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RESEARCH REPORT
Methods and issues of teaching and learning

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

PART 2. ABLE AND TOP-ACHIEVING STUDENTS

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ABSTRACT: Out of nine hundred and seventy-six seventh and eighth-grade students (the *total sample*), from nine urban and semiurban Greek middle secondary schools, who were tested on part of their basic physics and chemistry knowledge [*Chem. Educ. Res. Pract. Eur.*: 2001, *2*, 241-252], only 128 students (13.1%) scored relatively well ('able' students) and only 58 students (5.9%) scored well ('top' students). Boy 'able' and 'top' students outnumbered and outscored 'able' and 'top' girls. The gender gap especially in numbers increased with ability in favour of boys. Importantly, almost all of the 'able' (96.1%) and the 'top' (98.3) came from urban schools. In contrast to the total sample, no difference in the mean scores of the 'able' and the 'top' students between the two grades was observed, although there was an increase in the number of such students from one grade to the next. Compared with the total sample, both the submicroscopic (molecular and subatomic) and the critical-thinking questions had an increased contribution to the scores. Finally, twenty-three of these students were interviewed for the elicitation of reasons for their positive attitude and achievement in primary science. Parental education and involvement (home background) plus the teachers played a key role. The implications of the findings for instruction and learning are discussed. [*Chem. Educ. Res. Pract. Eur.*: 2001, *2*, 253-263]

KEY WORDS: *Primary physical science; primary-secondary interface; gender and primary science; able students; top-achieving students*

INTRODUCTION

In Part 1 of this work, a study that aimed at investigating the basic physics and chemistry knowledge and patterns of achievement that characterise students at the primary-secondary interface was described (Kampourakis, Georgiadou, & Tsaparlis, 2001). It was found that, on the basis of the used tests, the knowledge in physics and chemistry of most primary-school graduates in Greece was very weak, the weakest area being the knowledge of the physical world at the submicroscopic (molecular, atomic, and subatomic level), and the ability to deal with conceptual questions that demand higher than simple recall or recognition skills. In addition, boys outscored girls, while the location of the school (urban / semi-urban) had a great effect.

Despite the overall very low mean scores, a limited number of students scored relatively well. The current interest in able and promising students in science has prompted us to study further the achievement patterns of this subsample. A number of these students were interviewed with the aim to find out possible reasons and factors contributing to good achievement in primary science, such as liking the subject, the effect of school and teacher quality, parental education and involvement and the general socio-economic background.

RATIONALE

Reports on the international achievement in mathematics and science that have appeared in recent years confirm that some western countries, and notably the U.S., appear not to be achieving satisfactorily in middle and upper secondary school. A question arises then as to the extent to which modern curricula and practices cater for the gifted, talented and promising students in science.

According to the *Third International Mathematics and Science Study* (TIMSS), the majority of students in eighth grade from every participating country said that they liked science (Beaton et al., 1996). In addition, liking the subject correlated positively with achievement. Achievement, however, varies among different countries, with far-eastern countries (such as Korea, Japan, and Singapore) being near the top in elementary and middle school, while U.S. students scored near the top in science only in elementary school (third and fourth grade) but fell to a little above average in the seventh and eighth grades. This downward trend continues into the upper secondary level, falling eventually well below average and causing much concern in the U.S.

It is certain that teacher, school, and pupil quality influence student achievement (Barr & Dreeben, 1983; Darling-Hammond & Hudson, 1988). In addition, attitudes toward science may have important implications for science in schools, and especially for gifted, talented, and promising students. Parental and teacher influences are considered very important for shaping positive attitudes (George & Kaplan, 1998). Parental involvement has strong effect on high-school student grades (Fehrmann, Keith, & Reimers, 1987; Keith et al., 1993; Keith & Lichtman, 1994). Home factors have been found to be strongly related to achievement in each country of the TIMSS. We must then pay attention not only to student achievement per se, but to student attitudes and factors that influence them as well.

