls in science (e.g. Kahle & Lakes, 1983; Mullis et al., 1991; National Center for Educational Statistics, 1995; Lee & Burkam, 1996). For many countries that participated in the Third International Mathematics and Science Study (TIMSS) (Beaton et al., 1996), boys outscored girls. Thus, in the third and fourth grades, for about half of the countries, girls had significantly higher scores in earth and physical science; on the other hand, in the seventh and eighth grades boys for most countries significantly outscored girls in physics, chemistry, and earth science.

Table 6 shows the achievement of boys and girls in the three tests for both year groups. (A small number of anonymous papers were deleted from this analysis.) In all cases, boys achieved higher than girls. Bringing the three tests together, the difference for seventh grade is statistically significant ($t = 3.04$, $p < 0.01$), while for eighth grade the difference is nearly significant at $p = 0.05$ ($t = 1.89$). The drop of the gender gap from the seventh grade to the eighth grade may be attributed to the faster maturation of girls at the corresponding age. With regard to the separate tests A, B, and C, the superiority of boys is significant only in two cases, but not significant in the other four cases. In the cases of differences, these are statistically significant at either $p = 0.01$ or 0.05. Noteworthy is the increased standard deviations in the achievement of boys, reflecting a greater dispersion of the attention, interest, conscientiousness, dedication and maturation in the case of boys. Note that the differences in variance contribute to smaller statistic *t*-values.

TABLE 6. *Mean percentage achievement[a] of boys and girls on the three tests A, B, and C, and on the union of the three tests, for seventh and eighth grades.*

	Seventh grade		Eighth grade	
Test	**Boys**	**Girls**	**Boys**	**Girls**
A	*N* = 88	*N* = 70	*N* = 65	*N* = 71
	24.6	19.8	26.8	26.6
	(16.6)	(12.3)	(15.9)	(12.4)
B	*N* = 73	*N* = 71	*N* =76	*N* = 59
	19.8	14.8	24.0	21.7
	(12.5)	(7.1)	(13.2)	(8.8)
C	*N* =93	*N* =85	*N* = 78	*N* = 69
	12.1	11.3	17.2	12.2
	(11.5)	(9.2)	(12.6)	(9.4)
A+B+C	*N* = 254	*N* =226	*N* = 214	*N* = 199
	18.8	15.3	22.7	20.2
	(14.5)	(10.3)	(14.5)	(11.9)

[a] Standard deviations in parentheses.

The effect of the location of the school

Table 7 shows separately the achievement of urban and semi-urban schools. In all cases, there is a statistically significant superiority of the urban schools ($p < 0.01$). It is noteworthy, that the findings for the separate tests are similar for the two categories of schools.

TABLE 7. *Mean percentage achievement[a] on the three tests A, B, and C, and on the union of the three tests, for seventh and eighth-grade students from urban and semi-urban schools.*

	Seventh grade		Eighth grade	
Test	**Urban schools**	**Semi-urban schools**	**Urban schools**	**Semi-urban schools**
A	$N = 118$ 25.2 (16.3)	$N = 44$ 15.6 (8.0)	$N = 111$ 29.8 (14.7)	$N = 37$ 19.8 (11.0)
B	$N = 118$ 19.2 (10.2)	$N = 40$ 11.9 (8.5)	$N = 115$ 25.0 (11.4)	$N = 36$ 15.6 (9.4)
C	$N = 139$ 12.8 (11.1)	$N = 47$ 8.0 (7.7)	$N = 134$ 16.4 (11.7)	$N = 37$ 7.4 (7.5)
A+B+C	$N = 375$ 19.1 (13.8)	$N = 131$ 11.8 (8.6)	$N = 360$ 23.7 (13.8)	$N = 110$ 14.3 (10.7)

[a]Standard deviations in parentheses.

