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Abstract

Science and technology are developing at a very high rate of speed both in basic research and applied technology. New technologies continue to expand their important role in Western and other societies. We review here the most relevant advances in modern biotechnology, considering the new challenges that this technology poses to the 21st century society.

As science and new technologies continue to expand their important role in modern societies there is an obvious need for well-informed citizens. Scientific literate citizens are people who have the skills of critical discrimination, the abilities and the desire to take part in decisions about scientific issues that affects their daily lives. Thus nowadays, science education should become a bridge between science itself, technology, and the social and environmental contexts in which both science and technology operate. This paper deals with the need of developing a 'scientific literacy' during the formative stages of students and points out educational views, approaches and orientations to achieve this shift of the educational paradigms, to reach literate citizens that make informed decisions to link science, technology, environment and society.

Keywords: modern biotechnology, scientific literacy, Science-Technology-Society-Environment (STSE), education

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Construyendo Puentes entre la Biotecnología y Sociedad mediante la Educación STSE

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Resumen

Ciencia y tecnología se están desarrollando a gran velocidad tanto en la investigación básica como en la tecnología aplicada. El importante papel de las nuevas tecnologías se expande tanto en todas las sociedades. En el presente artículo revisamos los avances más relevantes en materia de biotecnología moderna, teniendo en cuenta los nuevos retos que plantea esta tecnología para la sociedad del siglo XXI.

Ante esta expansión, hay también una necesidad obvia de tener ciudadanos bien informados. Las y los ciudadanos alfabetizados científicamente son personas capaces de hacer juicios críticos, además de poseer habilidades y el deseo de participar en las decisiones sobre temas científicos que afectan a su vida cotidiana. Por lo tanto, hoy en día, la educación científica debe convertirse en un puente entre la misma ciencia, la tecnología y el contexto social y ambiental en el que la ciencia y la tecnología operan. Este artículo aborda la necesidad de desarrollar una "alfabetización científica" durante las etapas formativas de los estudiantes y se señala los puntos de vista educativos, enfoques y orientaciones para lograr este cambio de paradigmas educativos, con el fin de llegar a ciudadanos alfabetizados que toman decisiones vinculantes con la ciencia, la tecnología, el medio ambiente y la sociedad.

Palabras clave: biotecnología moderna, alfabetización científica, Ciencia-Tecnología-Sociedad-Medio Ambiente (STSE, en inglés), educación

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In western societies today, science and technology are cornerstones of development that affect and sometimes determine important aspects of the daily life of all citizens. In the last number of decades, there has been a revolution in the field of biological research. The idea of managing or manipulating biology to develop specific characteristics is not new. Beginning in the 1970s, scientists have used DNA to create genetically engineered cells and organisms. For instance, genetically modified foods are nowadays sold in grocery stores across the U.S., insulin produced through recombinant DNA technology has transformed treatment for diabetes, transgenic mice are indispensable to biomedical research, and medical testing for genetically linked illnesses is on the rise (Presidential Commission on the Study of Bioethical issues, 2010). Genomics and its related technologies (generally called modern biotechnology) have the potential to become one of the most important scientific and technological revolutions of the 21st century (Kirkpatrick et al., 2002). New techniques have been developed that allow both the sequencing of genomes and the global analysis of these genomes at different biological levels (gene, mRNA, proteins, etc). Modern biotechnology applications are vast and span the gamut of biomedical research (gene therapy, genetic illness and diagnosis, functional food etc.) and agriculture (bioenergy, transgenics, genetic modified organisms (GMO) and so on). One crucial achievement started in 1990 when the Human Genome Project (HGP) was officially initiated with the plan for completing human genome sequence in 15 years. Sequencing the human genome signified the beginning of an exciting new era of science. Finally, rapid technological advances accelerated the completion date to 2003, when highly polished sequence of the human genome was published, free and readily accessible to all. Actually, anyone with a computer and an Internet connection can now explore the draft sequence of the human genome (National Center for Biotechnology Information, NCBI). A challenge facing researchers today is that of piecing together and analyzing the plethora of data currently being generated through the Human Genome Project and scores of smaller projects.

