THE RESPONSIBILITY OF SCIENTISTS IN THE EDUCATION OF YOUNG PEOPLE

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We live in a world in which scientific discoveries follow one another with ever increasing momentum. Rarely have we the time required to reflect on the cultural, social and economic consequences of these findings, not to mention their ethical implications. It has become increasingly evident that science has ceased to be an exclusive bastion of the specialist, since it has entered the public arena and now relates to all sectors of society. In relation to this perspective, the scientific community has an inescapable obligation to both transfer this knowledge to the classroom in the teaching of the basic sciences and to participate in regulating the quality of this distribution. A good grounding in the basic sciences during the informative school years will not only produce better prepared candidates for higher education, but will also establish a society with more scientific understanding and thus enhance public participation in the ethical implications that may lie ahead.

Some of the strategies that the scientist will apply in fulfilling these criteria will be universally applicable, whereas others will depend on the level of economic and educational development within each country. Either way, to approach the subject of the responsibility of the scientist in the scholastic education of sciences, it seems advisable to take an individual country as a model. I will concentrate specifically on Chile, a country that has a population of about 15 million inhabitants and a per capita income of US$ 5,000 dollars (US$ 8,400 corrected according to purchase power). In Chile the percentages of the population that undergo primary, secondary and higher education are 98.6%, 90.0% and 31.5%, respectively. In regard to sci-

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ence, Chile possesses a small but effective community. Currently there are about 3,000 active investigators who annually publish close to 2,000 articles in mainstream scientific journals. This statistic of productivity is ranked fourth in Latin America, although it would be placed first if calculated on the number of publications per investigator.

It is just over a year (November of the 2000) – since the results from the Third International Mathematics and Science Study (TIMSS) were announced by the International Association for the Evaluation of Educational Achievement (IEA). The TIMSS, which was established in 1995, surveyed students of primary and secondary education from 41 countries. In the third version undertaken in 1999, Chile participated for the first time next to 37 nations, with a sample of 5,907 students of 14 years of age originating from 185 schools of differing socio-economic backgrounds. The selection of participating schools was made at random, as were the groups of students (all 14 years old, Chilean 8th grade of primary education) within each establishment.

Tests in Mathematics and Sciences both consisted of 30 questions and each student was given 90 minutes to respond to each section. The questions of the test, that were of multiple choice and written format, were processed by participant countries according to a pre-determined rigorous procedure designed to safeguard the universal validity of the test. Once the answers were obtained, the results were grouped in five categories, those including the top 10%, 25%, 50% and 75% population of students and a fifth category which included the lower 25%. It is hoped that those students who had been exposed to a curriculum content of basic Mathematics and Science would be grouped in the upper half, that is to say, in the first three categories.

The results obtained by Chilean students are dramatic, as much in Mathematics as in the Sciences. Chile occupied position 35 of the 38 participant countries, surpassing in both cases only the Philippines, Morocco and South Africa, and thus locating far below the general average (Table 1). In Mathematics, the three superior categories included only 15% of the Chilean students (1%, 3% and 15% in categories 1, 2 and 3, respectively). The fourth category included an additional 33% of students, those that according to the characteristics of the test possess a level of knowledge equivalent to that of an average 10 year old (Chilean 4th grade of primary education). The fifth category included 52% of the Chilean students. According to the definitions, this category includes students who do not even satisfy the requirements of the average 10-year-old. In simpler terms,

Table 1. INTERNATIONAL STUDENT ACHIEVEMENT IN TIMSS

Mathematics

01.	Singapore	604
02.	Republic of Korea	587
03.	Chinese Taipei	585
04.	Hong Kong	582
05.	Japan	579
06.	Belgium	558
07.	Netherlands	540
08.	Slovak Republic	534
09.	Hungary	532
10.	Canada	531
11.	Slovenia	530
12.	Russian Federation	526
13.	Australia	525
14.	Finland	520
15.	Czech Republic	520
16.	Malaysia	519
17.	Bulgaria	511
18.	Latvia	505
19.	United States	502
20.	England	496
21.	New Zealand	491
Average		**487**
22.	Lithuania	482
23.	Italy	479
24.	Cyprus	476
25.	Romania	472
26.	Moldova	469
27.	Thailand	467
28.	Israel	466
29.	Tunisia	448
30.	Macedonia	447
31.	Turkey	429
32.	Jordan	428
33.	Islamic Rep. Iran	422
34.	Indonesia	403
35.	**Chile**	**392**
36.	Philippines	345
37.	Morocco	337
38.	South Africa	275

