How do the National Science Education Standards Support the Teaching of Engineering Principles and Design?[1]

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Abstract - *The recently developed National Science Education Standards (NSES) have the overall goal of making scientific literacy, in all of our citizens, a reality in the 21st century. The NSES science standards address content in Science and Technology as well as science as inquiry, science in personal and social perspectives, and the history and nature of science in grades K-4, 5-8 and 9-12. We have examined the extent to which the NSES support the teaching of engineering principles and design within the traditional science content areas. We have identified sections within the standards that adequately address the need for exposing students to engineering and technology. We have also identified sections where engineering and technology are not included but where we believe that they have a major role. This paper is a summary of our findings and recommendations.*

I. Introduction

The recently developed National Science Education Standards (NSES) have the overall goal of making scientific literacy, in all of our citizens, a reality in the 21st century [1]. Besides the traditional areas in the physical, life, earth and space sciences, the NSES science standards address content in Science and Technology as well as science as inquiry, science in personal and social perspectives, and the history and nature of science. These areas are addressed in grades K-4, 5-8 and 9-12. Many of the ideas of the NSES were suggested earlier in *Science for All Americans* [2] and *Benchmarks for Science Literacy*[3] but they have come to fruition with more widespread acceptance in the NSES. For example, in *Science for All Americans*, recommendations were made to include within the teaching of K-12 science, topics on the nature of the science enterprise, how science, mathematics and technology relate to one another and how they relate to the social system in general.

The question as to whether the NSES support the teaching of engineering principles and design needs to be addressed because of the challenge of the global economy and the resulting greater need for better-trained and technically competent individuals in today's modern technological society [4]. More specifically, there is currently an unsatisfied need in industry for more engineers that is not met by US high school graduates [5]. In addition, the separate technology standards that are still being developed [6] are not yet widely adopted, and often do not impact college bound students. Research indicates that (i) there is insufficient coverage of engineering and technology in our school system and many of our K-12 students do not consider engineering and technology as career options [7], and (ii) high school graduates are often not adequately prepared for an undergraduate education in engineering and technology [8].

The paper begins with an overview of sections of the NSES that have applications and connections to engineering principles and design. The major portion of the paper will answer the following questions:

1. Are the NSES Science and Technology Standards sufficiently broad?
2. Do the standards generate enough interest in engineering and technology?
3. Do the standards provide adequate preparation for engineering and technology?

We next discuss whether there is a need to revise the standards based on the answers to the three questions. We will also allude to activities that support engineering principles and design and how to best disseminate them to K-12 teachers.

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II. The NSES Science and Technology Standards

In 1996 the National Committee on Science Education Standards and Assessment published *National Science Education Standards*. The Committee included individuals that are likely to "play a critical role in improving science education: teachers; science supervisors; curriculum developers; publishers; those who work in museums, zoos, and science centers; science educators; scientists and engineers across the nation; school administrators; school board members; parents; members of business and industry; and legislators and other public officials."

By including engineers and members of business and industry in the committee, the committee acknowledged the importance of engineering and technology as part of the preparation of the next generation of students. A consequence of their inclusion is that the standards include engineering applications as well as elements of engineering practice. We examine the standards from the point of view of engineering and technology.

II.1 Are the NSES Science and Technology Standards sufficiently broad?

The NSES standards provide a fairly broad exposure to a variety of topics in science. The content standards "outline what students should know, understand and be able to do in the natural sciences over the course of K-12 education". "It is important to know that the standards for science education are policies, not a curriculum; they are national, not federal; they are voluntary, not mandatory; and they are dynamic, not static" [9], p. 61]. The NSES are intended to promote the broad national science education goals of "science literacy" and "inquiry" in all students and they describe what all students must understand and be able to do when they finish high school. These are divided into eight categories:

1- Science as Inquiry: Here students go beyond the procedures of science (such as data collection) to "scientific reasoning and critical thinking to develop their understanding of science."
2- Physical science: Here students are exposed to topics in physics (properties of materials, mechanics, light, heat, electricity, magnetism), and chemistry (chemical reactions).
3- Life science: This includes organisms and their life cycles, reproduction, heredity, populations and ecosystems, evolution, the cell and its structure.
4- Earth and space science: This includes the earth and sky and the properties of their materials.
5- Science and technology: This includes the abilities of technological design, understanding science and technology and distinguishing between natural and human made objects.
6- Science in personal and social perspective: Here we have the impact of science and technology on students and their lives including personal, social and environmental aspects.
7- History and nature of science: The history of science helps students understand its nature and evolution as well as the effect it has had on human society.
8- Unifying concepts and processes in science: These tie together ideas from a variety of scientific disciplines to help students understand the natural world.