Biotechnology has stepped forward by the emerging during last decade of a new and revolutionary field: synthetic biology. Using a number of technologies and intellectual approaches, synthetic biology solves biological engineering problems by designing and reconstructing new biological parts, or systematically redesigning existing, natural biological systems. Synthetic biologists are expanding the boundaries of biotechnology by attempting to create the “software” of life from scratch. Can a complete genetic system be reproduced by chemical synthesis starting with only the digitized DNA sequence contained in a computer? This question was finally answered by Craig Venter’s team, when in 2010 they published the creation of a bacterial cell controlled by a chemically synthesized genome (Gibson et al., 2010). Briefly, C. Venter’s team synthesized in the laboratory a copy of the sequenced genome of a bacterium. This synthetic genome was introduced in another bacterium, with slightly different characteristics, and the new synthetic DNA got the control of the cellular machinery allowing cell division and thus, becoming the first living being that has all the genetic material artificially created. This has been the first synthetic cell, a clear landmark in synthetic biology.

With great Power comes great Responsibility

Some beneficial applications of modern biotechnology or synthetic biology could also be used in harmful or unintentionally dangerous ways. Other issues considering synthetic biology include the potential impact of organisms created by synthetic biology on the environment, the ownership of technologies, and distribution of the benefits of such research and its products (Garfinkel et al., 2008). In all aspects of modern biotechnology (genome sequencing, GMO products, synthetic biology, etc) raise both familiar and new ethical, social, environmental, and philosophical questions. All those questions and hazards must be faced by scientific literate citizens, people who have the skills of critical discrimination, the abilities and the desire to take part in decisions about scientific issues that affects their daily lives.

Sooner than later we all as a citizens will have to take decisions about issues derived of new biotech applications, e.g. the suitability of using large amounts of land to grow crops to turn into fuel rather than food, the legality of use GMO’s in our lands or the ethics behind the “genetic use restriction technology", colloquially known as suicide seeds. As well as answer ethical questions related to new biotech applications and genetic information management, e.g. who should have access to personal genetic information?, how will it be used?, how genetic information will be stored?, how we will control GMO?, etc. There are also concerns about who will benefit from synthetic biology, who will bear the risks, and who will decide. Modern biotechnology also renews old questions about whether scientists are "playing God". Questions have also been raised about ownership and control of products developed from modern biotechnology, including access, sharing, control of intellectual property, and regulation (Garfinkel et. al., 2008). Therefore society must understand that new advances in science and technology require taking informed decisions and those decisions must be taken by scientific literate citizens.

Scientific Literacy of Citizens

Undoubtedly, we are living a historical moment where multiple challenges must be handled by Humanity. In near future society should face important challenges that will require specific scientific advances to overcome problems derived from interactions of human activities with the global ecosystem. Globally we face a number of social, economic, and environmental issues resulting from interactions of human activities with the environment. With the human population at 7 billion people as of October 2011, and projected to be 9 billion by 2050, the pressures caused by these interactions are unlikely to abate. The need for food, clean water, fuel, and space will increase. Changes to the natural and built environments will continue to have significant economic and social impacts (Hollweg et al., 2011).

The perspective of a socially-viable science should be shared with citizens and, in this way, socially accepted technological innovations can be created (Gaskell et al., 2005). However, in order to involve society in the decision-making process about scientific policies, we need well-informed citizens who are able to make thoughtful decisions based on scientific conclusions combined with ethical and moral considerations. Thus, society should have a minimum scientific basis upon which to come to a reasonable opinion about, for instance, the use of genetically modified organisms (GMO's) in agriculture or medicine, how these products should be labelled, etc. Science educators, in collaboration with experts from other disciplines, are starting to debate ethical, legal, and social implications of science and technology in today's world. If the public has voice, say some, and it is involved in the decision-making process about scientific and technological issues better decisions could be made. In other words, a more participative society will lead to more socially appropriate and viable scientific innovations. Such questions as 'What kind of society do we want? How can new technologies help us to reach this new society?' that involve social values and ethics may answer questions that science by itself may not able to answer. Therefore, citizens should play and active role in terms of scientific policy.

In this 21st century, science education should become a bridge between science itself, technology, and the social and environmental contexts in which both science and technology operate. Much research in science education worldwide promotes, as an important goal of science teaching, the scientific and technological literacy of whole populations (Zoller, 2012; Dimopoulos & Koulaidis, 2003; Jenkins, 1997; Miller, 1998). Science literacy means developing the capability of evaluative system thinking in the context of science, technology, environment, and society, which in turn requires the development of students' higher-order cognitive skills (HOCS), system critical thinking, question-asking, decision-making, and problem solving. This should become the top priority goal of contemporary and future effective scientific education (Zoller, 2012). The underlying notion is to develop the knowledge and the mental habits that allow people to become responsible citizens, able to create their own informed opinions, all the while living in a society that is becoming increasingly complex and more dependent on science and technology.