CONCLUSIONS AND IMPLICATIONS FOR CURRICULUM AND INSTRUCTION

The findings of this work have shown that, on the basis of the used tests, the knowledge in physics and chemistry of most primary-school graduates in Greece is very weak. Quite problematic is the knowledge of the physical world at the submicroscopic structural level, as well as the ability to deal with questions that demand higher than simple recall or recognition skills (critical-thinking questions). A number of factors and facts can be held responsible for this situation:

- The difficulty of the scientific concepts for primary students.
- The absence of experiment from teaching.
- The lack of proper science background with most teachers.
- The large amount of material that is covered within the final two years of primary school, with the result that we have scattered bits of knowledge which are soon forgotten or are not easily accessible from long-term memory.
- The dealing with submicroscopic, abstract models of matter, that students cannot comprehend but simply memorise.
- The serial instead of spiral teaching.
- The absence of end-of-school-year recapitulating examinations.
- The use of traditional, teacher-centred instructional methods, and the lack of constructivist and co-operative learning.

Turning to the implications for curriculum and instruction, we draw together on the one hand the findings of this work, and on the other hand some relevant general recommendations that arise from the science-education literature. We think that science is not taught adequately at primary level in Greece. We suggest that it should be taught as a separate subject throughout primary school, organised in two cycles of three-year duration each, and with an increase in depth in the second cycle. The number of topics should not be very large. The emphasis should be placed on observation, experimentation, and description by the students themselves, with the aim to bring to the surface children's ideas about the scientific world. In addition to taking care to overcome the above mentioned restricting and inhibiting factors, we think it appropriate to select topics that would satisfy Harlen's criteria (Harlen, 1985). According to these, the content of science in primary school should:

- Provide the chance for development of basic concepts.
- Be interesting and challenging for the student.
- Assist the students to comprehend the physical world around them, through investigations and interaction with the objects and the phenomena that they encounter.
- Give the opportunity for the development of scientific processing ability.
- Give the chance for the adoption of scientific attitudes.
- Demand the use of simple and familiar equipment which does not constitute an obstacle to the study by drawing attention away from the phenomenon under study.

Our findings direct our attention to the study of concrete objects and concepts rather than of abstract ones. Children should deal with observable things that are related to everyday life. Although primary students seem to be familiar from school and television with the concepts of atoms and molecules, they demonstrate very soon all the misconceptions known from the research literature (Johnston, 1990). In addition, as shown by investigations in Australia (with fifth graders) (Australia, Educational Council, 1994), and in Britain (Primary SPACE), primary students do not refer to the submicroscopic corpuscular structure of matter when they try to explain differences between states of matter or for phenomena such as evaporation, condensation or chemical change. We also saw that even at the lower secondary level (eighth and ninth grades), students fail to relate macroscopic phenomena with atoms and molecules (Sequeira & Leite, 1990). We conclude that atomic and molecular structure is very hard to teach properly (Nussbaum, 1998), and certainly beyond the grasp of most children at the primary level. We are, thus, led to the proposal that all submicroscopic material (molecules, atoms, electrons, atomic nuclei, etc.), as well as the various models for the structure of matter should be excluded from the primary science curriculum. In addition, we must avoid mathematical relations, as well as chemical notation (formulae and equations). Care must be taken, however, to cater the certainly higher needs of some of the 'able' and 'top'-achieving students (see Part 2 of this work: Georgousi, Kampourakis, & Tsaparlis, 2001).

A proper balance should exist between physical and biological science, and this in not always the case (for instance in Australia: Adams, Doig, & Rosier, 1991). Within physical science in turn, some balance should exist between physics and chemistry; for, quite often, chemistry is underrepresented. This has the consequence that students not only miss the chance to deal with chemical situations that would enthuse them, but also do not learn useful knowledge (necessary for everyday life) about elements and compounds. A recent paper (Skamp, 1996) examined the possibilities offered by chemistry at primary level and suggested chemistry items that satisfy Harlen's criteria. Such items are acids, bases and salts, the behaviour of materials on cooling, dry ice, the preparation of solutions and of crystals, etc. According to Skamp, ten and eleven-year olds, when looking at a number of science activities, were more enthusiastic about chemical studies they made. This finding demonstrates that, despite the higher conceptual demand of chemistry than physics (something that has been confirmed by the present study), chemical topics, if carefully chosen and taught, can have their proper place in the primary curriculum.