Finally, of great interest is the well-known gender gap in science in favour of boys (e.g. Kahle & Lakes, 1983; Mullis, et. al., 1991; National Center for Educational Statistics, 1995). A large American study (Lee & Burkam, 1996) identified some important explanatory factors for gender differences in science for middle (eighth) grade students. Many reasons (historical, cultural, attitudinal, practical skills, etc.) are being invoked for the gender difference. It is very pertinent then to study gender differences in the case of the younger students of our study.

METHOD

The ‘able’ students of this study constituted a subsample of a sample from the general Greek student population of seventh and eighth-grade students (lower secondary school, age 11.5-13.5). One of three tests, A, B, or C, was administered to each student at the first week of the school year 1996-97. 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. For more details see Part 1 (Kampourakis, Georgiadou, & Tsaparlis, 2001).

Criteria for ‘able’ and ‘top’ achieving student selection

As criterion for selecting the ‘able’ and ‘top’-achieving students were scores ≥ 40% for test A, ≥ 34% for test B, and ≥ 27% for test C. These values were chosen by taking into account the actual differences among the three tests for the whole sample. The number of these students was 128 out of 976 (13.1%), of which 49 from the seventh grade and 79 from the eighth grade. This group are described as 'able' students. The increase from the one grade to the next can be attributed to social and environmental factors; it may also reflect the increase of the number of students with higher cognitive development (Shayer, 1991).

In addition, a narrower portion of the best (the 'top') achieving students was examined. This time, the score limits were set to $\geq 49.5\%$ for test A, $\geq 43.5\%$ for test B, and $\geq 36\%$ for test C. The number of these students was 58 (5.9% of the general sample) of which 25 from the seventh grade and 33 from the eighth grade.

Finally, twenty-three best-scoring students, nine from the seventh grade and fourteen from the eighth grade, were interviewed by one of the researchers (KG). The interviews were structured and took place in the students' homes, with the approval of and after previous arrangement with their parents. Both the students and their parents were informed by the researcher on the students' scores and the aim of the interview, and co-operated well with the interviewer. The average length of an interview was 45 minutes.

RESULTS AND DISCUSSION

Findings from the written tests

Of the one hundred and twenty-eight 'able' students, almost all (96.1%) came from urban schools, with only five students (3.9%) coming from semi-urban schools. In addition, of the fifty-eight 'top' students, only one came from a semi-urban school. If we compare these figures to the corresponding data for the general sample (75.3% urban versus 24.7% semi-urban), we see that the great majority of 'able' students in science came from urban districts. This must be attributed to the much higher socio-educational background in urban districts. The connection of student achievement in school with the immediate and wider social environment (the socio-educational level) is well known and has been examined in numerous studies in the context of the sociology of education.

Achievement patterns of 'able' students

Table 1 contains mean scores for the wider sample (N = 128) of 'able' students. Some interesting features appear from these data.

- First, as a rule, there was no difference now between the two grades. It seems that the best-scoring students in seventh grade had already reached a 'plateau' as far as social-environmental influence and cognitive development are concerned. Only scores on physics and chemistry showed some variation between the two grades. Recall, however, that there was an increase in the number of 'able' students from the seventh grade (N = 49) to the eighth grade (N = 79).
- The gap between physics and chemistry decreased in comparison with the total sample of this work, becoming non-existent for the eighth-grade able students. However, this is a mean effect, arising from the contributions of tests A, B, and C: in the separate tests, the general differences in performance between physics and chemistry, that were observed in the case of the whole sample of this work, remain. The above finding justifies the characterisation of chemistry as more demanding than physics for younger students.
- Both the submicroscopic and the critical-thinking questions had an increased contribution with respect to achievement on macroscopic questions, in comparison with the whole sample of this work. It thus seems that 'able' students, who should have an advantage with respect both to the social/environmental area and the cognitive development, were more comfortable with submicroscopic and critical-thinking questions. The increased standard deviations in the case of the submicroscopic, the critical thinking, as well as the chemistry questions reflect the fact that

TABLE 1. *Mean percentage scores,*[a] *on the union of the three tests,* [b] *for 'able'* [c] *students.*