Science

01.	Chinese Taipei	569
02.	Singapore	568
03.	Hungary	552
04.	Japan	550
05.	Republic of Korea	549
06.	Netherlands	545
07.	Austrialia	540
08.	Czech Republic	539
09.	England	538
10.	Finland	535
11.	Slovak Republic	535
12.	Belgium	535
13.	Slovenia	533
14.	Canada	533
15.	Hong Kong	530
16.	Russian Federation	529
17.	Bulgaria	518
18.	United States	515
19.	New Zealand	510
20.	Latvia	503
21.	Italy	493
22.	Malaysia	492
23.	Lithuania	488
Average		**488**
24.	Thailand	482
25.	Romania	472
26.	Israel	468
27.	Cyprus	460
28.	Moldova	459
29.	Macedonia	458
30.	Jordan	450
31.	Islamic Rep. Iran	448
32.	Indonesia	435
33.	Turkey	433
34.	Tunisia	430
35.	**Chile**	**420**
36.	Philippines	345
37.	Morocco	323
38.	South Africa	243

85% of 14-year-old Chilean students show an unsatisfactory proficiency in Mathematics.

In the Sciences, the results were somewhat better, as the average mark was closer to the international average. The three first categories included 22% of the student population, (1%, 5% and 22%, respectively). The fourth category included an additional 33%, which means that 44% of the Chilean students are located in the fifth category that could not not even answer the most elementary questions. In other words, 78% of the 14-year-old students have not reached a satisfactory level in the Sciences. Figure 1[2] (see page II) illustrates the performance of Chile in the TIMSS according to the designated categories.

Figures 2 and 3 (see pages II and III) enable better comparisons with other sample countries that are deemed representative of the five continents and different performances in the test. As it is evident, the countries with better education have the majority of their students in the upper three categories. In addition, these countries possess a high proportion of their students in the first category. In Mathematics, this is clearly the case of Singapore (46%), Taiwan (41%, not shown), Korea (37%) and Japan (33%).

Surprisingly, the TIMSS showed that diverse factors that commonly are associated with exam performance, such as the economic resources of the school, the number of students per class, the duration of the class, the style of management of the educational system, schooling of the parents, etc..., are not directly determining in the results obtained. The observation that only 1% of Chilean students are located in the highest classification category despite nearly 10% of the Chilean educational establishments being private schools is an eloquent representation of this phenomenon. Table 2 relates to the lack of correlation between the hours of education and productivity in the TIMSS. The socio-economic situation of the countries also failed to significantly influence the results, as demonstrated in the Mathematics test, where 14 countries that have a product to per capita ratio inferior to that of Chile, obtained better results.

What therefore, are the fundamental factors that affect education? The answer to this question is of vital importance for those teachers and scientists who wish to assume the responsibility of a collaborative role in the teaching of science. Possibly this is the variable that the TIMSS

[2] Figures 1 to 4 are adapted from the document entitled *The quality of Chilean education in numbers*, by B. Eyzaguirre and C. Le Foulon, Centro de Estudios Públicos, Saptiembre 2001, Santiago, Chile.

Table 2. YEARLY TEACHING HOURS AND PERFORMANCE

	Yearly teaching hours of Mathematics (a)	Average score in mathematics (b)	Productivity per hour (b)/(a)
Indonesia	222	403	1,81
Morocco	207	337	1,62
Chile	161	392	2,43
Czech Republic	139	520	3,74
Australia	138	525	3,80
Slovak Republic	137	534	3,89
Japan	127	579	4,55
Chinese Taipei	126	585	4,64
Singapore	126	604	4,79
Finland	93	520	5,59
Netherlands	94	540	5,74
Average	129	487	3,77

regrettably does not measure, that is to say, the quality of teaching. TIMSS only reflects the confidence that the teacher possesses in his or her preparation and ability to teach the subject. More than 40% of the mathematics and science teachers in Chile feel that they possess an insufficient level of preparation. Given this precedent, what can be asked of the students? Or, phrased in a more eloquent manner, what would be the outcome if the teachers in Chile took the test?

