Education Journal《教育學報》*, Vol. 31, No. 1, Summer 2003*

Assessment of Scientific Literacy of Hong Kong Students in PISA 2000

DIN-YAN YIP
Department of Curriculum and Instruction, The Chinese University of Hong Kong

SUI-CHU HO
Department of Educational Administration and Policy, The Chinese University of Hong Kong

This article reports the performance of 15-year-old students of Hong Kong in scientific literacy in an international study called PISA 2000. Hong Kong ranks the third position among 41 participating countries/regions.[1] The mean scores of Hong Kong students are higher than those of the OECD countries at all ability levels, and the difference is particularly great in the lower percentile levels. The high achievement of Hong Kong students in scientific literacy is attributed to the emphasis of the junior science curriculum on an investigative approach, and the adequate provision of qualified science teachers, supporting laboratory staff, laboratories and equipment. The strengths and weaknesses of Hong Kong students in different aspects of the scientific literacy framework are discussed. Suggestions are put forward to improve the science education of Hong Kong for developing scientific literacy in all students.

This article is a preliminary report of the performance of Hong Kong students in an international project conducted by the Organisation for Economic Co-operation and Development (OECD). This project, known as the Programme for International Student Assessment (PISA), aims at assessing students' literacy in science, as well as reading and mathematics, across different countries and regions. The PISA survey on science achievement is therefore different from most other international studies which focus mainly on assessing students' scientific knowledge as stipulated in the national science curriculum of each country or region.

The following sections will start with a brief introduction to the rationale and design of the PISA project, with particular reference to the meaning of the scientific literacy framework and the design of test items used for assessing scientific literacy. This is followed by an outline of the design of the study and an analysis of the performance of Hong Kong students relative to international mean performance, including both the overall performance and performance in different components of the scientific literacy framework. The final section discusses the implications of the findings on the science curriculum and assessment of Hong Kong.

The PISA 2000 Project

An Overview of PISA

The PISA project is a series of international surveys that assess how well 15-year-old students, who are approaching the end of compulsory schooling in most countries, are prepared to meet real-life challenges of a changing world. It focuses on young people's ability to apply their knowledge and skills to solve problems and make informed judgements and decisions in everyday life situations. This kind of ability is defined as "literacy," which is different from and more than the ability to recall or understand subject matter knowledge of the school curriculum. The project studies different aspects of literacy that are related to what students learn in the school, such as reading, mathematics, and science.

The first survey, known as PISA 2000, was conducted in 32 countries in 2000, and 11 additional countries/regions, including Hong Kong, in 2002. The PISA project originally aimed at studying different aspects of literacy of students in OECD countries, which are among the best economically developed countries in the world, but was later extended to some non-OECD countries. While PISA 2000 measures literacy in reading, mathematics, and science, its primary focus is on the domain of reading. The PISA survey will be repeated every three years, with the primary focus shifting to mathematics in 2003, and science in 2006, and back to reading in 2009.

The Scientific Literacy Framework

A desired outcome of a science curriculum for all students is to equip young people with the scientific knowledge and skills that are useful for future life in society, beyond the walls of the classroom. In order to function actively in society and make informed decisions based on available evidence, our students should be scientifically literate. In the PISA project, OECD (2001) defines scientific literacy as "the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (p. 23).

To be scientifically literate is thus far more than the ability to recall the facts and terms of science. Scientific literacy encompasses understanding of scientific knowledge, the processes by which this knowledge is developed, and the nature of scientific knowledge. Accordingly, the PISA project has designed tasks that aim to assess the following abilities:

1. Ability to demonstrate understanding of scientific concepts.
2. Ability to recognize scientifically investigable questions.
3. Ability to identify evidence needed in a scientific investigation.
4. Ability to draw or evaluate conclusions.
5. Ability to communicate valid conclusions.