Shifting educational Paradigms

As previously mentioned, researchers in education argue that scientific literacy of whole society should be the ultimate goal of scientific education. However, a meaningful education in science requires a revolutionized change in the guiding philosophy, rationale, and models of our thinking, behavior, and action (Zoller, 2012). The frame of the current paradigm of science education, mainly characterized to be teacher-centered, disciplinary, decontextualized and low-order cognitive skills (LOCS) oriented should move to more adaptive paradigms. Science education should be an interdisciplinary teaching approach, leading to the development of our students' higher-order cognitive skills (HOCS), promoting critical system thinking, problem-solving and decision-making (Table 1).

Table 1

Recommended Paradigms Shifts in Science, Technology, Environmental, and Society (STSE)-Oriented Education (Adapted from Zoller, 2012).

To Foster Critical Thinking Skills and Science Education and Environmental Approaches, Society and Educators Should Move

From These Current, Maladaptive Paradigms	To These More Adaptive Paradigms
Technological, economical, and social growth at any cost	Sustainable development in the global context
Corrective responses	Preventive actions
Reductionism; i.e., dealing with in vitro, isolated, highly controlled, decontextualized components	Uncontrolled, in vivo, complex systems
Disciplinarity	Problem solving-orientation, with decision making based on systemic, inter-, cross-, and transdisciplinary approaches
Technological feasibility	Economic and social feasibility
Algorithmic, LOCS-oriented[b] teaching	HOCS learning[c] in the STSE[a] interfaces context
Reductionist thinking	System and lateral thinking
Dealing with topics in isolation or closed systems	Dealing with complex, open systems
Disciplinary teaching (physics, chemistry, biology, etc.)	Interdisciplinary teaching
Knowing and recognizing orientation in teaching (e.g., applying algorithms for solving excercices)	Conceptual learning for problem solving and transfer
Teacher-centered, authoritative, frontal instruction	Student-centered, real-world, HOCS oriented learning

[a] STSE: Science, Technology, Society and Environment. [b] LOCS: lower-order cognitive skills. [c] HOCS: higher-order cognitive skills.

One of the most discernible trends of the last two decades in science curriculum development across a number of countries has been to use contexts and applications of science as a means of developing scientific understanding. Teaching in this way is often described as adopting a *context-based or STSE (Science–Technology–Society-Environment)* approach. The trend toward the use of context-based/STSE approaches is apparent across the whole age spectrum from primary through to university level, but is most noticeable in materials developed for use in the secondary age range (Bennet et al., 2006). The essence of the role of STSE in education is in teaching towards personal agency through active, civic participation in technologic and scientific decisions. This type of science education, if successful, should, over time, allow citizens to understand at some level important scientific processes, to analyze and assess them, and to be able to use some of the tools related to them. At the same time, STSE education should also lead to the development of participative and open-minded attitudes. These attitudes should be the basis of the decision making processes that citizens follow regarding the potential problems associated with specific scientific and technologic development (Jenkins, 2002; Manassero et al., 2001; Lee & Roth, 2002; Martín & Osorio, 2003; Martín, 2005).

One of the main questions inherent in the STSE approach is if or how scientific literacy could be promoted and developed by means of science teaching. Many different studies in educational research point towards the approach of social constructivism, based on Vygotsky's (1978) theory of social development, as the most appropriate way to carry out teaching and learning processes geared towards greater scientific literacy (See, for example, Freedman, 1997; Bennett, 2001). Learning gained through constructivist teaching practice could become the mechanism to adjust personally-held mental models based on new experiences. In constructivist theory, we are active creators of our own knowledge. Learning is not just the process to receive and integrate new information from the teacher (Driver et al., 1994). A constructivist approach confers an essential role on the social and cultural contexts of students, as they try to make sense of what is happening in society and thus to build their knowledge on this comprehension.