As anticipated, with this quality of primary science education, the level of knowledge in students who progress to higher education is insufficient. Several pieces of data serve to illustrate the magnitude of this problem. In Chile, since 1967, a system of national examinations has been used to gain entrance to university. The main exam is the Academic Aptitude test, which is obligatory and designed to evaluate verbal and mathematical ability. The mathematics section is composed of 60 questions that include direct operations, deductive logical reasoning, symbolic interpretation, data analyses, etc., with a degree of difficulty similar to that of the TIMSS for students of the same age. In the year 2000, more than half of the participating students (53%) failed to correctly answer 50% of the questions asked, with only one quarter of these students achieving a score of 60% or more which is representative of the ability to handle basic level mathematics.

Other important components of the national testing system are the Specialised Knowledge Examinations, which are based on the common curriculum and elective courses from the general education system. Close to 50% of university careers require these exams, at last half of which request Mathematics while only 5% request Chemistry. In the Specialised Knowledge Examinations the number of questions varies from 40 to 60 and the level of difficulty is regarded comparable to that of the TIMSS for students who have taken the advanced courses from the general curriculum education. Table 3 demonstrates these tests and the percentage of students undertaking them. In the sciences, the number of applicants ranges from 29% in Mathematics to 4% in Chemistry. As it is possible to observe, the results are clearly superior in the areas of History and Geography of Chile and in Social Sciences. The average number of correct answers per question in these last disciplines borders 45%, whereas in the sciences this figure varies between 34.2% in Chemistry and 18.3% in Mathematics. In the same vein, the percentage of students with a score equal or superior to 60% is extremely low, reaching only 1% in the case of Biology. Finally, a high number of students have negative scores in the tests, achieved by the cancellation of one correct answer by four incorrect answers. This statistical information paints a clear picture of the remedial work that must be undertaken once the students arrive to the university. Usually a large percentage of the curriculum during the first year of higher education is targeted at removing the deficiencies left by the Chilean primary and secondary schooling system.

Table 3. STUDENT ACHIEVEMENT
IN THE SPECIALIZED KNOWLEDGE EXAMINATIONS

	History and Geography	**Mathem.**	**Physics**	**Biology**	**Social Sciences**	**Chemistry**
% students taking SKE	63,0%	29,0%	6,0%	20,0%	17,0%	4,0%
Correct answers per question (average)	45,6%	18,3%	24,3%	23,8%	43,7%	34,2%
% students achieving at least 60% in the SKE	26,0%	6,0%	9,0%	1,0%	14,0%	13,0%
% students with negative achievement in the SKE	1,0%	33,0%	17,0%	6,0%	0,2%	9,0%

In Chile, this flaw is not unique to the education of science. Systematic studies also demonstrate deficiencies in respect to reading comprehension within the population. As illiteracy indicators no longer give sufficient information relating to the level of the education within a country, other techniques have been developed to achieve this aim. For example, the Organisation for Economic Co-operation and Development (OECD) has been conducting an international survey (IALS, International Adult Literacy Survey) for the last six years in an attempt to evaluate the reading comprehension of a country. A population age between 16 and 65 years was surveyed in a variety of countries with the aim of obtaining an accurate reflection on the literacy of the population and the country's education system. In 1998 this test was applied, for the third time, to a sample population composed of 18 member countries of the OECD, along with Chile and Slovenia. In Chile a sample population of 3,583 people was co-ordinated by the Faculty of Economy at the University of Chile. The test measured the ability to comprehend prose and written documents and to interpret quantitative data. Within each of these three areas the answers were grouped into five classifications. At the extremes, level 1 included people of low ability, incapable for example, to determine the dose of a medicine from the information printed on the package. In the highest group, level 5, the occupants demonstrated the capacity to integrate information from several sources and an enhanced capacity to process data. Level 3 is regarded the minimal grouping for those people who can participate successfully in the so called 'The Information Age'.