We believe that the eight categories in the standards are sufficiently broad to cover the educational needs of K-12 students including their need for engineering and technology literacy. The first category, science as inquiry, is integral to the curriculum organization of the other seven and it is intended to develop the students' cognitive ability based on critical thinking and science reasoning [9]. The ability to learn through inquiry would appear to be a basic skill needed to understand how science principles and concepts can be applied to engineering principles and design. Still, it seems intuitive that without the understanding of fundamental concepts in the physical, life and earth sciences, students are less likely to see useful connections between the natural world and the designed world. Robotics programs in schools, those that do not just focus on engineering skills, but also aim to bring out the best scientific concepts and technological principles through active learning, are good examples of this fusion of science concepts and technological design [10].

The Science and Technology category is intended to help students develop abilities associated with technological design and problem solving. It is also intended to help students develop understanding of the similarities and differences between science and technology and their influence on society.

II.2 Do the standards generate enough interest in engineering and technology?

For many students as well as their teachers, the line between technology and science is blurred. Popular television series and films often erroneously identify characters involved in engineering activities as scientists. Content Standard E states "Students in grades 5-8 can begin to differentiate between science and technology [1], p. 161]. This differentiation is to be achieved by including "activities in which the purpose is to meet a human need, solve a human problem, or develop a product". These are activities in which engineers are involved and their inclusion and identification as engineering activities is critical at this early stage. The Egg Drop is identified as an example of an experiment including such activities.

The NSES standards include some examples of engineering applications that could be used in K-12 classes. Examples include: 1. In grades 5-8, the use of mechanical toys to understand forces and motion and energy transfer [1] p. 149]. 2. The grades 9-12 standards specifically mention motors and generators as an application of electricity and magnetism [1], p. 180].

In Content Standard E (grades 5-8), we find the following procedure under the title of "Guide to the Content Standard":

1- Identify appropriate problems for technological design.
2- Design a solution or product.
3- Implement a proposed design.
4- Evaluate completed technological designs of products.
5- Communicate the process of technological design.

In Content Standard E (grades 9-12), we find the following procedure under the title "Abilities of Technological Design":

1- Identify problems or design opportunities.
2- Propose designs and choose alternative solutions.
3- Implement a proposed solution.
4- Evaluate the solution and its consequences.
5- Communicate the problem, process and solution.

These processes, especially the ones identified for grades 9-12, are similar to what an engineer typically does during the development of a new product. They reveal that engineers are not simply "tinkerers" and expose students to engineering activities not generally known to the public. For example, few non-engineers realize the importance of communication skills in the engineering profession. Many are unaware of the importance of evaluating design alternatives including non-engineering considerations such as cost, cultural background, etc. Although economic and business factors, environmental concerns, and ethical issues, are not specifically identified, they are major considerations when comparing design alternatives. The standards address these issues elsewhere [1], p. 166, 169, 198, 199] but we believe that their omission in the Science and Technology section is a mistake.

If a school or school district were to use the NSES as their framework for teaching science, we would expect that their science courses would provide the opportunity to generate an interest in engineering and technology. In reality, what is actually happening in the schools we have observed is that three obstacles appear to mitigate against generating an interest in engineering and technology. First, the education of science teachers generally does not include courses that promote an understanding of engineering principles and design. Second, state science standards may not give as much emphasis to technological design as the NSES. For example, the State of Nevada Science Standards [11], which were patterned after the national standards, do not include adequate reference to engineering and technology when compared to the NSES. There are exceptions, e. g., the State of New York [12]. And third, few activities that require students to use engineering design principles are included in the average science textbook. Section IV provides recommendations for alleviating these three perceived obstacles.

III.3 Do the standards provide adequate preparation for engineering and technology?

Most engineering disciplines require a high level of proficiency in basic mathematics and science literacy [8]. The standards represent a major overhaul of K-12 science and mathematics education. It is fair to say that the NSES provide the opportunity for adequate preparation in engineering and technology for all students, not just the students who have traditionally taken the upper level science and mathematics courses in high school. In all states, science and mathematics standards have been designed to provide minimum competencies for high school graduates. They are not designed to prepare students with the upper level mathematics and physical science concepts that are needed to enter university level engineering programs without remediation.

Regarding the NSES, the hope is twofold. First, that they will provide the motivation for more students who would not take upper level science and mathematics courses to do so. Second, that they will provide the interest in these students as well as the traditional high school students who take upper level courses in mathematics and the sciences to consider a career in engineering instead of business, law, medicine and other more popular professions. Previous research of the authors indicates that many high school teachers and students are largely ignorant of what engineers do [7].

