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TOOLS FOR PROMOTING SCIENCE LITERACY

Abstract: Scientific literacy is the ability of common people to know and understand scientific concepts and processes (National Research Council- NRC, 1997). Scientific literacy enables people to make informed decisions, to participate in civic affairs, and improve economic productivity. With scientific literacy a person can find answers to questions derived from everyday experiences. A literate person can understand, describe, explain, and predict natural phenomena. Scientific literacy implies that a person can understand and enjoy the wonders of Nature and technology, also improving his self-esteem. He can understand the scientific issues about important national or local decisions and express informed positions. One example is the debate about global warming. Is there a technological solution or humanity should adapt to the inevitable changes?

Science literacy is extremely important for sustainable development both in developed and developing countries. An environmentally aware society can make the right decisions about the environment and support their leader's efforts towards sustainability. If we compare the country ranking for science literacy with those for competitiveness and innovation, the relationship appear very clearly. Econometric models allow to calculate the impact of science literacy on a country's GDP (PISA, 2010). Science literacy can only be improved through a change of the educational system as a whole. Students require a broad overview of the major ideas that science offers, not just learning the fundaments of biology, chemistry and physics. The process of improving science literacy cannot be confined to school, but it should become a lifelong endeavour.

INTRODUCTION

There are many definitions of scientific literacy. According to NRC (1997) „scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying na-

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tional and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately".

The U. S. National Science Education Standards (NRC, 1997) established a number of content standards outlining what students should know, understand, and be able to do in science. These standards were designed and developed as one component of the comprehensive vision of science education presented in the *National Science Education Standards*.

The general welfare of a nation is stronger with a citizenry that is scientifically informed. Without an informed electorate, and a scientifically informed legislature, some of the most fundamental objectives may not be served. Understanding science enriches our appreciation of everyday activities. A scientifically illiterate person is effectively cut off from an immensely enriching part of life, just as surely as a person who cannot read.

Our society is inextricably tied to the discoveries of science like, the Copernican concept of the heliocentric universe, Charles Darwin's discovery of the mechanism of natural selection, the work of Freud, the development of quantum mechanics and the plate tectonics. In general the culture of the times was influenced by developments in science. Nobody can hope to appreciate the deep underlying threads of culture in his time without understanding the science at the base of it.

Doing science is different from using science. Even scientists are generally uninformed in scientific fields outside their own field of professional expertise. At the Harvard University an informal poll revealed that fewer than ten percent of graduating seniors could explain why it's hotter in summer than in winter (Hazen, 2002).

Science curricula have been generally determined by scientists as a basic preparation for a science degree. Such curricula focus on the knowledge of the fundaments of biology, chemistry and physics. However such an education does not meet the needs of the majority of students who require a broad overview of the major ideas that science offers, how it produces reliable knowledge and the limits to certainty (Osborne & Dillon, 2008).

SCIENCE LITERACY AND ECONOMY

The Programme for International Student Assessment (PISA) is an internationally standardised assessment that was developed by the OECD and administered to 15-year-olds in schools. Four assessments have so far been carried out (in 2000, 2003, 2006 and 2009). Tests are typically administered to between 4,500 and 10,000 students in each country. There is no relationship between the size of countries and the average performance of 15-year-olds in PISA.

If we compare (Tab. 1) the PISA 2006 country ranking for science literacy with that of the World Bank of 2010 for the GDP, we see that there is a poor relation between the two parameters, because the GDP is largely dependent on the size of the countries. If, instead, we compare the PISA ranking with the Competitiveness Index (World Economic Forum, 2010) and with the Innovation Index (Economist Intelligence Unit, 2009), the relationship is very evident (17 countries fall in the first 26 of the three rankings).