The results of this test were disappointing for Chile. More than 80% of the sample population was located in lower levels, 1 and 2. Level 3 included 13% of the sample with only 2% of Chilean population being classified in the upper levels 4 and 5. The statistical distribution was roughly the same in each of the three areas measured by the test (Figure 4, see page III). It is important to emphasise that extraordinary abilities are not required to reach levels 4 and 5, merely the ability to interpret what is being read. It is surprising that with close to 11% of the Chilean population possessing a completed university education, only 2% of Chileans are located in the higher levels of this test. Deplorably, Chile occupied the last place among the 20 countries evaluated.

Although every scientist must have a preoccupation in relation to basic science education in his or her respective country, in a country that possesses a diagnosis as I have just described, this preoccupation takes on an added ethical imperative. We could ask therefore, what can scientists contribute in this regard?. The answer to this question is not a simple one, as the demands of academic life do not leave much time for extracurricular activities. Further hindering this situation is that participation in this field generally does not yield economic reward, nor does it yield recognition in terms of academic merit. Despite these obstacles a varied range of alternatives are available, those that are of an institutional or individual nature. Without pretension of being exhaustive, I would like to elaborate on some of these alternatives.

Institutional activities include those that involve the establishments of higher education, private companies, scientific societies, scientific academies and other organizations, all of which – of course – requiring the active participation of scientists. As part of their dedication to teaching, the universities should be naturally inclined to contribute to improving the quality of science education. Perhaps the most obvious and available contribution in this respect are the university courses that are offered to school teachers during their vacations. For example, for several years the Pontifical Catholic University of Chile has been offering such courses. These courses rely on a professor in charge with the participation of several colleagues of the respective Faculty. It has been interesting to observe that it is the same schoolteachers that periodically return to the university to attend these courses and thus replenish their knowledge. Along similar lines, 'Project Seed' will be established this coming January at the University of Chile as an initiative of the Millennium Institute of Advanced Studies in Cellular Biology and Biotechnology, incorporating contributions from Fundacion Andes and the World Bank. This Institute will offer an 18 month course in Education and Tools in Modern Biological Sciences to 120 schoolteachers of secondary education from all over the country. In order to gain entrance to the course, each teacher must possess a personal computer and a network connection to their respective school. A fundamental part of the course will be the analysis of the scientific developments that are reported by the press, with the objective of learning the best methods to transfer this knowledge to the classroom.

Academic institutions may also offer stimuli to enhance teaching quality, such as the Father Molina and Michael Faraday Awards which the Pontifical Catholic University of Chile offers annually to teachers of Biology and Physics, respectively. Both awards recognise educational innovations, the search of quality in educational methods, creativity, personal contribution and commitment to enhancement of education, among other criteria. The awards are financial, with the purse divided between the teacher and as financial assistance in the purchase of educational equipment for the institution to which the recipient belongs. The press announces the call for candidates and the presentation takes the form of a formal ceremony performed in the presence of the University Rector and the Deans of the respective Faculties of Science, during which time a lecture is presented by a professor from either the Faculty of Biology or Physics.

Further institutional participation could consist of inviting teachers to do investigation in the university laboratories during the summer months. Although the level of university investigation is extremely different from the type of experimental demonstration used by the schoolteacher, the temporary exposure and experience of investigation may well increase the enthusiasm by which science is then taught in the classroom. In Hungary a program of this type, for students of 14 to 18 years of age began in 1995, with the participation of mentors of the highest scientific merit and with the support of both the government and private institutions.[3] Currently this program encompasses nearly 600 mentors, 68 of which belong to the Hungarian Academy of Sciences. Every year, a national student conference is organised and 20 to 30 student presentations are made. During this conference the mentors talk about their passion and approach to science. To date, the university laboratories and institutes of investigation have trained more than 1,400 talented young Hungarians from all the regions of the country. This same program has lead to the establishment of almost 100 science clubs in Hungarian schools, where more than 1,000 students are introduced to scientific research by established scientists who visit the clubs and speak about their own experience or summarise recent advances in their research fields. The operation of the program has also lead to the formation of a network for schoolteachers, who met for the first time in 1999 to exchange experiences and ideas. Further information about this program can be found at http://kutdiak.kee.hu .

