# Integrating Engineering Concepts under Current K-12 State and National Standards

**Mary R. Anderson-Rowland, Dale R. Baker,**
**Patricia M. Secola, Bettie A. Smiley, Donovan L. Evans, James A. Middleton**
**Arizona State University**

Abstract

Interest in engineering by entering college freshmen is near a 30-year low. Young women especially are not attracted to engineering. Engineering is not featured in popular television programs and usually gets overshadowed in news reporting. Students in middle and high school do not hear about engineering in school since middle school and high school teachers are not well informed about engineering and applied mathematics and science. If engineering is to remain a viable and growing profession, especially among women and minorities, teachers need to be educated so they can present engineering material in a way that meets state/national science curriculum standards.

Science standards, inherent in aligning curricula to these science standards, and a partial solution to overcoming these obstacles will be discussed in the paper. In particular, the WISE Investments program, sponsored by the National Science Foundation, [*] introduces teachers and counselors to engineering and helps the teachers develop modules that can be introduced into present mathematics and science high school classes. Examples of these modules, developed to interest young women in middle school and high school, are given. These enriched modules increase curiosity and bring excitement into the classroom for the teachers and their students.

Key Words: Middle School, High School, Engineering, and State/National Science Standards, Science education, Professional Development, Curriculum

## I. Introduction

Despite calls for increasing attention to the contexts and applications of science and mathematics in K-12 instruction, information on engineering, one primary mode by which scientific and quantitative information interfaces with the general populace everyday, is not normally found in middle school and high school curricula. Students, young women in particular, do not get the opportunity to learn that an interest in mathematics and science might lead to an interest in engineering. Indeed, the middle school years have been likened to a "black hole" of education. K-12 mathematics and science curricula rehash the same concepts and skills year after year, with little evidence that students either attain or retain that knowledge.[1] To be even more specific, while *some* students in the United States perform well and even excel in comparison with the best in the world, the *majority* of students perform less well than their international peers, [2] and increasingly, businesses and industries that rely on workers with technical knowledge are

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importing employees from overseas.[3] The reasons for this disparity are myriad, including lack of integration of concepts, little tie to the lives of students in the US curriculum, inadequate teacher knowledge of fundamental ideas that under gird mathematics and science fields, and general attitudes about what science, mathematics, and engineering are, and who becomes involved in them.[4] These reasons alone suggest that an integrated, application-based approach to learning science and mathematics may be helpful in cultivating an interest in, and an understanding of, fields such as engineering that utilize scientific and mathematical knowledge.

Unfortunately, K-12 mathematics and science teachers are generally not well informed about engineering as a profession. Causes for this may include the departmental separation within universities (i.e., biology, physics, chemistry, math, and education being separate from one another and none having close ties to engineering departments) with this department structure being replicated at the secondary and in some cases middle school level. This causes lack of interdisciplinary coursework and/or applications-based coursework in science and math in teacher preparation. Certification requirements and standardized tests generated in this "accountability era" continue to perpetuate the interest in the "pure" sciences in the curriculum.

Even if teachers are knowledgeable about engineering and wish to add engineering material to their math and science classes, they do not know where they fit in with state and national standards. Even though these standards address engineering and technology concepts, teachers emphasize the pure sciences. At the high school level, lack of understanding of engineering by curriculum designers and teachers make it difficult to get engineering concepts into courses. For similar reasons, having an *Introduction to Engineering* class accepted as a science class at the high school level is difficult because of state/local high school graduation "credit" requirements. Although middle school teachers are usually freer to introduce new subjects in their classes, they generally have even less understanding of science and mathematics than do their high school counterparts. This makes the task of integrating engineering concepts into the middle school curriculum just as difficult as it is in high school curricula.

Although, nationally-derived standards for "technological" education do exist [5], these suggested standards have not been adopted and addressed by many, if any, states or local governing bodies. These standards, if they were to be adopted, would address engineering and technology issues and force the K-12 educational community to include learning activities that promote the understanding of engineering. To the authors' knowledge, only the state of Massachusetts has begun to pursue the development of curricula that are aligned to their own (as opposed to the standards in Reference 5) "technological" education standards [6], although many foreign countries are actively working on technological education standards.

## II. The State/National Science Standards

Nearly all states have science content standards that schools must address. Many state standards derive from and are virtually the same as the national science content standards [7], with some adjustments to reflect local issues. The state/national standards outline what students must know by grade level, but they do not dictate the curricula that teachers must use to attain the outcomes. This may provide an opportunity for the inclusion of learning activities based on engineering

concepts. The national science standards[7] are divided into eight categories (unifying concepts and processes in science, science as inquiry, physical science, life science, earth and space science, science and technology, science in personal and social perspective, and history and nature of science) and are applicable to grades K-12.

