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State of the Art of Science Teaching(*)

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Abstract. *Available sources about research and field activities on Science teaching are referred to, and some of the most important characteristics the current works on Science teaching are discussed.*

Keywords. Science, Science Teaching, Science education, Logic, Religion.

1. Introduction.

Education reforms have been effected or are under way in most of the European and other countries during the last years. Although the extent and the kind of the reforms vary significantly from one country to another, they all share as a common factor the increased significance of Science Education which becomes a major constituent of school curriculum, comparable to language. This bust resulted in a plethora on works, empirical and other, related to Science education. Many works are also published on the INTERNET [1].

Science teaching which constitutes a major part of the contents of Science education has also attracted educators and researchers. A simple comparison on the quantities of articles in scientific journals on Science education and the publication of books dedicated specially to the different aspects of Science education shows a significant increase over the past decade. The increase in not only quantitative, providing useful empirical data but it also extends to more general aspects including the teaching approaches adopted, the underlying learning theories, the teaching means and the use of new technologies (especially informatics), and also, other parameters that may affect the effectiveness of Science Teaching.

2. A short commentary on the Literature.

Until some time ago, Science teaching and, more generally, Science education were dealt mostly as an adaptation (more or less similar to the teaching of all the other subjects of the school curriculum) of the general pedagogy which attracted the research emphasis on teaching. In current days, possibly because of the importance assigned to Science teaching, specific large extent studies are undertaken providing a plethora of recent data as candidates for inclusion to this, necessarily brief, work. Now, the expression "state of the art" may take different overlapping and parallel meanings:

- Current or contemporary trends in the field,
- New developments in the underlying theories,
- New approaches using or adapting already known models,
- Recent empirical data from relevant activities,
- Use of new equipment and or technology,
- Empirical results obtained recently,
- Etc.

There are many good works in every one of the above classes and it would be rather unfeasible to single out and present even representative works (not mentioning the great subjectiveness such a task may have). Consequently, this work presents, for the interested reader, a more or less extensive bibliography of collected works on available sources about research and field activities on Science teaching and focuses to some of the most common characteristics the current works on Science teaching exhibit.

2.1. Empirical results.

Works under this class describe the teaching of a specific topic from the Science subject matter of the school. The teaching is presented and the data are discussed in terms either:

- The (social, ethnic, economic or otherwise) school context,
- The application of a specific learning strategy,
- The contest of a specific problem with the Science topic discussed, e.g. misconceptions, alternate conceptions, specific understanding difficulties, etc.,
- The comparison between different teaching approaches,
- The use of new technology, especially computers,
- The use of an innovative experimentation,
- Etc.

Taking into account the specific terms under which the study has been performed, the, usually sound, empirical data provided are useful to the development of teaching strategies, to choosing a specific type of instruction, etc. Examples of this type of work appear in all journals, either specific to Science education or to education in general. The publications from schools and from teachers associations always provide valuable such data from actual school operation and quite often contain studies of a high scientific quality [2]. Specialized International Conferences are also a rich supply of such data (see for example [3], [4]). Local conferences provide also similar data with the advantage of addressing peculiarities of a specific education system.

Summer schools or special interest workshops is another valuable source of education data on a specific area or region.

2.2. Surveys and specialized studies.

Surveys refer to various parameters of the education system of a region. They are usually carried out within the activities of international bodies e.g. OECD [5], UNESCO [6], EU [7], or sponsored by (local or state) governments. Their focus is mainly on economic and on policy matters. However, recently their content has been extended to include specific chapters directly related to Science and Technology education (for example [8], [9], [10], [11], [12], [13], [14], [15]). These data provide useful information on developments in the regions considered.

Lately, another source of this specific type of data initiated within the European Union by Thematic Networks (or other Community funded actions) on Science and Technology (see for example [16], [17], [18]). Usually these are initially fostered by EU within the context of increasing the S&T Literacy (STL), a priority action.

Because of the importance Science teaching and, more generally, Science education receives in most of the European and other states, many reputed publishers include in their publication collections of refereed relevant studies produced in a regular basis (see some examples later).

3. Content.

Works on Science teaching from sources like the ones mentioned earlier were selected and their contents were analyzed in terms of:

- The theme and/or type of the work,
- The underlying learning theory, if any, in relation to skills, dexterities and attitudes to be attained,
- The type of instruction used and the type of assessment, if any,
- The subject matter chosen, its sequence into topics and its type (traditional versus modern Science),
- The target group,
- The experiment and, more general, the practice work involved, if any,
- The equipment used,
- Other related issues.