Using somewhat different criteria, the Educational Program for Children with Academic Talents (PENTA UC), was offered by the Pontifical Catholic University of Chile for the first time this year. This program aims to deliver the opportunity of enhanced education to young people between 13 and 14 years of age who possess a talent which cannot be developed to its full potential in the student's current socioeconomic environment. The Program relies on a Directorial Committee incorporating professors from the Faculties of Chemistry, Physics, Biological Sciences, Social Sciences

[3] P. Csermely, G. Halász, G. Jeney, J. Máthé, L. Mikló, D. Solymary, A. Szekeres, G. Tamás. *Biochem. Educ., 28*, 132-133, 2000.

and the Humanities. During the semester classes are given on Fridays in the evening and on Saturdays during the morning, in conjunction with two-week summer courses. All courses are presented by professors who are of a recognised standing in each of the disciplines. The students, who at the moment number 80, also rely on the support of two psychologists, who act both as their tutors and serve as a link with the schools where they study. Further details on this program are available at http://puc.cl/pentauc/

There is another institutional participation that requires a special collaboration from scientists, which is to improve the basic formation of the future science teacher. It is traditional for teachers to be educated in schools of pedagogy in an environment removed from the world of science. The courses that the future teachers take typically include History of the Education, Philosophy of the Education, Sociology of the Education, Curricular Design, etc, and like an appendix, at the end of the university career, some courses of sciences are added. Normally, these courses are given by university professors who do not belong to the Faculties of Science. Fortunately, the main universities in Chile introduced a fundamental reform in this respect, allowing that students who have a degree in any discipline can obtain a teachers degree after taking some courses of pedagogy given by the Faculty of Education.

It is also probable that industry may be interested in contributing to the improvement of scientific education. Perhaps in this case, its main contribution would be in the form of funds directed to the financing of the different programs. In this scheme, scientists must contribute not only to the design of the programs, but also will be required to obtain resources from the companies to finance them. On this theme, I wish to draw your attention to the 'Program in Science Education', a very interesting initiative that is being supported by GENER, an international electric power company with headquarters in Santiago, Chile. This Program is oriented to students between the ages of 6 and 14 from low-income schools. It is a 'hands on' educational scheme in which students are given the opportunity to gain knowledge through discovery, according to a carefully designed sequence of activities based on selected topics in the natural sciences and mathematics. The Program was developed by Chilean university professors who have extensive experience in scientific research and in both international undergraduate and graduate teaching. These professors train schoolteachers during the first two weeks of summer vacations. The training procedure involves confronting the schoolteachers with exactly the same research problems that will be presented to their students and thus advising the teachers on the problems and questions which may arise. Under supervision from these schoolteachers, the students have weekly 90 minutes workshops for around 35 weeks each year. The participating schools are provided with the same computer generated transparencies, lab instruments and other teaching aids used during the summer training sessions. To support the work of schoolteachers throughout the year, members of the university staff make weekly visits to each participating school and interact with teachers and students during the workshops. Staff members report weekly to the Program Director, who in turn reports monthly to GENER officials. Students participating in 'Program in Science Education' have demonstrated enhanced performance in both national and international proficiency tests. For example, a test consisting of three different problems taken from an earlier version of TIMSS was applied to six schools involved in the Program. Their scores were compared with those obtained by students from all countries that took this same test. Considering the schools as independent entities for each problem, they achieved places which would have ranked in the top thirteen countries which participated in TIMSS. Obviously, this is a considerable improvement, which is further enhanced by the observation that some of the students were two years younger than those from the other countries. The participating students also performed better than older students from the same schools who had not taken part in this Program. This Program started its operation in the summer of 1995 and since then over 200 teachers and 25,000 students from more than 40 different schools have participated. The Director of this Program is Dr. Sergio Hojman, a PhD in Physics from Princeton University and full professor at the University of Chile and at Andrés Bello University.

A summary of the participation of institutions in scientific education must also include those that form the scientific societies and the academies of sciences, a subject to which Dr. Jorge Allende has already referred to in this workshop.

