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Trends in Pre-College Engineering and Technology Education and the Pequeños Científicos Program*

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This article consists of describing the Pequeños Científicos program (literally translated as 'little scientists' program) led by an initiative at the School of Engineering at Universidad de los Andes and defines the program's goals to promote scientific and technological literacy. This article stresses the role that Science and Engineering Schools can play in the development of scientific literacy in K-12 education, and makes a stand for the importance of the ability to inquire, when learned from an early age, in the development of critical thinking and civic participation. In the Colombian context, the Pequeños Científicos program emerges as a partnership between Science and Engineering schools (at both college and graduate level), K-6 science teachers, institutions, science academies and museums that are devoted to children's education. Strategies of teacher training, evaluation, community relationships and the development of materials are discussed.

Keywords: pre-college science and engineering; scientific and technological literacy; Pequeños Científicos; science education initiatives in Colombia; program strategies

INTRODUCTION

THE ROLE that engineering schools play in society has rapidly changed over the last decade. Today society demands that its members acquire technological knowledge and attitudes on how to act on science and technology. Therefore, the goal of engineering students has also expanded in terms of research, development, and innovation. Technological innovation is a key factor in competitiveness. The appropriate use of technology is a skill that can help to solve some of the issues faced by our societies. However, in the wrong hands this same use of technology can become hazardous to the planet. With all this in mind, an engineering school must look towards scientific and technological education for all citizens, since they are the ones who will make important decisions that affect our everyday lives: such important issues include education, scientific and technological development.

The development of technological and scientific thinking in a large population will not only help individuals improve their performance at work, and advance them professionally, but it will also foster national competitiveness in the international marketplace. Furthermore, it gives the population the opportunity to make intelligent and informed decisions, as well as allow them to participate in a democratic process and in decision-making that may have vital social consequences. However, to achieve total citizen involvement in society, scientific, technological and democratic literacy are necessary, along with other skills and knowledge. Early educational opportunities are the key strategy by which these skills and knowledge can be developed. In this paper, we present the Pequeños Científicos Program, a Universidad de lo Andes school of Engineering initiative that involves many national and international participants in scientific and technological education in the K-6 science curriculum.

Pequeños Científicos began in Colombia in 1998 and is has now positioned itself as a reference project throughout the world. The way this project has been structured has allowed the participation of a variety of social groups, such as central and local governments, the National Science Academy,

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regional engineering schools and science museums, as well as the private industrial and commercial sector. With such collaboration the program has been allowed to grow, be self sustainable, and maintain a high standard of quality, while fulfilling its aims to teach and facilitate the learning of science and technology through strategies of hands-on and guided inquiry learning in the K-6 curriculum. Working inside the classroom, Pequeños Científicos involves teachers, scientists and children in a unique relationship of cooperation, knowledge construction and the development of competencies. Outside the classroom, teachers, coordinators and directors are involved in strategic planning and curriculum development initiatives to complement the changes introduced in the classroom; at the same time the teachers are supported by a number of stakeholders at all national levels. These characteristics make Pequeños Científicos a program that articulates the pedagogical knowledge of science education with the organization, logistics and structure of an engineering project involving the educational system. Given this context, this paper both outlines some of the major issues that science education in the 21st century must address, and articulates the Pequeños Científicos' strategies to develop scientific literacy through the participation of engineering schools in the K-6 classroom and science curriculum.

GENERAL PROBLEM OF SCIENTIFIC AND TECHNOLOGICAL LITERACY AND TENDENCIES

Scientific and technological literacy for all citizens has become a mayor necessity in the 21st century [1, 2]. According to the UNESCO [3], the definition of scientific and technological literacy has expanded from merely being able to read, understand and write about science and technology, to the ability to apply scientific and technological concepts and process skills to life, work and culture, including the development of attitudes and values that enable citizens to distinguish between worthwhile and inappropriate uses of science or technology. Citizens can no longer be part of a society without recognizing that technology and the use of scientific knowledge have entered into every sphere of human activity. Citizens without basic knowledge and skills of the scientific and technological domain will have fewer opportunities to become successful participants in our 21st century society. In today's growing scientific- and technological-based world, a certain level of understanding of the norms and methods of science, some key concepts and, the relationship between science/technology and society are vital in order for citizens to participate fully in the public sphere—not only to take part constructively in the socio-scientific, ethical and moral dilemmas of society, but also to prevent themselves being excluded and/or manipulated.