Although this analysis was not extensive to include all different aspects in these categories, there were interesting findings.

3.1 Theme.

The works examined were referring to different issues of Science teaching, e.g. the application of a learning theory or of a specific type of instruction etc (see above in 3. Themes). Many were also referring to related issues that affect Science teaching or provide a context for it such as the Science teacher's competence and how to develop it (for collections of related works see in [19], [20], [21]), the curriculum aspects and how to achieve them, existing or desirable objectives of Science education, the influence of the social environment of the school or the pupils (see for example [22], [23]) etc. It should be noted however that some of the works examined refer to issues related to Science teaching without a focus theme. This was more evident in works describing actual school practices referring to experimental or practice activities.

3.2 Underlying learning theory.

Although learning may occur spontaneously (every day's experience) or even without teaching at all, learning theories are fundamental in choosing an appropriate teaching strategy and enhance significantly teaching effectiveness when they are understood by the teacher and applied appropriately. This is more than true for Science where in addition to cognitive skills (simple and complex) other practical skills and dexterities are also to be attained. In quite a few of the works examined, a specific learning theory is missing and it cannot be inferred from the whole teaching architecture. As empirical evidence indicates, most of the teachers lack the necessary knowledge and if they possess it, they tend to repeat the teaching they themselves have been exposed to than to transform their knowledge into school practice and adventure on new teaching approaches. The scientific knowledge they have learned on this subject seems abstract and remote to school reality. The importance of Science education assigned by recently introduced national curricula in almost all countries revealed the necessity for an effective Science teaching and the requirement of a learning theory. To this end Piaget's work provide an expected choice [24] and constructivist teaching emerges as the theory environment for Science teaching with many relevant works appearing. Although in most of the cases the theory is applied correctly, in actual school instruction the active evolvement of the students with an appropriate time for reflection and (re)construction of their (new) cognitive schemes leaves large margins of improvements. In most cases the teacher "demonstrates inconsistencies", "explains or proves the theory" and "builds the model". The reasons may be attributed to the limited school time allocated or to unawareness of its importance. This is a problem attracting attention (see for example [25]). A useful source of related issues may be found also in [26].

3.3 Type of instruction used.

Empirical data on school operation show that narration, although still practiced to a large extent, diminishes. Instruction is at least enriched with audiovisual means. Experimentation at least as a demonstration quite often performed by the students themselves is constantly increasing. Teaching actions requiring the active student's participation (i.e. essays, observations) either at atomic level or in groupwork appear frequently [27]. Teaching by project assignments and experience teaching are constantly increasing. Assessment is improving and seems that is considered, at last, an integral part of the teaching although there is a lag in formative assessment. When formative assessment is included in teaching usually means a summative assessment on part of the lesson of the day and, if achievement results are low, the teaching is repeated in the same way (see more in [28]).

3.4 Subject matter.

The management of subject matter is almost within the traditional analytical way imposed in the course outline of the Science curriculum, a rather expected outcome, even when the curriculum permits flexibility. Encouraging is however that increasing advocating of a more synthetic (e.g. study of a phenomenon in total not its partial aspects) or of an interdisciplinary approach appear and relevant research and field work started to appears (see an example in [29]). Real life observations and their connection to the "theory" of Science disciplines only recently has attracted attention and started to enter classrooms.

3.5 Target group.

Apart from a minority of works where a target group is not clearly defined or it is stated to cover a wide range of grades (ages), the majority of the rest addresses mostly primary education, may be because pedagogy is associated with childhood. Middle and then high school general education follow (in this descending order) while technical vocational education is almost absent despite its significance in a technology based society. Higher levels of education are addressed mainly in pre- and in- service Science teachers. Practical skills, so interlaced with Science education, need still a proper attention and a systematic study (see more in [30]). Almost always the study is restricted to (complex) cognitive skills (e.g. problem solving). Within this context, conceptual change, scaffolding and related methods are used but quite often in a controversial way.

3.6 Practice work.

Experimentation has been made compulsory in most of the curricula introduced recently and are increasingly included in school Science teaching. Problems still remain and include:

- The type of experiment(s) used (demonstration or testing, by the teacher or by the students, …)
- The equipment used (simple or modern, in the classroom or in special laboratory, actual experiments or simulated ones, …) [31].
- The role of experiment within the teaching process.
- Reporting on experimental findings.
- Etc.