Although all the previous institutional activities require the active participation of scientists, there are other possible approaches that can be performed based on their own initiative. An obvious participation would be to present classes in primary and secondary schools. In Chile such an action is currently not possible, since teacher's union regulations prevent those who do not possess a university title in pedagogy from presenting classes. Paradoxically then, scientists and academics who present lectures at both undergraduate and graduate levels in universities, cannot present a class within the school system.

Despite this obstacle, scientists can use other forms of participation in the classroom. For example, maintaining contact with teachers and acting as scientific mentors. They can advise on the form of presentation of theoretical concepts and in the design of experimental demonstrations. Scientists could provide support material such as experimental software, videos and kits that would be of great benefit to teachers. With respect to presentation design, classes could be organised based on questions that will stimulate the students to think, instead of the simple regurgitation of information. Simultaneously, the laboratory exercises should be more than mere demonstrations. They should encourage the active involvement of students, and as far as possible, be oriented towards data processing to enable an understanding of the scientific logic involved in the experimental process and not simply the reporting of results.

Scientists could also incorporate the schoolteacher into their environment, inviting them to their meetings and providing connections to the scientific community as a whole. Additionally, the access to journals, catalogues and instruments that are not commonly available in the school system could be of great help to teachers. Through the channel of the electronic mail and electronic networking the interaction between the schoolteacher and the scientist can be quick, continuos and effective.

The fore-mentioned examples do not exhaust the alternatives of interaction between scientists and schoolteachers. Far from it, these ideas provide the stepping stones and building blocks that will ultimately provide the framework of a fully integrated scientific community. What is important, is to find the manner in which to harmonise the demands of academic responsibility with the fulfilment of a true ethical obligation, which is to enhance scientific education – and with this – enhance the participation of society as a whole in the ethical dilemmas which science will present. In the long term, better scientific development of our youth will enable society to not only value science on the socioeconomic benefits that derive from its applications, but instead regard science as an integrative, stimulating and everyday part of our culture.

Acknowledgements

I am indebted to Barbara Eyzaguirre for supplying me with valuable data concerning science education in Chile, to Dr. Mario Quintanilla for his stimulating comments and to Dr. Gareth Owen for his help in the preparation of this manuscript.

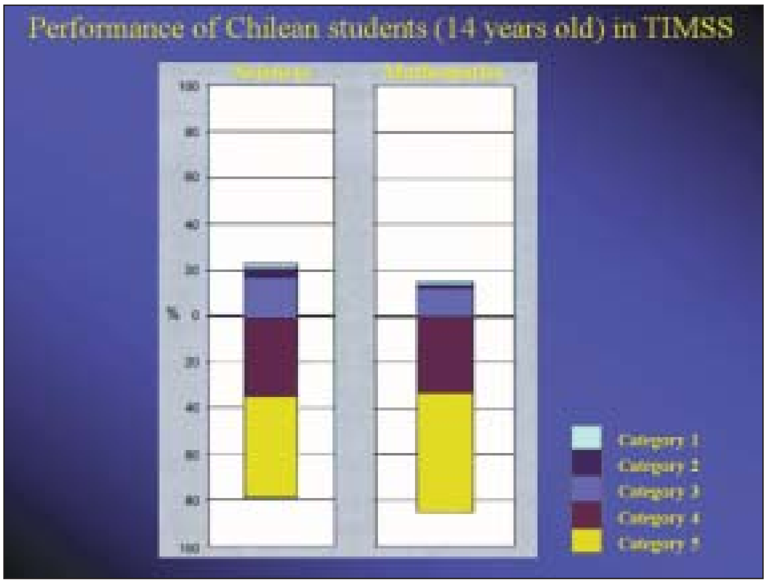

Figure 1.