The standards refer to broad areas of content, such as objects in the sky, the interdependence of organisms, or the nature of scientific knowledge. Each standard addresses fundamental ideas in science that all students should understand. Because each content standard subsumes the knowledge and skills of other standards, they are designed to be used as a whole. Although material can be added to the content standards, using only a subset of the standards will leave gaps in the scientific literacy expected of students.

Engineering usually goes unrecognized as a potential vehicle for addressing the content standards, primarily because teachers know so little about the field. However, engineering concepts are deeply embedded in the standards. Indeed, Project 2061, which initiated the current round of reform with *Science for All Americans* [8] and pushed for the establishment of national science content standards, specifically addresses the importance of understanding *The Designed World.* [9] Furthermore, the national technology standards developed by the International Society for Technology in Education have strong connections to engineering. [10]

Indeed, an engineering curriculum may be the best way for students to understand technological design or to distinguish between man-made and natural objects (Science and Technology standard). Understanding risks and benefits or natural hazards (Science in Personal and Social Perspectives standard) also has strong connections to engineering. Furthermore, much of the history of science is really the history of engineering when one considers the great inventions of the world such as the arch or the chronometer (History and Nature of Science standard).

## III. Science Education Program Standards

The national science standards also address what a comprehensive science program should look like (Science Education Program System Standards). These *program* standards describe the conditions necessary for quality school science programs. Program standards deal with issues at the school and district level and the actions needed to provide comprehensive and coordinated experiences for all students across all grade levels. They focus on six areas:

- The consistency of the science program with the other standards and across grade levels.
- The inclusion of all content standards in a variety of curricula that are developmentally appropriate, interesting, relevant to student's lives, organized around inquiry, and connected with other school subjects.
- The coordination of the science program with mathematics education.
- The provision of appropriate and sufficient resources to all students.
- The provision of equitable opportunities for all students to learn the standards.
- The development of communities that encourage, support, and sustain teachers.

State and local school districts adopting the National Science Education Standards must translate these standards into programs that reflect local contexts and policies. The program standards discuss planning and actions. Again, this can be done in many ways, because the Standards do not dictate the order, organization, or framework for science programs.

However, there are some barriers to introducing an engineering curriculum that are inherent to the organization of schools and the accountability movement that makes infusing engineering into the curriculum difficult. These barriers include the degree to which local curricula are prescribed, the methods used for the assessment of knowledge, the importance of the science assessments, and the abstract nature of what is viewed as legitimate science. High school curricula are the most prescribed and abstract and students and teachers are held accountable, through high stakes testing, to assessment instruments that are closely tied to the established curriculum. Thus, changing the high school curriculum is extremely difficult.

On the other hand, the middle grades (5-8) do not have these barriers. Furthermore, these grades are a critical period in students' lives regarding science. At this time, interest toward science and achievement appears to diminish and plans to take more science and mathematics are often discarded, especially by girls.[11] Thus, introducing an engineering curriculum at the middle grades, with the kinds of relevance to students' lives and real world applications that engineering provides, is a natural and logical approach to reforming science curricula.

## IV. WISE Investments

In 1999, the Women in Applied Science and Engineering (WISE) Investments Program, supported by a National Science Foundation Gender Equity Program, was established through the Office of Student Affairs (OSA) in the College of Engineering and Applied Sciences (CEAS) at Arizona State University (ASU). The mission of the OSA is to recruit, to retain, and to place CEAS students in engineering, computer science, and construction management. WISE Investments was established to support the recruitment and retention efforts in the CEAS. We believe that to increase the enrollment in our college, students in middle school and high school should be aware of the opportunities, challenges, and rewards available in engineering, computer science, and construction management. At the same time, we believe that our retention rates will improve substantially when more students understand the major engineering disciplines before they matriculate into the CEAS program.