Items for assessing Ability 1 are set on scientific knowledge that is important and relevant in everyday life. They may involve applying scientific concepts in realistic or novel contexts, explaining relationships in a specified situation, suggesting possible causes of certain observations, or making predictions about the effects of given changes.

Items on Ability 2 are concerned with identifying the question or idea that is being tested in a given investigation. They may also involve differentiating questions that can be answered by scientific methods from those that cannot, or suggesting a question that could be resolved by scientific processes in a given situation.

Items that assess Ability 3 focus on identifying the information that is needed for testing a given idea scientifically. They may involve recognizing what data should be considered or compared, what variables should be changed or controlled, or what action should be taken to collect relevant data.

Items for assessing Ability 4 are concerned with arriving at a conclusion from given data, selecting from alternatives to the conclusion that fits the data, or giving reasons for or against a given conclusion in terms of the evidence available or identifying the assumptions made in reaching a conclusion.

Items on Ability 5 involve communicating valid conclusions from available evidence and data, or presenting a scientific explanation in a way that is appropriate to a given audience. The emphasis is on the clarity of communication that is consistent with scientific understanding.

All the five abilities require the possession of some scientific knowledge, but they cannot be achieved by rote learning alone. Ability 1 is the most basic level of scientific proficiency, and it is concerned with understanding and application of scientific knowledge in real-life situations. Abilities 2, 3 and 4 are closely related because they constitute different steps in the process of scientific inquiry. They form a cluster of skills that reflect students' understanding of the scientific methods and the nature of science, which is essential for making informed judgement or decisions according to available evidence. Ability 5 is concerned with how to organize scientific ideas and communicate them in a comprehensive way. This ability is important for daily interaction among people on issues related to science.

Examples that illustrate the nature and demand of the assessment items in each of the five abilities of the scientific literacy framework can be found in the released items and sample items published in OECD documents (OECD, 2000, pp. 82–93; OECD, 2001, p. 84).

Design of the Study

The PISA Assessment Instrument

Types of Assessment Items

In the PISA science framework, the contents for assessment are focused on the thematic areas of "Earth and environment," "Life and health," and "Science in technology," rather than as traditional subjects such as physics, chemistry, and biology. These thematic areas are considered to be more relevant to all people in their lives beyond school than the traditional subject areas, and more in line with PISA's focus on the development of scientific literacy as a prerequisite for adult life. There are altogether 13 assessment tasks in the scientific literacy framework of PISA 2000, each task being set in a particular context and made up of a number of assessment items.

The assessment items can be categorized into two types according to the nature of responses required. The "closed items" include multiple-choice questions, True/False or Yes/No questions, and those that require answers of single word or phrase. All these questions make a low demand on communication skills. The "open items," on the other hand, require extended explanation and demand greater communication skills than the "closed items."

The distribution of assessment items in terms of abilities in scientific literacy and thematic areas is shown in Table 1, which is cross-tabulated with the types of responses required and with the number of items and scores for each group enlisted.

Development of the Assessment Instrument

The assessment instrument was developed by the PISA Consortium in cooperation with a panel of international experts from participating countries. The process started with the identification of the range of skills and competencies that are considered to be important for a person to be scientifically

Table 1 Distribution of Assessment Items for the Scientific Literacy Dimension

	Item types and number of items		
	Closed items	Open items	Total
Distribution of items by abilities			
To demonstrate understanding of scientific concepts	12 (13)	3 (3)	15 (16)
To recognize scientifically investigable questions	4 (4)	1 (1)	5 (5)
To identify evidence needed in a scientific investigation	3 (3)	2 (2)	5 (5)
To draw or evaluate conclusions	3 (3)	3 (4)	6 (7)
To communicate valid conclusions	—	3 (5)	3 (5)
Distribution of items by subject areas			
Earth and environment	7 (8)	6 (8)	13 (16)
Life and health	8 (8)	5 (6)	13 (14)
Science in technology	7 (7)	1 (1)	8 (8)
Total	22 (23)	12 (15)	34 (38)