Most problems here may be traced to the downgrading of practice work that prevailed and the lack of experienced teachers. Despite the progress made, the field is open to the investigation, the research and the teaching with the main problem being the smooth and consistent incorporation of experiments into the teaching practice. Also studies on this field will provide useful data about the outcome of students practice of science and may help to understand better the influence of practice work to conceptual learning, skills and processes associated with Science and, more generally, with cognition.

4.Perspectives

Science teaching aims at a more efficient Science education. Efficiency however depends strongly on the objectives attributed to Science education an issue directly related to the reasons Science is included in the school curriculum. These are:

- **Cultural.** Science is a cultural asset of human civilization and has its place especially in compulsory education.
- **Utilitarian**. Science is the basis of technology and thus a sine qua non for technology dependant societies and a significant means to welfare for the rest.
- **Personal**. Science poses inherent advantages to the cognitive development of young persons and consequently it is important especially to the primary school curriculum when cognitive skills are developed [32].
- **Social.** With so many decisions in technology dependant societies directly influenced by Science and Technology advances, Science literacy is crucial to democracy as an active participatory system [33].

Depending on the values and the perspectives of the context society ([22], [23]) different priorities may be assigned to the reasons above affecting thus the emphasis of Science teaching. Or:

The education we desire for our children must depend upon our ideals of human character, and our hopes as to the part they are to play in the community. A pacifist will not desire for his children the education which seems good to a militarist; the educational outlook of a communist will not be the same as that of an individualist. To come to a more fundamental cleavage; there can be no agreement between those who regard education as a means of instilling certain definite beliefs, and those who think that it should produce the power of independent judgement. Where such issues are relevant, it would be idle to shirk them. At the same time, there is a considerable body of new knowledge in psychology and pedagogy which is independent of these ultimate questions, and has an intimate bearing on education. Already it has produced very important results, but a great deal remains to be done before its teachings have been fully assimilated. This is especially true of the first five years of life; these have been found to have an importance far greater than that formerly attributed to them, which involves a corresponding increase in the educational importance of parents.

(Bertrand Russell,[35]
On Education, Especially in Early Childhood, *1926)*

If the priority is Utilitarian, facts methods and techniques would be pursued by Science teaching. If the priority is Personal, complex cognitive skills as e.g. problem solving must be pursued. If the priority is Social, project work and groupwork are useful resources. Usually a balanced mixture is aimed at. Our societies highly value the personal and social reasons also have declared an interest on the Utilitarian one. Consequently, Science teaching, especially in compulsory education, has to be adapted appropriately in order to improve [34] (or at least to not deteriorate) the quality of our societies. Towards this aim Science teaching must adapt appropriately. Areas of improvement include:

Syllabus. An update is necessary. After a century since relativity and quantum mechanics it is about time for them to reach schools [36].

These together with Statistical physics and recent developments must reproduce the syllabus in a coherent and consistent way. The up to now practice (in tertiary education also) to add separate additional chapters after traditional Science has been taught only confusion provokes.

Inquiry. Open type questions and problems are necessary to complex cognitive skill development. They should, however, be accompanied with scientific discipline. Physics by inquiry is a valuable resource[37].

Experiments. They should be performed, especially in smaller ages with simple materials. Self-made equipment presents inherent advantages and helps towards a better understanding of the basic notions [29]. They should be incorporated smoothly to the teaching activities with the skill of planning an appropriate experiment to test a hypothesis to be an explicit aim. The distinction of observational and/or experimental data from their interpretation and the corresponding theory is very important [43].

Modelling. Science teaching must develop reasoning (logic) [38]. The creation of models [39] is a very advantageous process, may be used more generally and should constitute an explicit objective of Science teaching.

Teaching. Everyday observation may be related to Science [40]. Combined with what children think [41] is very advantageous and leads to a better understanding and appreciation of Science.

Teacher education. A matter of urgency. Polymorphic practice [42], new and flexible methods of training [44] are valuable resources.

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6. Notes and References

[1] A search on Science education resulted in more than 300 000 hits on more than 50 000 sites. Narrowing and restricting the search still leaves more than 50 000 results. Although most of them are simple description of activities, a few have a significant value.

[2] see for example the "Handbook of Research on Teaching" 4th edition published in 2001 by AERA – the American Educational Research Association (http://www.aera.net/).