On the other hand, according to Perry [4], a nation's growth is closely related to its scientific and technological development, which currently is associated with the professional development and production of new knowledge that supports innovation and promotes the competitiveness of the productive sector in an interconnected and interdependent world. This new knowledge could be produced only by citizens and societies immersed in a network of relationships that foster and promote scientific and technological literacy. It is in this context that Science and Engineering schools could and should play a significant role.

According to Moreno [5], and Sorby and Baartmans [6], the National Research Council standards encourage participation of scientists and engineers in K-12 science education, as one way to support science education within their communities. Moreno describes the important role that scientists and engineers can play:

1. by becoming informed and involved in shaping policies affecting science education,
2. through individual cooperation with teachers, both in and out of the classroom (training / professional development initiatives) and
3. by partaking in large-scale systemic science education reforms projects that involve multiple stakeholders.

In the Colombian case, the participation of engineering schools in scientific and technological literacy initiatives involve efforts aimed at the improvement of elementary and secondary school education, acknowledging that their statement of purpose is closely associated with the scientific and technological development of their region or country. In order to fulfill their stated purpose, it is not sufficient solely to educate engineers, create new knowledge or work exclusively with undergraduate, graduate students and faculty, but rather it is necessary to reach out to all citizens and their educational settings, work spaces, families and communities. Moreover, engineering schools should also be aware and involved in K-12 science education to ensure future high quality applicants, motivated to continue engineering studies, and with a strong background in science, technology and mathematics.

Finally, the role of engineering schools does not end with their initiatives to reform K-12 science curricula and train teachers in learning strategies, but rather continues with the growing involvement of engineering and technology in teaching and learning processes. For example, the inclusion of Technologies of Information and Communication in the classroom heralds fundamental changes in the roles that teachers and pupils play. Furthermore, the findings from studies in neural networks conducted by engineers [7–9], have augmented the work of biologists, psychologists and neuroscientists by providing a deeper understanding of how the brain works, and how memory, perception, emotion and executive functions interact in the

learning process. This partnership becomes increasingly productive in the quest for understanding humans, and in turn helps in the design of effective teaching strategies.

TEACHING AND LEARNING SCIENCE AND TECHNOLOGY

One teaching strategy that has had a profound impact on how children learn science includes the reflection on the many ways that scientists study natural phenomena and proposes explanations based on empirical evidence. According to the National Research Council [10], Inquiry, as this strategy has been called, sets out to observe, plan, question, design and develop experiments, manipulate and propose explanations and hypotheses, gather and validate data, find patterns, communicate, debate, and provide conclusions in the way that scholarly scientists do, but to replicate this process at a child's level in the science K-12 classroom. This particular approach to education has been proven to provide some advantages over more traditional ways of teaching and learning science. The opportunity to construct and discuss scientific knowledge—based on a model of autonomous, collaborative and significant work, as done in the field—gives children the opportunity to participate in their own scientific knowledge constructions, while allowing them both to achieve progress in social and scientific skills and to support their peers' development. Additionally, children will develop oral and writing skills, since a large part of the scientific process is to register data and communicate findings. As these observations, conclusions and reflections are supported on evidence, children learn to observe the world from a rational point of view, and search for evidence that supports their own hypothesis and demand evidence for those of others. This component also accounts for the development of critical thinking and social participation skills. These are some of these characteristics that account for the growing interest on inquiry-based science education, a strategy that is promoted by all the science academies of the world and that is currently being implemented in over twenty countries. These initiative programs are backed up by national and regional standards on natural and Earth science [11, 12], as well as some technology standards [1, 13] that seek to promote an integrated approach to science, technology and social science education. [These include FOSS (Full option science system) of Berkeley, INSIGHT of EDC (Educational Development Center), and STC (Science and Technology for children) of the NSRC (National Science Resource Center).]

