Implementing Concepts of Pharmaceutical Engineering Into High School Science Classrooms

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Abstract

The New Jersey Institute of Technology in conjunction with the Center for Pre-College Programs and research groups within the Engineering Research Center for Structured Organic Particulate Systems (ERC-SOPS) established a summer Research Experience for Teachers (RET). The goal of the RET was to educate high-school science teachers in the opportunities and challenges involved with manufacturing of pharmaceutical products, and thus help educate the future generation of students, helping create a strong pipe-line of talented students interested in pursuing careers in engineering and science. Nine teachers representing chemistry, biology, and physics, were recruited from schools in local urban districts, and were able to develop skills and knowledge in science and engineering with a focus on the area of pharmaceutical particulate and composite systems from which they created instructional modules to be integrated into their teaching practices. The teachers worked in teams of two along with a faculty mentor on different projects that evolved from current research in C-SOPS which included: a) control and characterization of flowability of cohesive powders; b) The Electromagnetic Spectrum and Raman Scattering Spectroscopy; c) The Mixing Efficiency of Dissolution Testing for Pharmaceutics and Engineering; and d) Crystallization of Ultrafine (Nano and Micro) Particles of Active Pharmaceutical Ingredients. The evaluation process focused on the summer experience and the impact it had on the teachers and their classroom practices. During the summer research experience and through the following school year teachers completed survey instruments to gauge: 1) the effectiveness of the research experience and the supportive activities that took place, 2) changes in the teachers' concerns about integrating engineering skills into classroom practice, 3) their preparedness to teach the engineering skills they learned and 4) changes in their attitudes toward engineering and knowledge about careers in engineering. Results indicate that teachers felt the experience was useful and that their concerns about implementing engineering skills in their classroom changed from needing more information to considering the impact the change(s) in their teaching would have on their students. After completing the program teachers felt they were prepared to teach the engineering skills they learned, had more self-efficacy for helping students who might want to study engineering and teachers knew more about careers in engineering and what engineers do.

Introduction

Engineering plays a major role in shaping the world today. The application of science, mathematics and technology into engineering benefits people and makes the world we live in possible. Most students are unaware of the benefits that engineering provides people in their daily lives, from developing consumer goods, to creating artificial devices such as knees or hearts and are not interested in pursuing careers in engineering. Many bright, capable high school students choose not to pursue studies in science and mathematics and do not prepare academically for college degree programs that would allow them to pursue careers in engineering and technology (1, 2). As a result, the United States currently has a shortage of qualified workers in the science, technology, engineering and mathematics (STEM) fields that will continue at least into the next decade (3, 4). For the long-term economic health of this country it is important that more students undertake studies and pursue careers in these fields to meet the current needs of the American work force (5).

One of the more critical reasons most students, particularly those from underrepresented populations in urban school districts, are not interested in pursuing careers in engineering is that they are not exposed to topics in engineering during their K-12 studies. Most K-12 teachers have not been trained to incorporate engineering and technology topics into their classroom lessons and there is a lack of high-quality curricular materials in these areas (6). As a result, students are not exposed to the engineering and technology resources used to develop strategies for solving real-world problems.

There has been a growing interest by higher education institutions to bring engineering principles and applications to the secondary school classrooms. Comprehensive professional development programs are needed for teachers to address the new skills and knowledge needed for improved classroom teaching and learning (7, 8) if we expect them to integrate engineering concepts into their classroom practice (9-11). Some of the identified factors that should be included in successful professional development programs include: Long term effort, Technical assistance, as well as support networks, Collegial atmosphere in which teachers share views and experiences, Opportunities for reflection on one's own practice, Focus on teaching for understanding through personal learning experiences, and Professional development grounded in classroom practice.

A focus is needed on content included in currently available curriculum materials that creates connections between the science used in engineering applications in the real world and science curriculum standards for which teachers and administrators are held accountable (6, 12, 13). Most existing engineering curricula lack an appropriate translation into standards-achieving lessons for enriching the science curriculum. Hence, teachers need to be able to translate state content standards into effective practices, while integrating engineering concepts into standards-achieving lessons for enriching the science curriculum. However, many teachers lack knowledge about standards-based lesson planning, and the availability of resources for standards-based lesson planning. While substantial energy has been devoted to the identification of standard-based curriculum materials and achievement tests, little is known about new lesson planning, teaching, and student activities that may be needed in a standards-based classroom. O'Shea & Kimmel (14) have developed a protocol for standards-based lesson planning that allows teachers to systematically assess learning outcomes that are aligned with state content standards.