IV. Recommendations for Improving the Standards

The standards emphasize the importance of coordinating programs in mathematics with those in science [1], p. 115, 148, 175, 176]. However, they do not identify engineering and technology as a natural means of achieving this task. The standards should emphasize the importance of engineering and technology in the fusion and coordination of mathematics and technology contents. Our discussion of the NSES standards in Section III emphasized engineering and technology. The discussion reveals some deficiencies in the standards as well as some obstacles to their implementation. The main obstacles identified are:

1- Inadequate teacher preparation.
2- Discrepancies between state and national standards.
3- Inadequate K-12 Science Texts.

We now discuss these obstacles and deficiencies and provide recommendations for eliminating or mitigating them.

IV.1 Inadequate teacher preparation

The NSES suggest [1], p. 59] in the Professional Development section that the professional development of teachers should "introduce teachers to ... , and technological resources that expand their science knowledge and their ability to access further knowledge". In the opinion of the authors, this does not go far enough. There are already engineering outreach programs that address some of the deficiencies in the technology education of K-12 teachers [13], [14]. These are important programs that can be enriching to students and fill a temporary gap in the content knowledge of K-12 teachers. Still, our research [7] indicates that secondary science teachers must be exposed to engineering principles and design in formal classes, especially if the infusion of engineering principles and design into existing science classes is to be carried on year after year and last beyond the funding of special programs. Furthermore, the secondary science teachers cannot just be exposed to the content knowledge, they must apply it in hands-on activities that use their recently "learned" engineering principles; e. g., highway project design, packaging design, digital imaging, et cetera; if they are to infuse them into their classes.

IV.2 Discrepancies between state and national standards

Even after formal instruction and practice, some of the teachers do not make their new knowledge a part of their instruction for student learning in their secondary science classes. To make sure that they do so, state standards must be aligned better with the NSES [1], p. 239]. There are some states that have strong standards regarding engineering principles and design as a part of their science standards. But, in others, e. g., the state of Nevada, they may be totally lacking [11]. Teachers will only be accountable for what is in the standards. In general, only concepts that are in the standards will be taught in classroom instruction, especially since there are already complaints from teachers, administrator and parents that the standards are too extensive. Students who are taking the minimal science program for the proficiency exam will only learn what is included in the standards for which they will be tested. In the final analysis, the curriculum is very political and it comes down to whose knowledge is most important, not necessarily what knowledge is most important to a modern technological society. In such an atmosphere and in states that do not have a strong industrial base in technology and a need for a large number of workers with technological knowledge, industry may not have the awareness and political influence to insure that the standards include this type of knowledge. To rectify this, the CEOs, engineers and technicians in technology based industries must become more proactive, and must make sure the prior school knowledge needed for their workforce is included in the state and local district standards.

IV.3 Inadequate K-12 Science Texts

A final deficiency is the lack of science textbooks that include engineering/technology applications of the science concepts presented in the textbook. Most textbooks do not have any laboratory activities that allow students to carry out the processes identified in Content Standard E for grades 5-8 and 9-12 [7], p. 165, 192] and identified in Section III.2 earlier in the paper. Students may use some of these processes, e.g., identify problems or design opportunities, but they are usually limited to science activities/experiments that do not have technological applications. Occasionally an engineering activity is found in the physics part of a physical science textbook, e. g., design and testing of a model bridge. Teachers can design their own activities to give more engineering applications of the science concepts but without formal courses in their pre service or in service teacher certification programs that address engineering, they are unlikely to do so. The average teacher closely adheres to the textbook so engineering activities must be included in all science texts. Until this happens, teachers can draw from the web sites that have technology information and activities [15].

V. Conclusions

Upon examining the NSES standards, it is clear that if implemented, the result would be a significant improvement in the science and mathematics backgrounds of high school graduates. This alone would better prepare the students for careers in engineering and technology. The engineering and technology content of the standards also represents an improvement over the science frameworks in many of our school districts. Unfortunately, we believe that the standards do not go far enough in providing students with exposure to engineering and technology. More ominously, the engineering-related segments of the standards are likely to be the ones that are least familiar to K-12 teachers and are therefore those that are least likely to be implemented. Engineering principles and design may not even be present in many of the new state science standards. There is an urgent need for the following: First, certification requirements and in service training for science teachers that includes classes to increase the exposure of secondary science education majors to the engineering profession and to provide those teachers with the means of introducing engineering in their classrooms. Second, state science standards that are more closely aligned with the NSES and in some cases even exceed them. Third, textbooks that include more examples and lab activities that include engineering principles and design.

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