	Total	Total macro	Total submicro	Physics macro	Chemistry macro	Critical thinking
Seventh grade [d]	43.8	46.0	36.0	49.7	37.1	32.3
(*N* = 49)	(10.8)	(16.3)	(24.3)	(17.9)	(27.5)	(33.1)
Eighth grade [e]	43.0	44.8	36.0	45.3	43.9	30.5
(*N* = 79)	(10.2)	(14.5)	(25.2)	(16.2)	(23.9)	(29.1)

[a] Standard deviations in parentheses.
[b] The three tests contributed equally; that is, equal numbers of students from each sample were assumed. With the actual numbers of students from each test, total weighted mean scores were 44.1 (11.7) for the seventh grade (*N* = 49), and 43.2 (10.2) for the eighth grade (*N* = 79).
[c] See text.
[d] In the three separate tests, the total mean scores were 51.7 (10.1) for test A (*N* = 22), 44.8 (6.5) for test B (*N* = 8), and 35.0 (8.3) for test C (*N* = 19).
[e] In the three separate tests, the total mean scores were 50.0 (8.8) for test A (*N* = 28), 42.9 (8.6) for test B (*N* =26), and 41.1 (8.3) for test C (*N*= 25).

TABLE 2. *Mean percentage scores,*[a] *on the union* [b] *of the three tests, for 'top' achieving,*[c] *students.*

	Total	Total macro	Total submicro	Physics macro	Chemistry macro	Critical thinking
Seventh grade [d]	50.1	51.9	43.8	55.2	43.8	46.2
(*N* = 25)	(9.1)	(15.5)	(28.2)	(17.4)	(29.7)	(33.8)
Eighth grade [e]	50.4	51.7	46.0	51.7	51.7	39.8
(*N* = 33)	(10.5)	(15.7)	(26.3)	(17.8)	(25.6)	(33.5)

[a] Standard deviations in parentheses.
[b] The three tests contribute equally. With the actual numbers of students from each test, total weighted mean scores were 52.0 (9.9) for grade 7 (*N* = 25), and 50.6 (10.5) for grade 8 (*N* = 33).
[c] See text.
[d] In the three separate tests, the total mean scores were 57.6 (9.3) for test A (*N* = 13), 49.0 (3.6) for test B (*N* = 5), and 43.7 (7.6) for test C (*N* = 7).
[e] In the three separate tests, the total mean scores were 58.0 (7.5), for test A (*N* = 12), 51.2 (8.3), for test B (*N* =10), and 42.1 (9.3), for test C (*N* = 11).

among the 'able' students, there were some with very high and some with low achievement on one or more of these three categories.

Table 2 has the scores for the narrower portion of the best- (the 'top'-) achieving students (*N* = 58). Again, the same but stronger patterns appeared. Noticeable is the disappearance of the difference between physics and chemistry for the grade-eight 'top'-achieving students.

Gender Differences

Out of the one-hundred and twenty eight 'able' students of our sample, 70.1% were boys and 29.1% girls (compared with 52.4% boys versus 47.6% girls in the total sample). Of the fifty-eight 'top'-achieving students, 81.5% were boys and 18.5%. As student ability increased, so did the magnitude of the number gap in favour of boys.

TABLE 3. *Number and scores (%) of 'able' and 'top' achieving boys and girls in the three tests and the two grades.*[a]