Note: The numbers inside the parentheses indicate the scores allocated to the respective items.

literate. This framework of scientific literacy was agreed at both scientific and policy levels among the participating countries, and formed the basis for the development of the assessment instrument. Assessment items were then developed and contributed by participating countries, and reviewed by the panel of international experts. When a pool of items were selected, they were translated by different countries into their own languages, and the translation was monitored and reviewed by language experts in the PISA Consortium. These items were then piloted in the Field Trial in all participating countries. Following the Field Trial, the panel of experts considered a variety of aspects in selecting the items for the Main Study: (1) item reliability based on the Field Trial; (2) the outcome of the item review from participating countries with respect to potential cultural, gender or other bias; and (3) queries received during the Field Trial marking process. After a period of negotiation, a final set of items was adopted by participating countries to form the assessment instrument for the PISA 2000 Main Study. For technical details on the development of the assessment instrument, readers should consult the *PISA 2000 Technical Report* (OECD, 2002).

Sampling Procedures for the Subjects

In PISA 2000, students of Hong Kong were selected by a two-stage stratified sampling design according to the OECD criteria. In the first stage, schools were sampled systematically from each stratum with probabilities proportional to the number of 15-year-old students enrolled. For Hong Kong, schools were classified into three strata: government, aided, and independent schools. Independent schools included international schools and direct-subsidy schools (DSS). The distribution of schools is shown in Table 2. In the second stage, thirty-five 15-year-old students were randomly selected from the sampled schools. A total of 4,405 students from 140 schools were accepted for international comparison.

Table 2 Selected and Participating Schools for Each Sampling Stratum

School stratum	Ability level	Total number of schools	Number of schools sampled by OECD	Number of schools accepted by OECD
Government	High	18	7	7
	Medium	8	3	2
	Low	10	3	4
Aided	High	127	50	46
	Medium	130	47	44
	Low	101	31	29
Independent	Local (DSS)	23	6	6
	International	23	3	2
Total		440	150	140

The OECD standard procedures covered the timing of the testing sessions, the instructions given to students and general rules for test administration. It is expected that all participating countries/regions follow the procedures strictly so that the data are collected in comparable conditions. For PISA 2000, the Hong Kong PISA Centre trained 49 test administrators to administer the assessment in schools according to the OECD assessment procedures. After data collection, eight markers were recruited for science. They were teachers or prospective teachers in science. These markers were trained by workshops to understand and apply the marking criteria to ensure a high degree of reliability in marking.

Assessment of Scientific Literacy

In the assessment session, each student worked on an assessment booklet for two hours in their own school, with about half an hour spent on a questionnaire about themselves and the home background, and the remaining one and a half hours on items that assessed literacy in reading, mathematics, and science. There were nine different assessment booklets, each with a different combination of assessment items. Thus not all students were given the same assessment items. Each item might appear in several booklets, ensuring that it was answered by a representative sample of students. Details of the sampling procedure and assessment design for Hong Kong students are described in the Hong Kong regional report (Hong Kong Institute of Educational Research, 2003).

Results of the Study

Performance of Hong Kong Students on an International Basis

As in other domains of PISA 2000, the overall performance in scientific literacy is measured on a scale with a mean of 500 points for all students of the OECD countries and a standard deviation of 100 points, with about two-thirds of students across the OECD countries scoring between 400 and 600 points.

Performance of Hong Kong students in scientific literacy on an international basis can be estimated by comparing the mean national scores of all participating countries in PISA 2000 (Table 3). Hong Kong students' performance is the 3rd highest among the 41 participating countries/regions that satisfy the sampling criteria of OECD, with a mean score of 541 and a standard error of 3.01. The score of Hong Kong is slightly below that of Korea (score = 552 points) and Japan (score = 550 points), but the differences between the scores of these three regions are not statistically significant. Thus Hong Kong is among the top tier of countries/regions in the scientific literacy assessment, and is well above the OECD mean of 500 points. The OECD mean is computed from the scores of the OECD countries participating in PISA 2000, excluding the non-OECD countries/regions which generally show much lower performance. Among the participating countries of PISA 2000, the OECD countries in general show much better economic development than the non-OECD countries.