Since 1994, CEAS summer programs for middle school and high school students have served to educate and to recruit students for the engineering disciplines. We have also had a Mathematics, Engineering, Science Achievement (MESA) Program in place for many years. The MESA Program targets underrepresented minority students. Its goal is to prepare the students, especially minority students, for college. The OSA made school visits, participated in school fairs, and brought middle school and high school students to the campus. However, we felt that more could be done. We wanted to partner with middle school and high school mathematics and science teachers, as well as counselors, to educate middle school and high school students about engineering, computer science technology, and construction management. The objective was to

facilitate the students' interest in engineering and warrant the appropriate courses in high school to meet academic requirements for enrolling as college freshmen in the CEAS. [12,13]

The WISE Investments program provided the means to accomplish this objective, with the added goal of directly informing more young women about the engineering majors available in CEAS. WISE Investments recruits middle school and high school mathematics and science teachers and school counselors to participate in a yearlong professional development program that would enable the teachers to integrate engineering into their existing math and science curricula. The program also provides assistance to the middle school and high school counselors to incorporate engineering information in their academic and career counseling. These pre-college educators attend a two-week summer workshop on the ASU campus where they are presented with eight engineering labs, including computer science technology, and gender equity information. [14] During the second week the teachers work individually to develop modules that they can present in their classrooms. In addition, the teachers are divided into teaching teams where they will develop a Saturday Academy engineering module to present to middle school and high school girls. The teachers receive advice and assistance in developing the classroom and Saturday Academy modules from the CEAS faculty. Integration between the math and science classes is encouraged. During the school year WISE Investments personnel observe the teachers delivering engineering modules in their classrooms. The teachers are given helpful suggestions before they present an engineering module at a Saturday Academy. [15]

WISE Investments usually recruits approximately 45 girls for the Saturday Academies. However, for the 2001-2002 school year, 75 middle school and high school girls were recruited to attend eight Academies. In each academy, a teacher team presents a workshop on one of the engineering disciplines. The Saturday Academy module introduces the engineering field through a series of hands-on activities and labs emphasizing engineering as a "helping profession". Student evaluations are utilized to provide feedback to the teachers and the WISE Investments team for further improvement of the engineering module.

Pre/post questionnaires were used to determine the engineering career interests of the girls at the beginning and the end of the Saturday Academies. The results from the 1999-2000 cohort of the 25 participants who completed both the pre- and post-questionnaire were described in Reference 14. Industrial Engineering and Materials Engineering were the disciplines with the most increased career interest. Only 5 participants indicated an interest in Industrial Engineering at the beginning of the academies and only 3 participants indicated an interest in Materials Engineering. At the end of the academies, Industrial and Materials had been selected as a career interest by 11 and 10 participants, respectively.[14] Industrial and Materials Engineering are not generally well known, so a reasonable conclusion is that the these two majors were presented in a manner that was engaging to the young women. The change in number of interests of the young women from before and after the academies was analyzed by grade level. The five 7$^{th}$ graders indicated 26 *Likes* and *Strongly Likes* in the pre-questionnaire, but only 11 in the post-questionnaire. On the other hand, the five 8$^{th}$ graders changed from 11 interests to 28 in the post-questionnaire. Although the sample is small, the questionnaires showed that, in general, the career interests of the young women remained unfocused on a particular major in engineering.

This observation is in agreement with the large number of entering CEAS freshmen at ASU who are unsure which major in engineering and computer science is best for them.[15]

Of the participants of the 1999 through 2002 WISE Investments Saturday Academy cohorts, 11 women are of college age and 18 women will be completing high school in May 2002. Five of the 11 women of college age are attending ASU as engineering majors. To date, eight of the 18 women have been admitted to ASU for Fall 2002, seven in engineering and one in science. We know that, in at least some of the cases, the women, who have been admitted or have enrolled in engineering, were convinced that engineering was for them after attending the Saturday Academies.

The emphasis of WISE Investments Saturday Academies is to encourage female students to pursue engineering as a career option. The gender equity training the teachers and counselors received during the two-week workshop was to encourage them to develop the modules in a gender-inclusive manner. Although the Saturday Academies emphasized to the teachers that their material on engineering should be interesting to girls, the modules created by the teacher teams were expected to be equally appealing to the female and male students in their regular classrooms.

We were also interested in the change in perception and knowledge of engineering by the teachers and counselors as a result of the two-week workshop. In pre/post questionnaires conducted with the 1999 cohort, the participants were asked to define eight engineering disciplines. Of the participants, 80% showed improvement and 8% demonstrated exceptional outcomes.[16]

The WISE Investments program provides background information on engineering to the counselors and advisors so that they are confident enough to encourage or to support discussions with students about engineering as a career. [16] The teachers receive hands-on experience in engineering labs, but still need to know how the engineering experiment actually meets the science standard. The primary question remains, "How can the teachers present engineering modules and still meet state and national science standards?"