Different associations in different countries have driven STSE-based teaching programs. As examples, we found the association NASTS (National Association for Science, Technology and Society) at USA, ASE (Association for Science Education) at UK, the international IOSTE (International Organization of Science and Technology Education) and EOI (Organización de Estados Iberoamericanos), the european EASTS (European Association of STS) where The Netherlands is one of the main leaders (Acevedo & Acevedo, 2002). One of the most challenging problems that teachers must face towards any educational innovation is the lack of curricular material (activities, lesson plans, resources, etc). To solve this situation, the EOI, as a part of its program of sciences, has developed several initiatives focused on the design and assessment of new teaching materials and teacher training for the dissemination of scientific culture. As a result of these initiatives, the Spanish group ARGO (www.grupoargo.org) has developed new STSE resources for secondary education, using simulated case strategy to deal with citizenship participation in scientific and technological issues (Martín, 2005).

Other courses in different countries have being designed following the STSE approach. Among the most important projects we encountered: (i) “Science: the Salters Approach" (England and Wales) a 2-year context-based science course for students aged 14–16; (ii) “ChemChom” (USA) a 1-year STS course for high schools students (taught to groups aged between 12 and 17); (iii) “PLON *Projekt Leerpakket Ontwikkeling Natuurkunde*” (Netherlands) a 5-year context-based physics course for students aged 12–17; (iv) "STS British Columbia” (Canada) a 1-year STS program for students aged 16–17; (v) “Science and Technology For All” (Israel) a 1-year STS course for non-science students (Bennet et al., 2006).

Additionally, an interesting example of curricular modification, which has become a referent in Medicine teaching, is the Mc Master model. McMaster University (Canada) pioneered the first problem-based learning (PBL) curriculum in 1969, the rationale that introducers of this methodology proposed for the McMaster curriculum, which included learning in small groups for the study of clinical problems, was that itwould make medical education more interesting and relevant for their students (Neville, 2009). In PBL, fundamental knowledge is mastered by the solving of problems, so basic information is learned in the same context in which it will be used. Also, the PBL curriculum employs student initiative as a driving force and supports a system of student-faculty interaction in which the student assumes primary responsibility for the process. Neville (2009) summarized the cognitive attributes of PBL that promote learning, which are: (i) knowledge acquired in relevant context is better remembered; (ii) concepts are acquired in a way that they can be mobilized to solve/view similar problems; (iii) acquisition over time of 'prior examples' facilitates pattern recognition; (iv) promotion by PBL of prior-knowledge activation facilitates processing of new information; (v) elaboration of knowledge occurs at the time of learning; and (vi) provision of similarity of context for knowledge acquisition and subsequent application also facilitates recall.

Looking closer in our country, at the Universitat Rovira i Virgili, URV (Spain), an interesting project focused in didactics of science based on STSE approach has been developed, the project APQUA (Aprenentatge de Productes Químics, els seus Usos i Aplicacions). APQUA started in 1988, as a result of the collaboration between the URV's Department of Chemical Engineering and the SEPUP, Science Education for Public Understanding Program of the Lawrence Hall of Science of the University of California in Berkeley. APQUA is a project for scientific literacy addressed to whole society, focused on the chemical products and their processes and the risks which its use represents towards the people and the environment. APQUA has broadened and consolidated its Educational Program, which provides children and adolescents with knowledge and understanding of science and technology. Actually, APQUA has been highly widespread in Spain, since more than 173.000 students of 1.110 schools of elementary and secondary education have followed APQUA modules.

Summarizing, it has been clearly exposed through this article the challenging historical moment that we, as a society, are living. In one hand, the fast development of science and technology allow the whole world to face future challenges by creating powerful tools. Nonetheless at the same time, difficult and complex decisions rise in the horizon to link science, technology and the social and environmental contexts in which both science and society operate. This perspective points out the need of a citizenship more concerned in scientific issues. However, in order to involve society in the decision-making process about scientific policies, we need well-informed citizens who are able to make thoughtful decisions based on scientific conclusions combined with ethical and moral considerations. From this point of view, scientific literacy promoted through compulsory education appears as the clue strategy to achieve this responsible and concerned society on scientific issues.

References

Acevedo Romero, P., & Acevedo Díaz, J. A. (2002). Proyectos y materiales curriculares para la educación CTS: enfoques, estructuras, contenidos y ejemplos. In: *Revista electrónica de la OEI.* Retrieved from: http://www.oei.es/salactsi/acevedo19.htm#1a

Bennett, J. (2001). Science with attitude: the perennial issue of pupils' responses to science. *School Science Review, 82,* 59-67.