Another way to estimate the general level of scientific literacy reached by Hong Kong students relative to other countries is to compare the mean scores of Hong Kong students with those of students of the OECD countries at different performance levels (Table 4).

Across the OECD countries, the cutting scores at the 95th, 90th and 75th percentiles are 657, 627 and 572 points respectively. At the lower end of the scale, the cutting scores at the 25th, 10th and 5th percentiles are 431, 368 and 332 points respectively. At each of these percentile levels, the score of Hong

Table 3 Performance of PISA 2000 Countries in Scientific Literacy

	Mean	*SE*	
Korea	552	2.7	▲
Japan	550	5.5	▲
Hong Kong – China †	541	3.0	
Finland	538	2.5	▲
United Kingdom	532	2.7	▲
Canada	529	1.6	*
New Zealand	528	2.4	▲
Australia	528	3.5	▲
Austria	519	2.5	*
Ireland	513	3.2	*
Sweden	512	2.5	*
Czech Republic	511	2.4	*
France	500	3.2	*
Norway	500	2.7	*
United States	499	7.3	*
Hungary	496	4.2	*
Iceland	496	2.2	*
Belgium	496	4.3	*
Switzerland	496	4.4	*
Spain	491	3.0	*
Germany	487	2.4	*
Poland	483	5.1	*
Denmark	481	2.8	*
Italy	478	3.1	*
Liechtenstein †	476	7.1	*
Greece	461	4.9	*
Russian Federal †	460	4.7	*
Latvia †	460	5.6	*
Portugal	459	4.0	*
Bulgaria †	448	4.6	*
Luxembourg	443	2.3	*
Thailand †	436	3.1	*
Israel †	434	9.0	*
Mexico	422	3.2	*
Chile †	415	3.4	*
Macedonia †	401	2.1	*
Argentina †	396	8.6	*
Indonesia †	393	3.9	*
Albania †	376	2.9	*
Brazil †	375	3.3	*
Peru †	333	4.0	*

Notes: ▲ denotes scores that are not significantly different from that of Hong Kong.
* denotes scores that are significantly lower than that of Hong Kong.
† Non-OECD countries/regions

Table 4 Scientific Literacy Scores of Students of OECD Countries and Hong Kong in Different Performance Levels

	OECD mean score	Hong Kong score
95th percentile	657	671
90th percentile	627	645
75th percentile	572	600
50th percentile	500	541
25th percentile	431	488
10th percentile	368	426
5th percentile	332	391

Kong students is always higher than the OECD average, indicating that Hong Kong students generally achieve a higher level of scientific literacy than the international average. As revealed in Figure 1, the differences between the Hong Kong scores and OECD averages are particularly great at the lower percentile levels. For example, at the 90th and 95th percentiles, Hong Kong students get 18 and 14 points more than the OECD mean scores respectively; whereas at the 5th to 25th percentiles, the Hong Kong scores are about 58 points higher than the corresponding OECD mean scores. This means that the difference in performance between the low and high achievers is much lower in Hong Kong than that in OECD countries in general. It is also worth noting that Hong Kong is the only non-OECD region that scores above the OECD means at all percentile levels. All the other non-OECD countries perform far below the OECD means (OECD, 2003, p. 286).

Performance of Hong Kong students in different components of scientific literacy

To gain a better understanding of the strengths and weaknesses of Hong Kong students, their performance in each of the five components of the scientific literacy framework is compared with the international mean (Figure 2).

With reference to the international mean scores in Figure 2, the 15-year-olds across all countries in PISA 2000 are relatively good at understanding concepts, recognizing questions, and identifying evidence, but weak in drawing or evaluating conclusions and communicating conclusions. Hong Kong students generally show a similar pattern of performance, with the highest score in "understanding concepts" and the lowest score in "communicating conclusions."