Table 1. [1] Gross domestic product 2009 (World Development Indicators database, World Bank, 2010). [2] Science literacy ranking (PISA, 2009), [3] Competitiveness, World Economic Forum, 2010. [4] Triadic patents per million population (Economist Intelligence Unit, 2009)

[1] World Bank GDP (2009)	millions US dollars	Sc. Literacy [2]PISA (2009)	Score	Competitiveness [3]WEF (2010)	Score	Innovation [4]EIU (2009)	patents per million population
1 United States	14,256,300	1 Shanghai-China	575	1 Switzerland	5.63	1 Japan	117.21
2 Japan	5,067,526	2 South Korea	558	2 Sweden	5.56	2 Switzerland	107.56
3 China	4,984,731	3 Finland	554	3 Singapore	5.48	3 Sweden	81.01
4 Germany	3,346,702	4 H. Kong-China	549	4 United States	5.43	4 Germany	76.38
5 France	2,649,390	5 Singapore	542	5 Germany	5.39	5 Netherlands	66.94
6 United King.	2,174,530	6 Japan	539	6 Japan	5.37	6 Israel	60.28
7 Italy	2,112,780	7 New Zealand	532	7 Finland	5.37	7 South Korea	58.40
8 Brazil	1,571,979	8 Canada	529	8 Netherlands	5.33	8 United States	53.11
9 Spain	1,460,250	9 Australia	527	9 Denmark	5.32	9 Finland	53.04
10 Canada	1,336,067	10 Estonia	525	10 Canada	5.30	10 Luxembourg	50.48
11 India	1,310,171	11 Netherlands	522	11 H. Kong-China	5.30	11 Denmark	42.18
12 Russian Fed.	1,230,726	12 Germany	520	12 United King.	5.25	12 Austria	39.70
13 Australia	924,843	13 Taipei-China	520	13 Taipei-China	5.21	13 France	39.35
14 Mexico	874,902	14 Liechtenstein	520	14 Norway	5.14	14 Belgium	34.44
15 South Korea.	832,512	15 Switzerland	517	15 France	5.13	15 United King.	27.41
16 Netherlands	792,128	16 United King.	514	16 Australia	5.11	16 Norway	25.59
17 Turkey	617,099	17 Macao-China	511	17 Quatar	5.10	17 Singapore	24.31
18 Indonesia	540,277	18 Poland	508	18 Austria	5.09	18 Canada	24.04
19 Switzerland	500,260	19 Belgium	507	19 Belgium	5.07	19 Australia	18.74
20 Belgium	468,552	20 Ireland	505	20 Luxembourg	5.05	20 New Zealand	15.32
21 Poland	430,076	21 Hungary	505	21 Saudi Arabia	4.95	21 Ireland	14.95
22 Sweden	406,072	22 United States	503	22 South Korea	4.93	22 Italy	12.33
23 Austria	384,908	23 Norway	500	23 New Zealand	4.92	23 Slovenia	6.36
24 Norway	381,766	24 Sweden	495	24 Israel	4.91	24 Taipei-China	5.01
25 Saudi Arab.	369,179	25 Italy	489	25 Unit. Arab. Em.	4.89	25 Spain	4.55
26 Iran	331,015	26 Denmark	459	26 Malaysia	4.88	26 Hungary	4.06

THE STRONG ECONOMIC IMPACT OF SCIENCE LITERACY

For the purposes of PISA, scientific literacy refers to an individual's:

– Scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues

– Understanding of the characteristic features of science as a form of human knowledge and enquiry

– Awareness of how science and technology shape our material, intellectual and cultural environments

– Willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

A report by PISA uses recent economic modelling to relate cognitive skills to economic growth. The relationship indicates that relatively small improvements in the skills of a nation's labour force can have very large impacts on future well-being. The record on the relationship between those skills and economic growth provides a means of evaluating the cost of not improving schools. The gains, put in terms of current Gross Domestic Product (GDP), appear very high.

There are many ways in which we could improve the cognitive skills of the population, such as health programmes, the introduction of new teaching technologies, but PISA analysis is focused on schooling programmes.

Programmes to improve cognitive skills through schools take time. The impact of improved skills will not be realised until the students with greater skills move into the labour force. The impact of skills on GDP at any point in time will be proportional to the average skill levels of active workers. If we assume a work life of 40 years, it implies that new workers with improved science skills are 2.5% of the workforce. Thus, it takes 40 years until the full labour force is at the new skill level.