Research Experiences for Teachers (RET) are seen as a vehicle for introducing engineering into secondary school curricula and as a strategy for increasing student interest in engineering, and ultimately increasing enrollment of qualified students in engineering degree programs (15-17). Miller & Winter (15) described a 5-week summer experience for middle and high school science, mathematics, and technology teachers. Follow up experiences were difficult due to geographical distances between teachers and the University. No evaluation data were included. Orlich, Zollars & Thomson (16) provided a 6-week research experience for high school science teachers and were able to maintain communication with the teachers and their students through technology. Instructional modules were developed as a result of the research experiences. There were plans to develop an instrument to measure students' attitudes towards engineering. Conrad, Conrad & Auerbvach (17) provided engineering research experiences for physics teachers, with a focus on modern physics concepts and applications to microelectronics packaging. Assessments included pre- and post-surveys and surveys of teachers' activities during the school year.

An RET at New Jersey Institute of Technology (NJIT) has been designed to provide high school science teachers with a professional development program that enhances their research skills and their knowledge of science and engineering concepts that enables them to incorporate real-world applications (e.g., pharmaceutical engineering) into high school science curricula. As part of the program teachers developed instructional modules they could use to integrate engineering principles into their classroom teaching. The project also focused on helping the teachers refine their instructional planning skills and providing them with an effective protocol for developing standards-based lesson plans.

The Setting

The RET program at NJIT is a collaboration of the Engineering Research Center for Structured Organic Particulate Systems (ERC-SOPS) and the University's Center for Pre-College Programs initiated under an NSF-sponsored four-university project. The goal of the program is to educate high-school teachers in the opportunities and challenges involved with manufacturing of pharmaceutical products, and thus help educate the future generation of students, helping create a strong pipe-line of talented students interested in pursuing careers in engineering and science.

Over the past several years, a number of research and education initiatives have been developed at NJIT in areas related to particulate systems and multiphase systems, and pharmaceutical processing and engineering. These initiative have resulted in the development of a strong research program in engineered particulates (especially particulates of various types of nano-structured composites), and in educational programs including; novel graduate-level degrees, research programs for undergraduates, outreach activities targeting K-12 teachers and students; all of which have helped to strengthen NJIT's research and education role in these critical areas.

The Center for Pre-College Programs (CPCP) at NJIT has almost 40 years experience working with the public school systems in Newark and others across the state of New Jersey (18). The mission of the Center is to improve the quality of education in elementary and secondary New Jersey school districts, especially urban districts, by; 1) Providing leadership in the planning, development and assessment of STEM education programs; 2) Developing and coordinating academic programs to serve elementary and secondary school teachers; and 3) Conducting outreach programs across the state for students, parents, teachers and school administrators.

Among the many successful programs at CPCP is Pre-IOP, the Pre-Engineering Instructional and Outreach Program, established to work with the public school systems of Newark and the surrounding cities to raise awareness about the importance of pre-engineering concepts in science and mathematics curricula (10, 19). Pre-IOP included the development of pre-engineering curriculum modules (aligned with the New Jersey Core Curriculum Content Standards) for use in middle and high school mathematics and science classrooms. Teacher professional development programs were established to train teachers how to integrate the pre-engineering curriculum into their classroom teaching as a way for their students to apply their classroom lessons to real-life problems. Outreach efforts were found to increase awareness of careers in engineering and knowledge about what engineers actually do. Use of the pre-engineering curriculum in science, mathematics and technology classroom was found to increase students' and teachers' attitudes toward engineering and knowledge of careers in engineering (20, 21). The RET program at NJIT continues the work of PrE-IOP by incorporating pharmaceutical concepts into the high school science curriculum.

The Research Experience

The 2007 NJIT Research Experiences for Teachers (RET) program provided the opportunity for nine high school science teachers (chemistry, biology, and physics) to engage in a six-week experience in a research group of the Center for Structured Organic Particulate Systems (C-SOPS). Working side-by-side with university research faculty, graduate students, and undergraduate students (participating in a parallel REU-Site program), in discovery based, hands-on research projects, teachers developed basic knowledge and skills in the area of pharmaceutical particulate and composite systems that can be incorporated into their teaching practice. Implicit was the opportunity for intellectual professional growth for the teachers.