		Test A		Test B		Test C		(A + B + C) [b]	
		Boys	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**
7th GRADE	**ABLE**	*N* = 16	*N* = 6	*N* = 8	*N* = 0	*N* =10	*N* = 8	*N* =34	*N* =14
		53.2	47.4	44.8	-	37.8	31.0	45.3	39.2
		(11.1)	(5.9)	(6.5)	-	(10.3)	(3.3)		
	TOP	*N* = 10	*N* = 3	*N* = 5	*N* = 0	*N* =5	*N* = 1	*N* =20	*N* = 4
		59.0	52.7	49.0	-	46.2	36.0	51.4	44.4
		(10.1)	(1.4)	(3.6)	-	(7.6)	-		
8th GRADE	**ABLE**	*N* = 13 [c]	*N* = 12	*N* =17	*N* = 4	*N* =18	*N* = 4	*N* =48	*N* = 20
		52.6	47.8	44.1	38.1	36.2	36.0	44.3	40.6
		(10.3)	(7.0)	(8.8)	(4.3)	(9.4)	(6.2)		
	TOP	*N* = 8	*N* = 3	*N* = 8	*N* = 1	*N* =8	*N* =2	*N* =24	*N* =6
		58.3	58.5	50.8	44.5	42.8	41.2	50.6	48.1
		(9.0)	(4.4)	(8.2)	-	(11.0)	(1.1)		

[a] Standard deviations in parentheses. [b] For the union of the three tests, equal numbers of boys and girls were assumed.

TABLE 4. *Gender gaps (differences in achievement) in favour of boys in the three tests and the two grades.*

		Total sample	'Able' students	'Top'-achieving students
7th Grade	Test A	4.8	5.8	6.3
	Test B	5.0	-	-
	Test C	0.8	6.8	10.2
	A+B+C	3.5	7.4	7.0
8th Grade	Test A	0.2	4.8	0.3
	Test B	2.3	6.0	6.3
	Test C	5.0	0.2	1.6
	A+B+C	2.5	3.7	2.5

Table 3 has the number and achievement of 'able' and 'top' achieving boys and girls in the three tests A, B, and C, and their union for the two grades. We note that boys outscored girls in the union of the tests; in the separate tests, in most cases boys scored higher than girls. In addition, we note that, as a rule, the magnitude of the gender gap increased as we move from the general sample to the 'able' students (Table 4). In conclusion, 'able' boys not only outnumber 'able' girls, but it may be that on the average they outscored them too. These findings are in agreement with those of a large American study for middle (eighth) grade (Lee & Burkam, 1996).

The interviews: Patterns of achievement of 'top' students, parental and teacher influence, and the general socio-economic background

At the outset, it must be stated that all students interviewed came from urban schools, almost all from a prestigious school, but had studied in various primary schools. Boy students outnumbered girls: nineteen (82.6%) versus four (17.4%).

Home background (parent education and parental involvement)

Only one student's father had received just elementary education. Of thirteen (56.5%) students, the fathers had a higher degree (undergraduate diploma) in subjects that were related with science and mathematics (science, engineering, medicine, agricultural-studies), while of six students (26.1%), both parents had such a degree. The effect of parents' education both on their children's achievement in school, and on the formation of positive attitude towards science is well documented (Fehrmann, Keith, & Reimers, 1987; George & Kaplan, 1998).

Although most students (nineteen) stated that they used to study school science on their own, that is without external assistance at home, one cannot exclude that some parents are directly involved and assisting students in their study. Otherwise, parental involvement is indirect, through provision at home of a favourable environment and the proper resources (encyclopaedias, books, computers, etc.).

Preferences for school subjects and future careers

Table 5 shows the preferences / liking of the interviewed students for various school subjects. Eighteen students stated one of mathematics or science subjects as first choice, while fifteen as second choice. Mathematics was the first choice of about half of the students, while the separate science subjects attracted fewer choices. This may be attributed to the dominant part played by mathematics (together with language) in the Greek school curriculum. Some students liked mathematics and science because they considered them easier and more interesting; moreover, they liked physics and chemistry because of the experiments. Between physics and chemistry, more students (14, 60.9%) preferred physics. Sixteen students (69.6%) attributed their interest in science to personal reasons, while the rest paid attention to (a) their usefulness for future careers, (b) the teacher, or (c) the books.

With respect to their preference for likely future professions, thirteen students preferred carriers related to science and/or mathematics (civil engineer, physicist, chemist, computer engineer, mathematician), two students preferred medical professions, one teaching of English, while seven stated that they had not thought of a career yet. None mentioned careers not related to higher-education studies.