## V. Engineering Modules That Meet Science Standards: A First Step, Partial Solution

The WISE Investment program has done an excellent job in broadening the teachers' understanding regarding how their curriculum can be related to engineering. Prior to their involvement in WISE Investments, teachers were unable to make the connection because they did not have a strong concept of engineering and its real-world applications. Not only does the experience give teachers exposure to engineering, it helps them introduce engineering concepts and experiments into the curriculum in a manner that supports the science standards. In developing engineering modules to present to their science classes, the teachers have found at least three methods to ensure that the modules on engineering will meet the science standards. These methods provide a first step, partial solution to the obstacle of integrating engineering into the classroom curriculum.

In the first method, the concept or skill covered by a science standard is described and an engineering activity is used to teach the concept or skill. For example, a Materials Science lesson plan would be incorporated with the "Science as Inquiry" standard using a silly putty experiment. The national standard that addresses Science as Inquiry (for middle school science) states that "As a result of activities in grades 5-8, all students should develop: abilities necessary to do scientific inquiry, and understandings about scientific inquiry." [7]

Silly putty consists of long chain molecules that can, with some resistance, slip over each other as the putty is stretched. If the putty is stretched suddenly, the resistance to stretching can become so large that the chains break and the putty splits into two pieces. To gain experience at meeting the Science as Inquiry standard, students might engage in qualitative discussions of long chain polymers and the ability of the chains to slide over one another in a substance like silly putty. The chains can be illustrated by interlocking fingers or by using a box of cut strings. Asking the students to speculate on how the ability of such a polymer to stretch might change if the chains were to be cross-linked in some way easily segues into an actual confirmation of their expectations (i.e., their hypothesis) by experiment.

At this point, student teams can be given a thermoplastic glue, water, and sodium borate to make a silly putty-like material. Many types of glue consist of entangled chains (providing the long chain molecules), while sodium borate provides boron atoms that cross-link the chains together. Each team is told to choose, within given constraints, the amount of sodium borate that they add to a specified mixture of the glue and water. Having each team compare the array of mixtures produced by all the teams will then allow the students to evaluate their hypothesis about the relationship between cross linking and "stretch ability" or flexibility of the polymer.

The students thus use the Science Inquiry by hypothesizing, analyzing the results, and drawing conclusions about their hypothesis. In addition, the students could be asked to hypothesize on the final consistency of the mixture if a different amount of water had been added. The student teams would experiment with different amounts of water, analyze the results, and draw conclusions. This is also an ideal time to point out the need to vary only one parameter at a time, as long as there is no interaction, in order to evaluate relationships in multi-parameter systems. If there is interaction, then a multi-variate analysis will need to be introduced. Of course, the teacher will also use this experiment as an opportunity to talk about Materials Engineering.

In the second method, a science standard is chosen and then several engineering activities are described that meet that standard. For example, a middle school teacher chose a district standard from her school's Science Curriculum manual: "Students will understand basic concepts of matter and energy," where two of the three targets are to "Identify the properties of matter and describe its composition and classification" and to "Define motion and describe the relationship between forces and motion." [17] Below is the teacher's engineering module (in the context of the national science standards [7]):

Physical Science – Grades 5-8
Content Standard B:
As a result of their activities in grades 5-8, all students should develop:

an understanding of properties, composition, and classification of matter

Activity:
Develop a safe, non-toxic, inexpensive play substance.
(Engineering discipline: Chemical Engineering)

an understanding of motion and forces

Activity:
Design a parachute that will safely carry a raw egg to the ground from a height of 20 meters.
(Engineering discipline: Materials Science; Aerospace)

The second of these content standards, Motion and Forces, is essentially intended as a precursor to a more detailed and rigorous development of Newton's laws of motion that is addressed in the grades 9-12 standards. The intent in the middle grades is to instill an understanding:

- That motion (position, velocity and change in velocity) can be measured (and graphed);
- Of what a force is;
- That force and change in motion are related;
    - No net force leads to no change in velocity (but not necessarily to no change in position); and
    - That an unbalanced force leads to a change in velocity.

These are very confusing concepts to students, and early confusion often leads to deeply held and hard to change misconceptions. [18] Experience teaches us that this teacher's ideas would lead to a fun experiment for students, but would not be an easy way for students to learn the principles called for in the standards. The teacher's ideas had to be moderated to ensure that she/he knew how to use the motion of the egg/parachute to convey the correct understanding of motion and forces, an understanding the took mankind centuries to unravel. For example, rather than using a fixed length of the drop, measuring the terminal speed of the parachute for various parachute sizes at a fixed payload weight (or terminal speed for various payload weights for a given parachute) allows many aspects of motion and forces to be discussed.