Bennet, J., Lubben, F., & Hogarth, S. (2006). Bringing Science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education, 91,* 347-370. doi: 10.1002/sce.20186

Dimopoulos, K., & Koulaidis, V. (2003). Science and technology education for citizenship: The potential role of the press. *Science Education, 87*(2), 241-256. doi: 10.1002/sce.10054

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12. doi: 10.3102/0013189X023007005

Freedman, M. P. (1997). Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal of Research in Science Teaching*, *34*(4), 343-357. doi: 10.1002/(SICI)1098-2736(199704)34:4<343::AID-TEA5>3.0.CO;2-R

Gaskell, G., Einsiedel, E., Hallman, W., Horning-Priest, S., Jackson, J., & Olsthoorn, J. (2005). Social values and the governance of science. *Science*, *310*, 1908-1909.

Garfinkel, M.S., Endy, D., Epstein, G.L., & Friedman, R.M. (2008). Synthetic biology. In: From birth to death and bench to clinic: The Hastings Center bioethics briefing book. Retrieved from: http://www.thehastingscenter.org/uploadedFiles/Publications/Briefing_Book/synthetic%20biology%20chapter.pdf.

Gibson, D. G., Glass, J. I., Lartigue, C., et al. (2010). Creation of a bacterial cell controlled by a chemical synthesized genome. *Science*, *329*, 52-56. doi: 10.1126/science.1190719

Hollweg, K. S., Taylor, J. R., Bybee, R. W., Marcinkowski, T. J., McBeth, W. C., & Zoido, P. (2011). *Developing a framework for assessing environmental literacy.* Washington, DC: North American Association for Environmental Education. Retrieved from: http://www.naaee.net.

Jenkins, E. W. (1997). Towards a functional public understanding of science. In Levinson, R., Thomas, J. (Eds.), *Science today, problem or crisis?* (pp. 137-150). Routledge.

Jenkins, E. W. (2002). Linking school science education with action. In W.M. Roth & Désaultels, J. (Eds.), *Science education as/for sociopolitical action* (pp. 17-34). Peter Lang, New York.

Kirkpatrick, G., Orvis, K., & Pittendrigh, B. (2002). GAME: A teaching model for biotechnology. *Journal of Biological Education, 37*(1), 31-35. doi:10.1080/00219266.2002.9655843

Lee, S., & Roth, W. M. (2002). Learning science in the community. In W.M. Roth & J. Désaultels (Eds.), *Science education as/for sociopolitical action.* Peter Lang, New York.

Manassero, M. A., Vázquez, A., & Acevedo, J. A. (2001). *Avaluació dels temes de ciència, tecnologia i societat.* Palma de Mallorca: Conselleria d'Educació & Cultura del Govern de les Illes Balears (Ed.).

Martín, M. (2005). Cultura científica y participación ciudadana: materiales para la educación CTS. *Revista Iberoamericana de Ciencia, Tecnología y Sociedad-CTS, 6*(2), 123-135.

Martín, M. & Osorio, C. (2003). Educar para participar en ciencia y tecnología. Un proyecto para la difusión de la cultura científica. *Revista Iberoamericana de Educación, 32,* 165-210.

Miller, J. D. (1998). The measurement of civic scientific literacy. *Public*

Understanding of Science, 7(3), 203-223. doi: 10.1088/0963-6625/7/3/001

National Center for Biotechnology Information (NCBI). Human genome resources. Retrieved from: http://www.ncbi.nlm.nih.gov/projects/genome/guide/human/

Neville, A. J. (2009). Problem-Based Learning and Medical Education Forty Years On. A Review of Its Effects on Knowledge and Clinical Performance. *Medical Principles and Practice*, *18,* 1–9. doi: 10.1159/000163038

Presidential Commission for the Study of Bioethical Issues (2010). New directions: The ethics of synthetic biology and emerging technologies. Retrieved from: http://www.bioethics.gov/cms/sites/default/files/PCSBI-Synthetic-Biology-Report-12.16.10.pdf

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge. Harvard.

Zoller, U. (2012). Science Education for Global Sustainability: What Is Necessary for Teaching, Learning, and Assessment Strategies? *Journal of Chemical Education, 89,* 297-300. doi: 10.1021/ed300047v

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