In conclusion, the study of familiar and less abstract phenomena and concepts, coupled with experimental teaching, an overall constructivist teaching approach, the spiral curriculum, the use of recapitulating examinations, the emphasis on fostering of higher-order cognitive skills (Zoller, 1993; Zoller & Tsaparlis, 1997), and co-operative work (Alexopoulou & Driver, 1996) should contribute to the improvement of science teaching and learning at primary level. Relevant to the above is the recent research finding in the USA (Schwartz & Leferman, 2000) that primary students who were taught by *science specialists* (as compared to primary classroom teachers): "(a) were engaged in open-ended, inquiry-oriented, science based activities of the kind often advocated (by current reform efforts), but mostly absent in elementary school; (b) demonstrated problem solving and higher order and critical thinking skills".

Last but not least, mention should be made of the findings that girls as well as less privilegedly located schools were disadvantaged. We will discuss further these two issues in Part 2 of this work, in connection with the 'able' and 'top' achieving students.

Prospects for further work

The two cohorts of students of our study have in June 2001 completed eleventh and twelfth grade respectively, and have participated in general state examinations in a considerable number of subjects. In addition, those who have completed twelfth grade (that is, upper secondary education) have participated in the selection process for tertiary education of Greece, a selection that is based mainly on their achievement in the general state examinations. It will therefore be of the outmost interest to study their performance in these examinations in comparison with their achievement in the tests of our present study. The aim will be to see to what extent achievement in primary science affects (that is, is a *predictor* of) students' future school performance and eventual choice of higher studies and careers. Such a study is now in progress. We will report our findings in due course.

ACKNOWLEDGMENTS: We are grateful to all teachers and students for their contribution to the realisation of this study. We also thank Dr. Norman Reid for his contribution to the considerable improvement of our manuscript.

CORRESPONDENCE: *Georgios TSAPARLIS, University of Ioannina, Department of Chemistry, GR-451 10 Ioannina, Greece; fax: +30 651 98798; e-mail: gtseper@cc.uoi.gr*

REFERENCES

Adams, R., Doig, B., & Rosier, M. (1991). Science learning in Victorian Schools: 1990. Hawthorn: Australian Council for Educational Research.

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.

Australian Educational Council (1994). *A statement on science for Australian schools* (pp. 12-13). Carlton: Curriculum Corporation.

Beaton, A.E., Mullis, I.V.S., Martin, M.O., Gonzalez, E.J., Kelly, D.L., & Smith, T.A. (1996). *Science achievement in the middle school years: IEA's Third International Mathematics and Science Study.* Boston, MA: Center for the Study of Testing, Evaluation, and Educational Policy.

Bloom, B.S. (1956). *Taxonomy of educational objectives: The classification of educational goals, Handbook I: Cognitive domain*. New York: McKay.

Chalkia, K. & Kostopoulos, D. (1997). Attitude and views of primary teachers with regard to the coverage of physics topics in the curriculum and the school books (*in Greek*). *Proceedings of a Seminar on Science Education and Technology in Primary School*, pp. 57-62. Athens: University of Athens, Department of Primary Education.

Duckworth, E. (1964). Piaget rediscovered. *Journal of Research in Science Teaching*, *2*, 172-175.

Ebbinghaus, H. (1913). *Memory*. C.H. Ruger, & C.E. Bussenius (transl.). New York: Teachers College. (Originally published in 1885, reprinted by Dover, 1964.)