[3] CBLIS – Computer Based Learning in Science is held biennially and focuses in the use of Informatics to various aspects of Science Education. The 2003 (6th) Conference was held in Nicosia, Cyprus the 2005 (7th) Conference will be held at the University of Zilinska in Slovakia (see links: http://www.ucy.ac.cy/cblis2003/ and http://www.student.utc.sk/~jasomja/cblis/)

[4] EERA – European Education Research Association (http://www.eera.ac.uk/) operates the annual European Conference on Educational Research (ECER) in which Science education is represented. The 2004 conference will be hosted by The University of Crete in Rethymno at Sep. 20-25, 2004.

[5] OECD - Organization for Economic Cooperation and Development outlines its publications and activities in various economic sectors. Its publications include regular indexes on Education with specific chapters on Science and Technology education and corresponding Trends and Achievements, Outcomes of Learning, etc. Many of the publications are also available electronically. The OECD PISA activities (Programme for International Student Assessment) are well known (http://www.oecd.org/home/).

[6] UNESCO - United Nations Educational, Scientific and Cultural Organization was established in 1946 (www.unesco.org). Many of UNESCO's publications are available electronically.

[7] On the European Union – EU site (http://europa.eu.int/index_en.htm) there is a plethora of data on Science and Technology education.

[8] OECD- Science, Technology And Industry, Scoreboard, Benchmarking, Knowledge-Based Economies, a regular publication.

[9] OECD – Education at a glance, a yearly publication with indices on Science and Technology issues including Learning outcomes and Science achievements.

[10] OECD - Investing in Education, Analysis Of The World Education Indicators.
[11] OECD - Schooling For Tomorrow, Learning to Bridge the Digital Divide.
[12] OECD - The Appraisal of Investments in Educational Facilities
[13] UNESCO Handbook for Science Teacher
[14] New UNESCO Source Book for Science Teaching.
[15] EU – database. It contains a wealth of documents on Education and Training (see Url in [7]).
[16] ESERA – the European Science Education Research Association that also operates a biennial conference. Selected works from the 2001 3rd International Conference may be found in *Science Education Research in the Knowledge Based Society* by Dimitris Psilos et al. (eds), KLUWER Academic Publishers 2003 (http://www.physik.uni-dortmund.de/didaktik/esera/home.htm).
[17] (http://www.biol.ucl.ac.be/STEDE/) STEDE – Science Teacher Education Development in Europe.
[18] Hands on Science operating this Conference (http://www.hsci.info/).
[19] New Teacher Education for the Future International Perspectives Edited by Yin Cheong CHENG, King Wai CHOW, Kwok Tung TSUI, KLUWER Academic Publishers, 2001.
[20] Advances In Research On Teaching, Editor: Jere Brophy, Volume 2, Teachers' Knowledge Of Subject Matter As It Relates To Their Teaching Practice, JAI Press Inc. 1991.
[21] Science Teacher Education: An International Perspective, Edited by Sandra K. Abell, KLUWER Academic Publishers.
[22] Place of Science in a World of Values and Facts, Loucas G. Christophorou, Kluwer 2001.
[23] Science, Technology, and Society: A Sourcebook on Research and Practice, Edited by David D. Kumar and Daryl E. Chubin, Kluwer Academic Publishers 2000.
[24] Jean Piaget (1896-1980) a Swiss biologist with many published papers in the field. However he is known for his works in developmental and cognitive psychology. He started psychology studying his children's intellectual development and is best known for his theory on the stages of cognitive development. He was interested in intellectual development of young persons and not in Science teaching and used topics from natural sciences (field he understood well) for his empirical observations on how children were acting. As a result his works became a supportive host to Science teaching.
[25] Constructivist Teaching In Primary School, Social Studies, Mathematics, Science, ICT, Design And Technology Suzanne Gatt & Yosanne Vella, Published by Agenda - Malta, 2003.
[26] Children and Primary Science, Tina Jarvis, NICHOLS PUBLISHING 1991
[27] There is an increasing tendency to use groupwork almost exclusively. While this type of teaching action seems appropriate for lower grades atomic works may be more advantageous for personal and vocational development especially for practice (psychomotive) skills.
[28] Science & Technology Education Library VOLUME 12, Formative Assessment and Science Education by Beverley Bell And Bronwen Cowie KLUWER Academic Publishers.
[29] P. G. Michaelides, Tsigris Miltiadis, Science Teaching with Self-made Apparatus, paper to be presented in this Conference.
[30] Practical Work in Science Education: Recent Research Studies, Editors: John Leach and Albert Paulsen, Roskilde University Press, KLUWER 1999.
[31] Complex equipment may be necessary in high grades (ages) experimentation where the phenomena under study may require it or the measurement accuracy should be rather high. Their complexity however may hinder the principles of the phenomenon under study especially in lower grades (ages) where a conceptual understanding of basic principles is more appropriate. Simulations may be appropriate for an easier understanding of the workings (theory) behind the phenomenon under study or for difficult to operate situations (e.g. volcanoes, nuclei, etc). They are also useful to the manipulation, process and multivariate presentation of the data obtained. Their use however deprive the experience of a direct observation or of the planning and execution of an experiment and they are not usually appropriate to smaller ages when complex cognitive skills are to be attained.