TABLE 5. *Students' preferences for the various school subjects.*

School subject	First choice	Second choice
Mathematics	11	5
Physics	3	5
Chemistry	2	3
Computers	1	2
Biology	1	1
Letters	2	3
Other	2	0
No preference	1	0
Total	23	19

Students' wider interest in science

Fifteen students (65.2%) had read out-of-school books and/or had seen documentaries on television related to scientific topics. Eleven mentioned a recent scientific discovery, most of them cloning. Scientific fields that attracted their attention were astronomy, medicine and biology (genetics), atomic and nuclear physics, and electronics. Finally, everybody knew the name of a Nobel laureate scientist, with Albert Einstein and Marie Curie being best known.

It must be pointed out, however, that a switch in attitude was observed with the older, eighth-grade students. Six out of thirteen found that the high-school books were uninteresting, with unclear points (leading them to rote learning) and difficult numerical problem solving. They considered physics and chemistry less pleasing and more difficult than in primary school. Note that a decline in achievement in mathematics and science in middle and upper secondary U.S. schools has been a notable finding of the TIMSS (Beaton et. al., 1996).

'Able' students and the submicroscopic structure of matter

We found that there had been an increase of achievement of the 'able' students on questions that dealt with the submicroscopic structure of matter, contrasting the low achievement of the whole sample. The students interviewed stated an increased interest in submicroscopic topics, with the concomitant attention paid to them in their study. Three students stated that they had read on their own relevant out-of-school books.

The role of experiment

No case was reported where their primary teacher carried out systematic experiments: ten students stated that never had an experiment been carried out in their primary classes; nine students stated that some experiments were done from time to time; and only two students had frequently seen experiments in their classes.

They remembered vividly experiments they had seen. Thirteen experiments were mentioned, with, most noticeably, the experiments dealing with the thermal expansion of solids, the communicating vessels, and Newton's disc. In general, their interest for experiments came out very distinctly from the interviews. Fourteen students stated that they had tried to do some experiments at home, in some cases from special out-of-school books describing science experiments.

Students' opinion on their primary teacher(s)

The opinion of the students about their primary teacher or teachers varied. Six students had one teacher in the fifth and sixth grades, while sixteen students had a different teacher in each of these grades (one student had more than two teachers, and made no comment). In twenty-nine cases of comments, their opinion on their teacher was good to very good. In ten cases of comments, there were no good opinions.

As 'good' was considered the teacher who: *explains the lesson well; performs in some way the actions; repeats the most important parts of the lesson; provides examples and information that is not in the school book*. As 'very good' was considered the teacher who, *in addition to the above, is carrying out some experiments*. [This is consistent with evidence provided by the large American study with eighth graders (Lee & Burkam, 1996), that teachers who offer regular laboratory experiences in their classes are better prepared to teach science.] Finally, as 'not good' was considered the teacher who *does not provide sufficient explanations, shows little interest for children, and delivers the lesson by reading the school book*.

CONCLUSIONS AND IMPLICATIONS FOR INSTRUCTION AND LEARNING

"Lifelong scientific literacy begins with attitudes and values established in earlier years" (National Research Council, 1996, p. 2).

If we accept this position, we must exploit every method to improve 'able' students' science attitude and achievement. As we did in Part 1 of this work, 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.

It was found in this investigation that while the knowledge in physics and chemistry of most primary-school graduates in Greece was very weak, with weakest the knowledge of the physical world at the submicroscopic (molecular and subatomic level), and the ability to deal with conceptual questions that demand higher than simple recall or recognition skills, a relatively small proportion of students could deal adequately and even satisfactorily with the above areas.

The finding that many 'able' students can do relatively well on 'submicroscopic questions' (in contrast to the overall sample) is of paramount importance. It has been argued in the literature, convincingly in our opinion, that the submicroscopic concepts are beyond reach for young students (e.g. Herron, 1978; Johnstone, 1991; Fensham, 1994; Tsaparlis, 1997). Our results suggest that we can make an exception for the 'able' students. For these, submicroscopic concepts not only may be within their grasp, but also they may entice them and increase their interest in science. Such knowledge, then, can have its place, offered as an optional reading (for instance, in separate sections or boxes in the textbooks) both in elementary and middle school. Additional assignment by the teachers of reading books and scientific periodicals, and of using CD-ROMs and the *Internet* can greatly enhance the chances offered to these students to explore the magical world of subatomic particles. Parental involvement can also be useful.