The simplest way to see the impact of any improvement in cognitive skills is to trace out the increased GDP per capita that would be expected at any point in the future. Thus, for example, it is possible to say what percentage increase in GDP per capita would be expected in 2050, given a specific change in skills started today. The value of improvement in economic outcomes from added growth depends, of

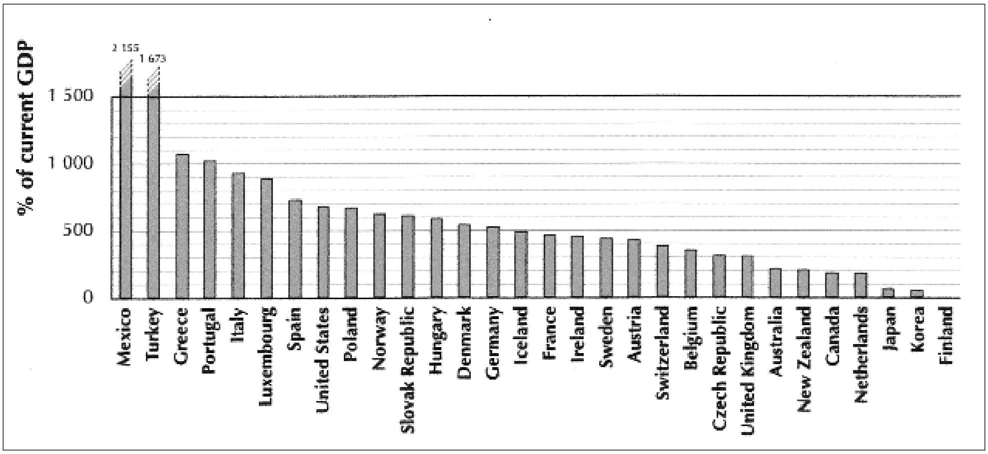

Fig. 1 – Increase of GDP due to a reform that improves student performance in each country to reach the level achieved by Finland, at 546 points on PISA scale (average of mathematics and science in 2000, 2003 and 2006) expressed in % of the current GDP (PISA, 2010).

course, on the path of economies that would be obtained without educational improvement.

Bringing all countries up to the average performance of Finland, OECD's best performing education system in PISA, would result in gains in the order of USD 260 trillion (Fig. 1). The report also shows that it is the quality of learning outcomes which makes the difference.

Even reducing the projections substantially to allow for plausible minimal estimates suggests very large implications of improved cognitive skills and human capital. If the estimated impacts of cognitive skills were twice as large as the true underlying causal impact on growth, the resulting present value of successful school reform still far exceeds any conceivable costs of improvement.

DEVELOPING COUNTRIES

Broad access to scientific information is key for people to understand, participate and respond to the challenges that development poses to civilization. Understanding of issues such as global warming, loss of biodiversity, evolution, implications of genetic research, and many other topics is essential, almost a requisite, for personal involvement in these issues. (De La Rosa C., 2000).

Industrialized nations have easy access to scientific information. Libraries, electronic information, and other means of global information access, have multiplied the ways in which people can obtain information. Developing nations have inadequate science resources. Access to scientific literature in developing countries is marginal.

Scientific literature is mainly for the English-speaking world. Libraries in developing nations cannot purchase expensive scientific journals. There are many more books and science articles published in English about issues of relevance to developing countries than in their native languages. While English is one of the universal languages, it is by no means spoken or understood in many non-English speaking countries.

University libraries in these countries can barely afford to subscribe to a few journals in each specialty field. The rest are generally unavailable to scientists and students. Without access to current literature, the preparation and publication of works directed to the more general public is delayed or impaired. Educators, in general, have even less access to accurate, relevant and up-to-date information on most issues related to science.

Some of the responsibility for the conservation of tropical natural resources lies on the shoulders of developed countries. Most of the new scientific information about this issues is being generated in the developed world. Sharing this information in effective ways is a joint task. To improve scientific literacy in developing countries we could:

– Develop personal relationships with scientists and educators in developing countries. There are many scientists that have made these relationships part of their careers, but the pattern needs to expand to concerned citizens, philanthropists and educators.

– Support the development of exchanges between institutions and organizations, whether these are universities, colleges, high schools or non-profit education or conservation organizations.

– Share the wealth of information. It is easy to make books, journal subscriptions and magazines available to counterpart organizations or even individuals in developing countries.

– Provide and promote subsidies for the publication of key works (books and articles) in the countries' native languages, making them widely available and their cost reasonable to the local citizens.

TOOLS

According to the American National Science Teachers Association (Siebert & McIntosh, 2001), teachers should promote inquiry-based instruction and provide classroom environments and experiences that facilitate students' learning of science. Professional development activities should involve teachers in the learning of science through inquiry, and integrate knowledge of science, learning, and pedagogy.