[32] In a Piagetian context children in primary education are in the stage from concrete operational to formal. Natural phenomena (at least the ones in primary Science) are directly observable by the senses (or with the help of simple easily understood equipment) thus more easily perceptible than the phenomena (objects of study) in other disciplines where an abstract notion is necessary for their perception (for example migration apart from the observation of a person relocating him (her) self the subjective notion of permanently moving – making a new home- is also required). Because physical phenomena are usually perceptible by all normal persons they may provide a common reference system of notions and this was called by Einstein in his "Lectures at Princeton" truth).

[33] Democracy as we know it is based on active participation of the citizens to the decisions taken acting on their own capacities and not as followers of a "gifted leader" (as sheep under the herdsman). As an increasing number of decisions is dependent upon Science and Technology (S&T) developments, in order for citizen for the citizen to be able to participate on his (her) own he (she) not only should be S&T literate but also he (she) must have cognitive skills permitting decisions on incomplete knowledge, i.e. also in areas he (she) is not an expert. Otherwise science will be mixed with religion as in the Dark middle ages or in some places (for example contemporary USA – see http://www.ncseweb.org/ where Science education, especially de theory of evolution became a legal matter competing with religious doctrine). Note 1: the effective Science and Technology education has been declared by UNESCO "democratic right", a right to democracy.

[34] Science, Technology, and Social Change, Edited by Diederik Aerts, Serge Gutwirth, Sonja Smets and Luk Van Langehove, KLUWER Academic Publishers, 1999.

[35] Bertrand Russell (1872-1980) one of the greatest philosophers. Current Logic in advance from Aristotle is heavily based on his works (Russell's paradox). He is widely known for his peace initiative during the "cold war" period. He was a prolific writer of scientific works some of which were written in jail where was imprisoned because of his political activity. He was also author of many articles addressed to general public(http://www.humanities.mcmaster.ca/~russell/)

[36] George Kalkanis 'Which (and How) Science and Technology Education for Future Citizens?', pp. 199-214 of Vol. II of the proceedings of the University of Cyprus, '1st IOSTE Symposium in Southern Europe – Science and Technology Education: Preparing Future Citizens', Paralimni-Cyprus 29/4-2/5 2001.

[37] Lillian C McDermott, Peter S Shaffer and C P Constantinou, "Preparing teachers to teach physics and physical science by inquiry", Phys. Educ. 35(6) November 2000, pp. 411-420.

[38] Reasoning in Physics: The Part of Common Sense by Laurence Viennot, KLUWER Academic Publishers.

[39] Developing Models in Science Education, Edited by John K. Gilbert and Carolyn J. Boulter, KLUWER Academic Publishers 2000.

[40] P. G. Michaelides, "Everyday observations in relation to Natural Sciences" in Learning in Mathematics and Science and Educational Technology, University of Cyprus July 2001, Volume II pp. 281- 300.

[41] Everyday Thoughts about Nature, William W. Cobern, KLUWER Academic Publishers 2003.

[42] P. G. Michaelides, "Polymorphic Practice in Science", pp 399-405 of the proceedings of the 1st Pan-Hellenic Conference on the Didactics of Science and the introduction of New Technologies in Education, University of Thessaloniki, Thessaloniki May 29-31, 1998 (in Greek).

[43] P. G. Michaelides, "Understanding difficulties in Science observations", oral presentation, 2nd Pan-Hellenic Conference on the Didactics of Science and the introduction of New Technologies in Education, University of Cyprus, Nicosia May 3-5, 2000 , book of abstracts page 26 (in Greek).

[44] P. G. Michaelides, An affordable and efficient in-service training scheme for the Science Teacher, "Sixth International Conference on Computer Based Learning in Science 2003 (CBLIS03), University of Cyprus, Nicosia, Cyprus, 5 - 10 July 2003" proceedings pp. 792-799.