Also, some research works, founded by the National Science Foundation, are even promoting an integration of mathematical, scientific and technological domains, creating a research network named STEM (Science, Technology, Engineering, and Mathematics).

A considerable number of teaching materials in Inquiry has been constructed for the scientific and technological domain, particularly in the K-8 level. Results from the implementation of these programs and materials demonstrate interesting insights into scientific knowledge construction and skill development, although the vast majority of the studies cover only a few schools or classes [14, 15], and only a few of them have had an impact at national or international levels.

International evidence shows that changing the whole education system of a country is a huge challenge, considering the size of the system. Therefore it is important and necessary to target the system as a whole, seeking to adjust its different components. The NRC [11] suggests subdividing the system into five major divisions:

1. Professional development,
2. Curriculum,
3. Assessment and Evaluation,
4. Materials, and
5. Community.

Additionally, it proposed the implementation of strategic planning exercises with different stakeholders that would generate changes both in teacher's praxis and in the broader organizational framework of the system.

ENGINEERING ON EDUCATION, THE PROPOSED SYSTEMIC SOLUTION IN THE COLOMBIAN CONTEXT

The Pequeños Científicos program structures itself under a systemic view around the development of competitiveness, professional development and a deep sense of social responsibility. It acknowledges the centrality of citizen formation based on scientific and technological literacy by developing social and relational skills in students, and a critical reflection on the way that science and technology affects their lives. In order to achieve the aforementioned social goals, Pequeños Científicos involves a number of different national and international participants who can give significant an insight and feedback, as well as sustain the initiative in the long run. One of these participants is the Universidad de los Andes School of Engineering, which acts as a central coordination site. It has worked around three core principles that guide the program's growth and development:

1. using and adapting strategies, materials, and achievements that have been proved to be successful on pedagogy and science education around the world;
2. promoting alliances with other existing programs in the country that can be seen as complementary, and

Fig. 1. Pequeños Científicos' general evaluation system.

3. allowing other organizations to participate fully in the program.

Their work has focused on research and development of teaching training strategies, curriculum models, assessment and evaluation tools and systems, materials for the classroom and community relationships models. Since all these spheres converge to improving the way children learn science and technology, Pequeños Científicos has worked with teachers and schools to develop an appropriate learning atmosphere for children. Typically, there is a one-year training period for teachers and schools, covering around 80 hours of presential work, and two days a week implementation in each classroom. Scientific, methodological, strategic planning and sensibilitation workshops are offered on a monthly basis for all the participants who are currently working on the program, as well as for those willing to participate. Also, in situ observation and feedback are offered to teachers and schools in two different points in the training year, focusing on the learning atmosphere and the change in conceptions about science, teaching and learning. At the same time, the community relationships system is starting to create links between schools, local universities, science academies, museums, and local business and industry representatives so academic, scientific, pedagogical, and financial recourses can be transferred and shared. Finally, the evaluation system of the Pequeños Científicos program, which has been recently created and inspired by the standards of the ISO 9001-2000, begins its work with an initial training component. Focusing on Quality, Coverage and Consolidation, the evaluation system seeks to gather and analyze data on these dimensions, reporting results and producing reports for the different members of the community involved, as well as for those interested in the program. Figure 1 shows the organization of the system.

Among the principal achievements of the Pequeños Científicos Program, we can count the following in each of these areas:

Coverage and growth

The program seeks sufficient coverage to change the way that a considerable percentage of Colombian children learn science and technology. In relation to this goal, the Colombian program has reached more than six regions, 83 private and public schools, 477 teachers and 19,080 children. Official data for the year 2006 can be seen in Table 1.

Given that one of the goals of the program is to reach a significant number of Colombian children, providing them with the opportunity to develop scientific, technological and civic skills, the actual data suggest that there is still a long way to go. The numbers actually participating represent only a small percentage of the Colombian K-6 population (5,193.055 children, according to MEN [16]).