More specifically, the performance of Hong Kong students is in par with the international means in "recognizing scientifically investigable questions"

Figure 1 Student Scores in Scientific Literacy at Different Percentiles

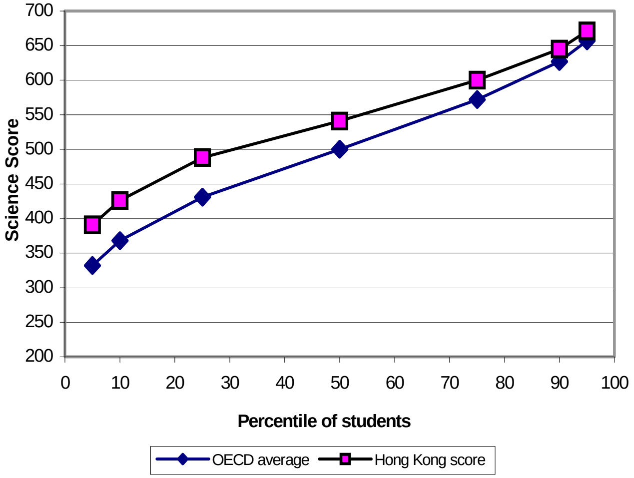
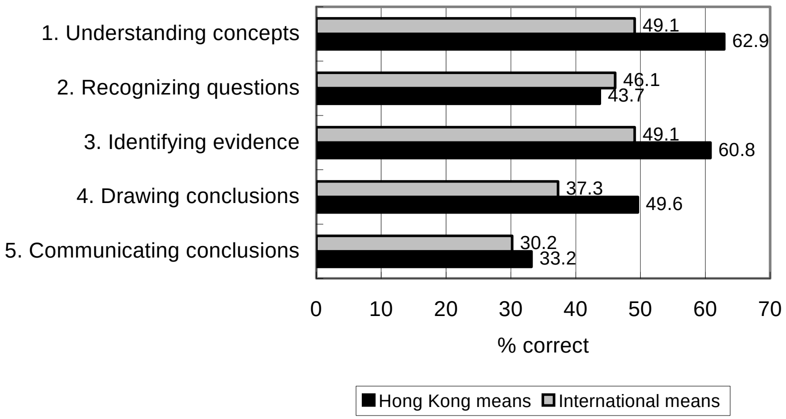


Figure 2 Comparison of International and Hong Kong Means on the Five Components of Scientific Literacy



and "communicating valid conclusions," but is much better in "understanding scientific concepts," "identifying evidence," and "drawing conclusions." However, the implications made from the above comparison should be treated with caution, as certain components are being assessed by a small number of items which may not lead to a valid assessment of students' abilities.

For example, out of a total of 34 items, there are only four items on “recognizing questions” and three items on “communicating valid conclusions.”

Discussion

In the scientific literacy framework of PISA 2000, the performance of Hong Kong students is at the top third position among the 41 participating countries/ regions, being comparable to that of the students of Korea and Japan. The high achievement of Hong Kong students is also evidenced by the fact that their scores in science are always higher than the OECD means across different percentile groups (Figure 1). The difference between the Hong Kong and OECD mean scores is particularly high in the lower-ability levels, suggesting that the lower achievers of Hong Kong are less disadvantaged in science learning.