As part of the above teacher's lesson plan, students would use engineering problem solving techniques to design, develop, and test their products. In addition, the activity for developing a safe, non-toxic, inexpensive play substance was conducted by a teacher team at the Chemical Engineering Saturday Academy.

One difficulty with Science Standards is that they do not naturally relate to everyday experiences. In a third method, a group of teachers showed how by changing the language,

where applicable, engineering can be introduced to the students. Teachers would have students role play the part of engineers. For instance, students would work in teams with each student in a team starting with a specific role. Each lab group position would be renamed (i.e, the monitor would be the Industrial Engineer, the materials person would be the Materials Science Engineer). Instead of only referring to chemistry, teachers would mention chemical engineers. Where appropriate the teachers would change the semantics. Instead of a science lab they would refer to the activity as an engineering lab. One science teacher said that she had taught about soils for years, but it had never occurred to her, before her training in WISE Investments, to also talk about the Civil Engineers that work with soil.

Teachers who have completed the WISE Investments program have by and large been able to integrate engineering into their existing science and math curriculums. Through classroom observations, WISE Investments has found that some high school teachers have the most difficulty in finding the time to introduce the engineering modules because of strict, established curriculums as opposed to the middle school teachers, who do not have the strict, established curriculums.

## VI. Conclusion

Engineering information can be introduced in middle and high school grades with the current science standards. The teachers and counselors who have participated in the WISE Investments Program have learned that engineering involves applied mathematics and applied science. They have discovered that their teaching is more interesting and enriched by including engineering in their math and science classes. The teachers have also enjoyed working in teams and collaborating with other teachers to present engineering in their curriculum.

A major task of WISE Investments is to present the modules that have been developed in a way that clearly shows what math or science standard is being addressed and to disseminate these modules so that more teachers can include information on engineering in their classes. While this is being accomplished, efforts should be made to have MESA classes recognized as science content classes. More students are likely to take a MESA class if the class counts as one of the four science requirements suggested as an appropriate preparation for enrolling in an engineering college.

Ideally, Arizona will follow Massachusetts' lead and have engineering as a mandated subject for all high school students. However, until that is a reality, we can make great strides in getting the word on engineering out to stakeholders by following the methods presented in this paper.

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## Biographies

MARY R. ANDERSON-ROWLAND

Mary R. Anderson-Rowland is the Associate Dean of Student Affairs in the CEAS at ASU. Awards for her support of diversity include the YWCA Tribute to Women 2001 Award (Scientist/Researcher). She was named an ASEE

Fellow in 2001 and one of "30 Prominent Business Women in Phoenix" in 2002. She is a frequent speaker on the myths of engineering and the opportunities in engineering, especially for women and minority students.

DALE R. BAKER
Dale R. Baker is a Professor of science education in the Department of Curriculum and Instruction at ASU. She is also the Co-Editor of The Journal of Research in Science Teaching. Her teaching responsibilities include science curricula, teaching and learning, and assessment courses with an emphasis on constructivist theory and issues of equity. Her research focuses on issues of gender, science, and science teaching.

PATRICIA M. SECOLA
Patricia M. Secola is the Student Services Coordinator Associate in the WISE Investment program. Pat has been employed at Arizona State University for 17 years. Prior to working with WISE Investments, she was a Financial Aid Counselor, Sr. Throughout her career at Arizona State University, Pat has served on several university committees that have addressed diversity and student recruitment and retention concerns.

BETTIE A. SMILEY
Bettie A. Smiley is currently enrolled in the Ph.D. program for Educational Leadership and Policy Studies at ASU. She has a M.S. Degree in Educational Administration, a M.S. in Special Education, and a B.S. in Vocational Education. She works as the Assessment Assistant for the WISE Investments program in the College of Engineering and Applied Sciences at ASU.

DONOVAN L. EVANS
D. L. EVANS is the Director of the Center for Research on Education in Science, Mathematics, Engineering and Technology, and a Professor of Engineering in the Mechanical & Aerospace Engineering Department at Arizona State University. His principal areas of interest are Engineering Education Improvement, Engineering Design, Energy Studies, System Simulation, Thermodynamics, Heat Transfer, and Fluid Mechanics.

JAMES A. MIDDLETON
Jim Middleton is Associate Dean for Research in the College of Education at ASU. He earned his PhD at the University of Wisconsin-Madison. He takes an active role in promoting research and creative activities in mathematics, science, and technology across the University. He is currently Principal Investigator of the AriZona Teacher Excellence Coalition, a $13.8 million grant from the US Department of Education.