Consolidation

The program aims for the whole proposed curriculum structure to be taken up by schools, making sure that it can be sustained under their typical operation restrictions. This standard is proposed with the aim of providing children with a quality science education program that covers all the elementary grades, assuring a learning atmosphere based on the inquiry principles of Pequeños

Table 1. Program coverage

City/Region	Children	Teachers	Schools
Bogotá	9280	232	28
Manizales	1760	44	12
Ibague	1920	48	11
Medellin	1840	46	21
Cali	4120	103	10
Bucaramanga	160	4	1
Total	19,080	477	83

Científicos, and coherent with the national science and citizenship standards [12,18].

On this the program has been able to identify some achievements and challenges. From the 83 schools that have been involved in the implementation of the program it is possible to confirm that at least 13 of them have been successful integrating the science education principles of the program. However, for 60 of the institutions we can only say that they have strong interests in adopting our curriculum, and still there are 23 institutions that see the challenge to be more difficult. In 2006 new strategies and efforts have been directed at consolidating the schools, involving them in a more exhaustive strategic planning process, while cooperating with the district education bureau, and private institutions.

Quality

The Pequeños Científicos Program anticipates that a growing number of children acquire and develop scientific and citizenship skills as a result of their work in the program [16]. However, to reach this goal we must first start to work with teachers and schools to assure an adequate learning atmosphere. Results taken from in situ observations show that for a sample of 293 teachers in the country there are significant differences in their classes between two assessment times. Assessment was made through a structured observation protocol, focused on the following five domains:

1. Class preparation,
2. Communication,
3. Learning atmosphere,
4. Inquiry and,
5. Autonomy.

Student tests were applied between the two observation times. Results showed significant differences in all the domains, where an increase in the score was recorded. ($t_{\text{Class preparation}} = -3.206$, Sig. = 0.002; $t_{\text{Communication}} = -7.056 = 0.000$; $t_{\text{Learning atmosphere}} = -5.820$, Sig. 0.000; $t_{\text{Inquiry}} = -7.091$, Sig. = 0.000; $t_{\text{Autonomy}} = -4{,}713$, Sig. = 0.000).

Also, the program is currently working on the application of a Learning Atmosphere pen and paper test, for both teachers and students, as well as a Citizenship and Social Competencies pen and paper test, designed as part of a funding research carried out in 2005 for Colciencias [19].

Over the last few years, three formal evaluations, as well as external expert observations have given us some important insights into the changes that have been taking place in schools, both in the professional performances of the trained teachers, and in the children's behavior. (Two research studies were carried out by the CIFE—Centro de Investigación y Formación en Educación de la Universidad de los Andes, founded by Banco de la República y el IDEP and one by the auditory team of the Secretaría de Educación de Bogotá.)

Results reported by these authors show that children seem to improve their competence in communication, and enhance their cooperation and listening skills as well as their ability to work autonomously and be able to substantiate their opinions. It also has been observed that children who have previously shown difficulties in integrating into the school system have found that Pequeños Científicos not only helps them adjust but actually makes them happy participants. Furthermore, evidence shows that students have developed scientific knowledge and skills, such as the ability to perceive using all their senses and to articulate and relate their observations. It has also been noted that teachers have transferred pedagogical skills that they obtained during training to some of their other areas of work.

CONCLUDING REMARKS

The Pequeños Cientificos program been on the national and international scene for a relatively short time, but in spite of this, the program has been able to involve a considerable number of people from Colombian society, who by their importance and ability have provided significant support to the transformation of science and technology education for all in an emerging country like Colombia. The participation of the Universidad de lo Andes School of Engineering, as well as some of the best universities of the country and other stakeholders, ensures that the program could in the long run impact positively on the scientific and technological literacy of the country's population, where quality scientific and technological education is a fundamental condition for national social and economical development. The Pequeños Científicos program is an example of how the association between science and engineering faculties and schools, along with schools and K-6 teachers and children, can promote significant changes for the better in the country's scientific and technological development. Pequeños Científicos' preliminary results are hopeful. However the real challenge for the program is yet to come, taking into account its growth, improvement in quality, coverage and consolidation.

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