These observations indicate that the secondary school system of Hong Kong, in comparison with other participating countries, has effectively reduced the difference in science achievement between the low and high achievers, while at the same time maintained an overall high level of performance in science. The smaller difference in science performance between the high- and low-achieving Hong Kong students relative to the OECD average is rather unexpected in that the secondary students in Hong Kong are highly segregated in abilities when they enter secondary schools. The pre-entry academic ability of a secondary student in Hong Kong is measured by the Academic Ability Index (AAI), which is a score based on the student’s academic performance in school-based examinations in the last two years of primary education moderated by a public aptitude examination. According to Yip, Tsang, and Cheung (in press), over two-thirds of the total variances of AAI in secondary students lie between schools, while less than one-third of the total variances are found within schools. This means that Hong Kong students are quite homogeneous in terms of initial academic ability within each secondary school, but vary widely between schools. Although there is no evidence that the relatively small difference in science performance between the high and low achievers in Hong Kong is related to its highly segregated school system, it is tempting to suggest that streaming of students in secondary schools may allow a more strategic deployment of resources and support in enhancing the learning outcomes of the low-achieving students.

The majority of schools in Hong Kong are maintained by government funding with similar provision of staffing and resources. Thus schools that take in the academically lower achievers are not disadvantaged in terms of supply of qualified teachers, supporting staff and equipment. Furthermore, in recent years, some of these schools have received additional support from the government and other educational organizations in various ways, such as the supply of additional teachers for implementing small-class remedial teaching, the design and implementation of school-based curriculum, and the development of teaching skills that facilitate the learning of low achievers (e.g. Curriculum Development Institute, 2002; Lee, Lam, Ma, & Cheung, 2002; Wong & Chu, 2002).

When considering the performance on the five components of scientific literacy, the mean scores of Hong Kong students are much higher than the international mean scores in "understanding concepts," "identifying evidence," and "drawing conclusions," but the scores on "recognizing questions" and "communicating conclusions" are similar to the international means. The strengths of Hong Kong students can be attributed to the focus of the Hong Kong junior science curriculum on the mastery of scientific knowledge and the adequate supply of trained science teachers. The Hong Kong science curriculum also advocates for the use of an investigative approach that involves the students collecting evidence through carrying out practical work (Curriculum Development Committee, 1986). The curriculum also encourages science teachers to integrate practical work with the learning of science concepts (Curriculum Development Council, 1998). Such an approach is facilitated by the adequate provision of science laboratories, equipment, and laboratory technicians in all schools.

However, the implementation of the science curriculum, particularly with regard to the investigative approach, is limited by the teaching approach of the teachers. Didactic teaching is still prevalent in science lessons and science teachers tend to provide highly prescriptive instruction to students on practical work. This kind of practical work requires students to follow prescribed procedures, make observations, identify evidence, and draw conclusions from their experimental data, but provides little opportunity for them to pose problems and formulate hypotheses, or to design experiments and work according to their own design (Yip and Yung, 1998). Through such kind of learning experience, our students are capable of "identifying evidence" and "drawing conclusions," but are relatively weak in "recognizing questions that can be investigated scientifically," which is a fundamental step in designing scientific investigations.

During science lessons or practical sessions, Hong Kong students are usually given worksheets which can be completed with single words or simple phrases. They are not required to discuss or interpret their data in words or present their discussion and conclusions in a systematic way. The prevalence of this mode of learning activities may help to explain why Hong Kong students, similar to those of other countries in general, are weak in communicating scientific explanations and conclusions. This ability requires the students to integrate and organize their scientific concepts, and present their ideas verbally in a logical way. Such a skill is rather demanding for 15-year-olds and its development needs the use of interactive learning activities and ample opportunities for its practice. Before 1998, over 90% of secondary schools in Hong Kong claimed to use English as the medium of instruction (EMI) for their subjects, including junior science. Although a mixed code of Chinese and English was used by teachers in most EMI schools, all written work was in English. However, most EMI students were limited in English proficiency and had difficulty in communicating through English, both orally and in writing (Brimer et al., 1985; Hirvela & Law, 1991; Johnson, Chan, Lee, & Ho, 1985). This limitation may explain why activities and practical reports in science lessons do not demand much communication skills in English, and this practice may in turn adversely affect the development of communicative skills in conveying scientific explanations or conclusions.