Teachers should continually assess their own teaching and student learning. Assessment practices should be varied and focus on both achievement and opportunity to learn, be consistent with the decisions they are designed to inform, and result in sound and fair decisions and inferences. Inquiry should be viewed as an instructional outcome (knowing and doing) for students to achieve in addition to its use as a pedagogical approach.

Science programs should provide equitable opportunities for all students and should be developmentally appropriate, interesting and relevant to students, inquiry-oriented, and coordinated with other subject matters and curricula. Science programs should be viewed as an integral part of a larger educational system that should have policies that are consistent with, and support, all *Standards* areas and are coordinated across all relevant agencies, institutions, and organizations.

Achievement of the vision of the National Science Education Standard (NRC, 1997) will not occur without the support and efforts of all those dedicated to quality science education.

The *Standards* are not limited to the specification of what students need to know and be able to do. Rather, they address the educational system as a whole and require that all aspects of the educational system change. In this way, the *Standards* provide for sustainable change and they provide you with a dynamic environment in which educational change can realistically occur and be maintained.

Instructors need to recognize that students construct knowledge based on previous understanding and experience. This theory is called constructivism (Lorsbach & Tobin, 1992). Constructivism is a theory of knowledge used to explain how we know what we know. A constructivist epistemology is useful to teachers if used as a referent; that is, as a way to make sense of what they see, think, and do.

Traditional Classrooms	Constructivist Classrooms
Students are viewed as "blank slates" onto which information is etched by the teacher.	Students are viewed as thinkers with emerging theories about the world.
Teachers generally behave in a didactic manner, disseminating information to students.	Teachers generally behave in an interactive manner, mediating the environment for students.
Assessment of student learning is viewed as separate from teaching and occurs almost entirely through testing.	Assessment of student learning is interwoven with teaching and occurs through teacher observations of students at work and through student exhibitions and portfolios.

Source: Brooks, J. G., and M. G. Brooks. (1993) *The Case for Constructivist Classrooms*. Alexandria, VA: ASCD, 17.

Fig. 2 Fundamental differences between traditional and constructivist classrooms (Siebert & McIntosh, 2001).

A concrete action for improving science education is being carried out by the French Academy of Sciences in cooperation with the École Normale and other partners. This initiative, *La main à la pâte* (Charpak et al., 2006), through its website provides resources, services and exchanges (http://lamap.inrp.fr) for helping teachers of sciences in the primary school.

La main à la pâte was launched in France in 1996, and then extended to many other countries, on the basis of these ten constructivist principles:

1. The schoolchildren examine an object or a process of the real world, close and touchable and do experiments on it.

2. During their investigations they think and comment, put in common and discuss their ideas and results, construct their knowledge, since a pure manual activity is not enough.

3. The activities proposed by the teacher are organized in sequence in view of a progression in learning. They leave a large part of autonomy to the children.

4. A minimum of two hours per week is devoted to the same theme for several weeks. A continuity of activities and pedagogical methods is assured to the schoolchildren.

5. Each schoolchild keeps an exercise book describing the experiences with his own words.

6. The major objective is the progressive appropriation, by the children, of the scientific concepts and operational techniques, accompanied by the consolidation of the written and oral expression.

7. Families and/or the neighbours are solicited by the work done in the classrooms.

8. Locally, scientific partners (universities, high schools) accompany the work in the classrooms and put at their disposal their competence.

9. Locally, the institutes for the formation of teachers put their pedagogical experience to the service of the teachers.

10. The teacher can obtain through an Internet site, modules, ideas for activities, answers to his questions. He can also participate to a cooperative work through a dialogue with colleagues, pedagogists and scientists.

ICSU (International Council for Science) and IAP (Inter Academy Panel) are financially associated for hosting an Internet portal on science education, which has been realized by „*La main à la pâte*". This multi lingual portal is active since 2004.

In order to explore the problems of science teaching in Europe, the Nuffield Foundation convened two seminars involving science educators from nine European countries. The seminars investigated the extent to which the issues were common across Europe, the similarities and differences between countries, and some attempted solutions and remedies.

The report of these seminars (Osborne & Dillon, 2008) carries a very clear message: School science education has never provided a satisfactory education for the majority. Now the evidence is that it is failing in its original purpose, i. e. to provide a route into science for future scientists. The challenge therefore, is to re-shape science education: to consider how it can be made fit for the modern world and how it can meet the needs of all students; those who will go on to work in scientific and technical subjects, and those who will not.