The first week was an orientation program that included an introduction to NJIT and to ERC-SOPS and its research activities, methodologies, instrumentation, and safety procedures. Teachers were introduced to the scientific tools, protocols, and equipment necessary for gaining meaningful hands-on experience in the laboratory, from which they could develop basic knowledge and skills in the area of pharmaceutical particulate and composite systems that they can incorporate into their teaching practice. The teachers were introduced to the basic knowledge and skills they would need to be a contributing member of the research teams, and to be able to develop standards-based lessons/modules that they would share with their colleagues and bring back to their classrooms. Presentations were made by research faculty on research projects in which the teachers could be involved. A discussion among NJIT faculty and teachers considered the broader impacts of the program on healthcare and the role of the high school science teachers. Teachers were also provided with an introduction to the technical literature and methodologies for searching the web to support their research activities, as part of the development of the teachers' information literacy and related skills and knowledge. On-going discussion during the summer experience focused on the development of lessons and modules.

RET projects were small sub-projects within many of the research at ERD-SOPS, recognizing that much of the research deals with concepts that can be difficult to translate into laboratory and instructional activities for high school classrooms. Simplified versions of the basic concepts in a research project were developed. For example, dissolution of particles can be related to basic concepts of solubility, equilibrium, and rates of processes by developing simple experiments that involve observing dissolving of sugar crystals of varying size, with or without stirring or agitations. Teachers worked in teams of two that also involved at least one graduate student and one undergraduate REU student. The REU students will have had several weeks of experience by the time the RET program begins, and hence the team consisting of one graduate student and one REU student will be well-versed in the research project that the RET participants will participate in.

For example, in one project, a method for dry particle coating was utilized to deposit a very small amount of nano-sized additives with high degree of precision onto drug or excipient particles in order to change their flow and other properties. RET participants examined the application of this technique on improvement, control and characterization of flowability of cohesive powders in a predictive manner through dry particle coating. Another project focused on crystallization, the most common method used in the pharmaceutical industry for generating particles of active substances or intermediates. The teachers examined the role of agitation on crystal size as part of the research study the hydrodynamics of a stirred tank-impeller assembly, with particular attention being paid to solid dispersion and the determination of the minimum agitation speed for off-bottom solid suspension, both in the presence and the absence of an impinging jet apparatus. Other teachers examined the feasibility of using some water soluble edible polymer and FDA approved surfactant to disperse water insoluble drugs molecules in aqueous medium. Detailed characterization of materials was conducted using dynamic light scattering, FT-infrared, Raman and solid-state NMR spectroscopy. The materials were also characterized for film thickness, controlled release, dissolution rate testing, kinetics and selectivity. Another project involved the mixing efficiency of dissolution testing for pharmaceuticals.

Development of the instructional modules were critical to the RET program. Teachers and their mentors met frequently to develop a simple topic that is closely related to the pharmaceutical industry as well as the research they were conducting. To be effective, the modules had to address important issues including:

- What are the real-life implications of the research?
- What experiments will best relate the information to students in an exciting, insightful way?
- What are the materials and methods required to perform these experiments? Will there be insurmountable safety issues in planning such an experiment?
- The step-by-step procedure for disseminating the information to students in a logical way.
- Are the necessary tools accessible in the HS laboratories?
- What assessment will be used to show that students have internalized the information?

Because there were an odd number of teachers, one of the teachers served as a "swing teacher" working jointly with each team to monitor progress of the teams and communicate with the mentors. The swing teacher developed an instructional module that encompassed the research projects of the other teachers, "A Step toward Discovery: Inquiry Skills in Science", designed to help students think like engineers and scientists, while connecting relevant mathematics and science skills.

Standards-Based Lesson Planning

Curricular materials in support of the integration of engineering into science instruction have been made available through organizations such as NASA, ASME and IEEE, as well as through universities and teacher developed lesson plans. However, only concepts included in state content standards are taught in the classroom, as teachers believe they will only be accountable for what is in the standards (14). As a result, the only curriculum materials usually considered, let alone implemented, are those that reinforce state content standards, since student achievement (and schools' and districts' achievement) is measured largely by student performance on the statewide assessment tests (22). So, if teachers are to make engineering principles a part of their instruction for student learning, then engineering principles and design must be a part of the state science standards. Unfortunately, most existing engineering curricula lack an appropriate translation into standards-achieving lessons for enriching the science curriculum. Translation into standards-achieving lessons is critical (6).