We suggest a number of reasons which explain the ability of the 'able' students to deal with both the 'submicroscopic questions' and the questions that demanded critical thinking:

- These students come from more stimulating environments, where reading, learning, thinking, questioning are all encouraged.
- They are simply more able students for genetic reasons.
- Their expectations and aspirations are higher.
- Their greater knowledge and confidence allow them to use their working-memory space more efficiently, allowing more opportunity for higher-order thinking.
- Their higher cognitive level.

Our interviews support clearly the first three explanations, while ample empirical evidence exists in the literature in favour of the last two explanations.

'Able' and 'top'-achieving boys not only outnumbered 'able' and 'top'-achieving girls, but they also outscored them. In agreement with the findings of the large American study for eighth grade (Lee & Burkam, 1996), the disadvantage of girls was more pronounced as ability increased. The reasons for the gender differences in attitude and achievement in science are mainly historical and cultural. There have been in the literature many attempts at encouraging girls to take a more positive attitude to science and scientists, as well as to increase their science self-concept and their achievement (e.g. Greenfield, 1997; Solomon, 1997; Robertson, 1987; Young, 1994).

Of great concern is the fact that students from semi-urban districts failed to be among the 'able' and "top'-achieving students in science.

Parental involvement is very conducive to a positive science attitude by students (George & Kaplan, 1998). By providing the proper home environment (books, computer, discussion, etc.), parents can play an important part in shaping children's attitudes, which in turn result in high achievement. Parents may be able to encourage girls to improve their science self-concept.

Advice of students by both teachers, parents, and the media on science-related careers is very important. The role of history in science teaching (e.g. Gauld, 1991; Matthews, 1994) can be most helpful in the case of 'able' students. Knowledge of modern scientific advancements can greatly contribute too.

Experiment has a special role to play. Learning science just from textbooks or by listening to teachers lecturing and performing demonstrations is not sufficient. 'Hands-on' and 'minds-on' activities and experiences (National Research Council, 1996) gained by doing experiments and constructing knowledge are essential for 'able' students. In addition, laboratory experiences have been found to be especially beneficial for girls (Lee & Burkam, 1996). At this point, let us point out that the rich, colourful illustrations that characterise most current textbooks, in spite of their attractiveness and usefulness, may have an undesired side-effect. Some teachers may be encouraged not to deal with experiments (even demonstrations), and may refer students directly to the illustrations to see the outcome of an experiment.

The design of better curricula, based on the recommendations from science-education research and the making of better complete instructional packages (student and teacher books plus good modern educational media, such as videos and CD-ROMs) are means for improving not only the attitude, the learning, and the achievement of all students, but also of 'able' students. On the other hand, constructivist teaching as well as methods which (it is maintained that) contribute to the acceleration of cognitive development (e.g. Adey & Shayer, 1994) can be useful too.

Last but not least, comes the teacher. He/she has the major role to play. We need knowledgeable, methodological, enthusiastic, friendly teachers who will work hand-in-hand with the students as mediators in the construction of knowledge by the students. The teachers of today may not always meet the required high standards (Arons, 1990). Teachers need both understanding and help from academicians, science educators, politicians, administrators, the public, and students. It may also be the case that the appointment in primary schools of *science specialists* will contribute to a qualitative improvement of teaching primary science. In point of fact, according to a recent research finding in the USA (Schwartz & Leferman, 2000) 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".

Prospects for further work

As mentioned in the end of Part 1, the students of our study have in June 2001 completed eleventh and twelfth grade respectively, and have participated in general state examinations of Greece in a considerable number of subjects. A study of the performance on these examinations of the students of our present study is now in progress, with the aim 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. We will report our findings in due course.

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