Besides the mastery of scientific knowledge and investigative skills, scientific literacy also encompasses understanding of the nature of scientific knowledge, and an appreciation of the potentials and limitations of the scientific process, which will enable a person to apply scientific knowledge and skills to solve everyday life problems, and to make informed decision on social and personal issues related to science. Unfortunately, these elements of scientific literacy are neglected in our science curriculum, and this is evidenced by the weaker performance of Hong Kong students in "recognizing scientifically investigable questions." Many students find it difficult to identify the kinds of questions that science can attempt to answer, or the specific question that might be tested in a particular situation. In an analysis of the design of the junior science curriculum in Hong Kong, Cheung (2000) shows that the science syllabus is dominated by academic and cognitive processes orientations, but neglects the humanistic, society-centered, and technological orientations. The teaching and learning activities presented in the syllabus are mainly concerned with the development of process skills, such as observing carefully, classifying, measuring, handling equipment properly, inferring, predicting, controlling variables, and interpreting data (Curriculum Development Council, 1998).

Conclusions and Implications

The results of the PISA 2000 study indicate that Hong Kong students perform well in scientific literacy, being significantly above the mean performance of the OECD countries, especially for the academically lower achievers. The high achievement of Hong Kong students can be related to the implementation of a science curriculum that focuses on the development of both academic ability and process skills. It emphasizes the mastery of scientific knowledge and at the same time advocates an investigative approach that aims at integrating practical work with the learning of science concepts. Such a curriculum orientation probably accounts for the particularly high performance of Hong Kong in comparison with other countries in "understanding concepts," "identifying evidence," and "drawing conclusions." Other contributory factors include the adequate provision of qualified science teachers, supporting laboratory staff, laboratories and equipment. The smaller difference in scientific literacy scores between the low and high achievers of Hong Kong relative to that of other countries suggests that the various strategies used to support schools that take in students of lower academic abilities have been effective in enhancing the learning of these students. Such support should be maintained or strengthened in order to achieve a more equitable science education for all children, as the lower achievers are usually associated with disadvantaged socioeconomic backgrounds.

The prevalent use of didactic teaching and recipe-type practicals, however, deprives our students the opportunities to engage in asking questions for investigation, proposing hypotheses, and designing experiments to collect evidence. Accordingly, Hong Kong students are relatively weak in "identifying investigative questions." The relative low performance in "communicating scientific explanations and conclusions" can also be related to the common use of the didactic teaching style by science teachers in which students play the role of passive receiver rather than constructor of knowledge. Using a second language for science teaching and learning in EMI schools also discourages the use of interactive learning activities and therefore the development of communicative skills.

The above-mentioned deficiency of the science curriculum of Hong Kong can be made up by teaching the methods of science and nature of scientific knowledge explicitly to students, through the use of concrete examples. Guided discussion of historical episodes on the development of scientific ideas has proved to be an effective strategy for achieving this goal (Bybee et al., 1991; Irwin, 2000; Yip, 2003).

In Hong Kong, as in many other places, most science teachers have been brought up on a diet of recipe-type practical work in schools and universities. They are ill-prepared for anything other than teacher-directed learning styles (Germann, Haskins, & Auls, 1996; Hodson, 1993). Even for those who are prepared to take up the challenge of teaching science with an investigative approach, they may not have the necessary knowledge, skills, and resources to do so. In response to this problem, Yip and Yung (1999) have initiated a teacher development program that aims at equipping science teachers with the strategies and methods for developing the concepts and skills of scientific investigation in students in a systematic way. However, the Curriculum Development Council, the Hong Kong Examinations and Assessment Authority, and various teacher education institutes should take a more active role in this type of program to prepare our teachers to teach investigative work effectively and develop suitable resources for conducting genuine investigations.

Note

1. There are altogether 43 countries/regions which participated in PISA 2000. Data from Romania was not available. The response rate of the Netherlands was below the standard specified by OECD. Thus, only 41 countries/regions are listed in most of the tables or figures in this article.

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