The recommendations made by the Nuffield report deserve careful consideration by educators, policy makers and scientists.

Everybody agrees that science should be a compulsory school subject, but there has been little debate about its nature and structure. Rather, curricula have simply evolved from pre-existing forms.

These curricula have been determined by scientists who perceive school science as a basic preparation for a science degree. Such curricula focus on the foundational knowledge of the three sciences – biology, chemistry and physics. However such an education does not meet the needs of the majority of students who require a broad overview of the major ideas that science offers. Both the content and pedagogy associated with such curricula are failing to engage young people with the further study of science. Science education for all can only be justified if it offers something of universal value for all rather than the minority who will become future scientists. For these reasons, the goal of science education must be, first and foremost, to offer an education that develops students' understanding both of the canon of scientific knowledge and of how science functions.

School science offers an education in science and not a form of pre-professional training. Most school science curricula do attempt to serve two goals – that of preparing a minority of students to be the next generation of scientists – and that of educating the majority in and about science, most of whom will follow nonscientific careers. Knowledge is usually presented in fragmented concepts where the overarching coherence is not even glimpsed, let alone grasped – an experience which has been described as akin to being on a train with blacked-out windows – you know you are going somewhere but only the train driver knows where.

In addition, there is large gap between the focus of school science – commonly the achievements of the 19 th and early 20 th Centuries – and the science that is reported in the media, such as astrophysics, neuroscience and molecular genetics.

The report (Osborne & Dillon, 2008) provides a number of recommendations to the EU. The first one, and maybe the most important, says:

„The primary goal of science education across the EU should be to educate students both about the major explanations of the material world that science offers and about the way science works. Science courses whose basic aim is to provide a foundational education for future scientists and engineers should be optional".

Other recommendations regard other important subjects, such as

– the importance of investing greater effort in ensuring that the quality of science education before the age of 14 is of highest quality, because most students develop their interest before that age;

– informing students, both about careers *in* science and careers *from* science where the emphasis should be on the extensive range of potential careers that the study of science affords;

– the importance for the EU to invest in improving the human and physical resources available to schools for ensuring that teachers of science of the highest quality are provided for students in primary and lower secondary school;

– improving the ways in which science is taught is essential. Transforming teacher practice across the EU is a long-term project and will require significant and sustained investment;

– investing in research and development in assessment in science education;

– recruitment, retention and continuous professional training of science teachers must be a policy priority in Europe.

CONCLUSIONS

Improving science literacy requires re-conceptualizing science literacy to be both a state and lifelong process, as both a personal choice and an economic necessity, and as both a personal enhancement and civic participation. Today there are enormous resources for continuing a lifelong education. Books on every field of science, television, radio programs, and science web sites that elucidate every conceivable scientific topic.

This new conception of science literacy implies that science literacy is a task of both formal and informal science education; it creates a demand for all professionals to become both science literacy participants and educators. In order to realize the above vision, there should be a perceived continuum between formal and informal science education. It is also necessary to educate science professionals in workforces to become science and the public educators, and improving science literacy should become an integral component of human resources development in workforces.

Having a huge majority of the population scientifically illiterate in a modern democratic society is a prescription for disaster. Many, if not most, of the significant issues influencing our society today have a major scientific or technological component. Scientifically illiterate voters cannot even begin to understand the debates associated with, for example, complex environmental issues, or genetic-engineering regulations.

There are other reasons why our society would benefit immensely from a commitment to a major increase in science literacy. In the new global civilization, there is ample evidence that competence in scientific and technological disciplines will be a key parameter in distinguishing between those nations and societies that achieve and/or sustain economic health and those that do not. Most of the new jobs of the 21st century will be in fields that are related to science and technology. Having most of our work force at least not uncomfortable with top-level scientific concepts will clearly strengthen our ability to compete in the global marketplace.

The primary goal of science education cannot be to produce the next generation of scientists. Societies need to offer their young people an education in and about science that will develop an understanding of the major explanatory themes that science has to offer.

Achieving this goal requires a long term investment in curricula that are engaging, in teachers of science by developing their skills, knowledge and pedagogy; and in assessment systems that adequately reflect the goals and outcomes we might aspire to for science education. We have managed to transform a school subject which engages nearly all young people in primary schools into one which the majority find alienating by the time they leave school. In such a context, to do nothing is not an option.

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