Fensham, P. J. (1994). Beginning to teach chemistry. In P.J. Fensham, R.F. Gunstone, & R.T.White (eds.), *The content of science*, Ch. 2. London: the Falmer Press.

Georgousi, K., Kampourakis, K., & Tsaparlis, G. (2001). Physical science knowledge and patterns of achievement at the primary-secondary interface. Part 2. 'Able' and 'top' achieving students. *Chemistry Education: Research and Practice in Europe* (CERAPIE), *2*, 253-263. [http://www.uoi.gr/conf_sem/cerapie]

Harlen, W. (1985). *Teaching and learning primary science*, p. 93. London: Harper & Row.

Harlen, W. & Holroyd, C. (1997). Primary teachers' understanding of concepts in science. Impact on confidence and teaching. *International Journal of Science Education*, *19*, 93-105.

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

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

Johnston, K. (1990). Students' responses to an active learning approach to teaching the particulate nature of matter. In P.L. Linse, P. Licht, W. de Vos, & A .J. Waarlo (eds.), *Relating macroscopic phenomena to microscopic particles.* Proceedings of a symposium, pp. 247-265. Utrecht: University of Utrecht, Centre for Science and Mathematics Education.

Kahle, J.B. & Lakes, M.K. (1983). The myth of equality in science classrooms. *Journal of Research in Science Teaching, 20,* 131-140.

Lee, V.E. & Burkam, D.T. (1996). Gender differences in middle grade science achievement: Subject domain, ability level, and course emphasis. *Science Education*, *80*, 613-650.

Millar, R. (1996). Towards a science curriculum for public understanding. *School Science Review, 77* (280), 7-18.

Mullis, I.V.S., Dossey, J.A., Foertsch, M.A., Jones, L.R., & Gentile, C.A. (1991). *Trends in academic progress: Achievement of U.S. students in science, 1969-70 to 1990; mathematics, 1973 to 1990; reading, 1971 to 1990; writing, 1984 to 1990*. Princeton, NJ: Educational Testing Service.

National Center for Educational Statistics (1995). *Findings from the condition of education 1995; No. 5. The educational progress of women* (NCES 96-768). Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

National Research Council (1996). *National science education standards: Observe, interact, change, learn*. Washington, DC: National Academy Press.

Nussbaum, J. (1998). History and philosophy of science and the preparation for constructivist teaching: The case of particle theory. In J.J. Mintzes, J.H. Wandersee, & J.D. Novak, (eds.), *Teaching science for understanding - A human constructivist view,* Ch. 6, pp. 165-194. London: Academic Press.

Piaget, J. (1964). Development and learning. *Journal of Research in Science Teaching*, *2*, 176-186.

Primary SPACE. *Science processes and concept exploration*. Liverpool: Liverpool University Press.

Schwartz, R.S. & Lederman, N.G. (2000). Achieving the reforms vision: The effectiveness of a specialists-led elementary science program. *School Science and Mathematics*, *100*, 181-193.

Sequeira, M. & Leite, L. (1990). On relating macroscopic phenomena to microscopic particles at the junior high scholl level. In P.L. Linse, P. Licht, W. de Vos, & A .J. Waarlo (eds.), *Relating macroscopic phenomena to microscopic particles.* Proceedings of a symposium, pp. 220-232. Utrecht: University of Utrecht, Centre for Science and Mathematics Education.

Shayer, M. (1991). Improving standards and the National Curriculum. *School Science Review*, *72* (26), 17-24.

Shayer, M. & Adey, P. (1981). *Towards a science of science teaching*. London: Heinmann Educational Books.

Skamp, K. (1996). Elementary school chemistry: Has its potential been realized? *School Science and Mathematics, 96*, 247-254.

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.

Zoller, U. (1993). Are lecturing and learning compatible? Maybe for LOCS: Unlikely for HOCS. *Journal of Chemical Education, 70*, 195-197.

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