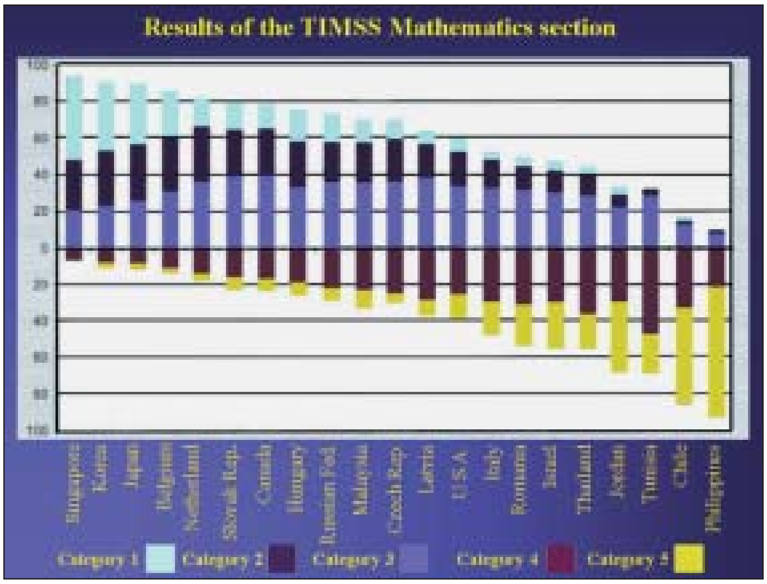

Figure 2.

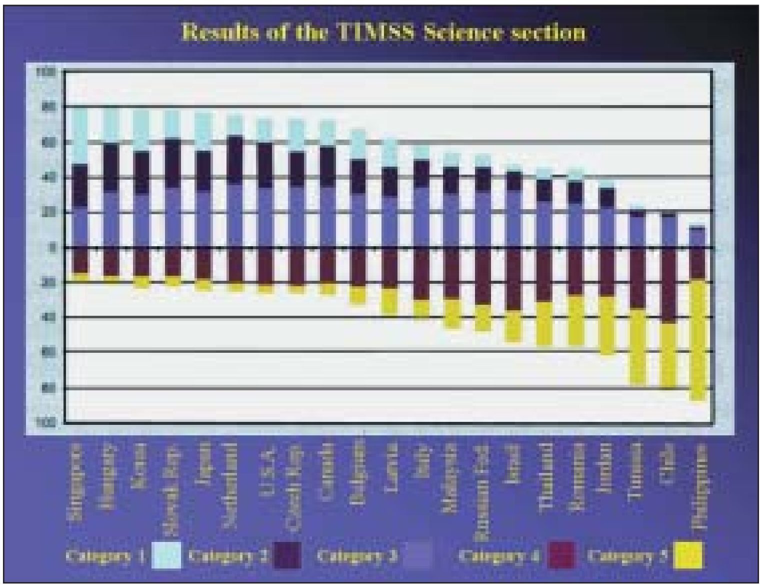

Figure 3.

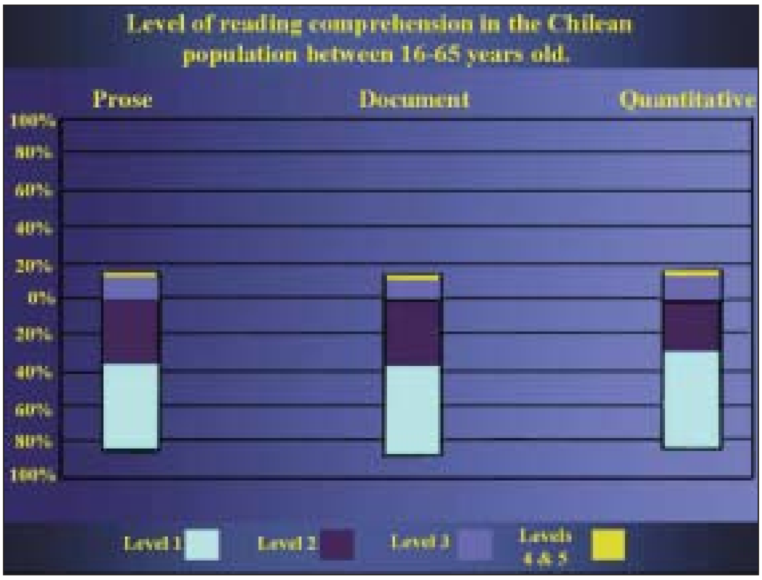

Figure 4.