The use of standards-aligned curriculum materials is necessary, but not sufficient for students to achieve the standards (14, 23). Curriculum with topics aligned to engineering standards is also not sufficient. Alignment with standards must also include the assessment of student achievement of the skills and knowledge defined by the standards. Criteria must be established that allow teachers to determine whether their students have achieved the standard. Several curriculum efforts have reported developing procedures for relating learning objectives with standards and assessment of student performance (24, 25). However, the reported alignment of standards is mostly a referencing to standards only, and assessments are generally missing or do not measure student achievement of the learning objectives.

Research suggests that lesson and unit plans are essential and powerful tools for instructional improvement and increased student achievement (23). When teachers prepare truly standards-based lessons, their teaching is focused on student achievement in relation to specific standards (24). Aligning curriculum, instruction, and assessment with goals for student learning (i.e., learning objectives) is an essential first step (25). A protocol for the creation and implementation of standards-based lesson plans has been developed at CPCP and utilized in previous and current professional development programs (14). The protocol starts with the concept that is to be taught. One or more measurable learning objectives are identified for the lesson. For each learning objective the corresponding statement from the content standards is then specified. The activity for the lesson is examined to be sure that it provides the student the opportunity to acquire the skill and/or knowledge specified by the learning objective and the appropriate statement of the standards. Finally the expected student performance is described (a student behavior or work product) that will provide the evidence that the student has acquired the skill and/or knowledge of the learning objective and the statement of the standard. The RET participants were introduced to the protocol and a template was developed for use in the development of their instructional modules.

Evaluation

Teachers' Concerns about Integrating Engineering skills into Classroom Teaching: Teachers concerns about integrating engineering skills into their classroom teaching were measured using The Teachers' Concerns Questionnaire (TCQ) adapted from the Concerns Based Assessment Model (CBAM) [26]. Repeated administrations of the TCQ are used to identify teachers' concerns and track changes in their concerns as they engage in educational reforms, focusing on how they progress through seven stages of concern: Awareness, informational, personal, management, consequences, collaboration and refocusing. Teachers completed the TCQ at the beginning and the end of the RET program and again a few months into the school year after they had some time in their classrooms. All three sets of responses were examined and indicate that initially, some teachers showed low levels of awareness and\or some were not very interested. By the end of the program most teachers appeared to have increased their awareness and many had moved into the information gathering stage. Not until a few months into the school year did some of the teachers begun shifting toward whether the new curriculum would help their students learn math and/or science. Three teachers completed the TCQ toward the end of the school year, expressing fewer personal and management concerns about the time commitments required to implement their new instruction modules. The teachers were focused on how the implementation may have impacted their students and appeared to be shifting into the collaboration stage.

Teachers' Readiness to Teach: At the end of the RET program teachers completed a Readiness to Teach Questionnaire (RTQ). The RTQ (20, 21) requires teachers to indicate how ready they feel they are to teach lessons on new topics and\or skills they have learned on a scale from 1 to 4 where 1='I would have to start from scratch', 2='I would need more training to teach this topic', 3='I would have to look at my notes to do this' and 4='I can teach a lesson on this topic tomorrow'. For example, one item asks 'How ready are you to teach the concept of steady state?' Teachers were asked to complete the Readiness to Teach again a few months into the school year after they had some time in their classrooms. At end of the summer program average scores for the 13 topics ranged from 2.8 to 3.8 indicating that most of the responses were 3='I would have to look at my notes' or 4='I can teach a lesson on this topic tomorrow'. Only one teacher gave any responses that indicated 1='I would have to start from scratch'. Less than 20% of the responses indicated 2='I would need more training to teach this topic'. For many topics the percentage of teachers that indicated 4=' I can teach a lesson on this topic tomorrow' was over 50%. Average scores for most of the 13 topics increased slightly a few months into the school year; ranging from 3.2 to 3.8. The average scores for two of the topics did not change and only one topic 'Drug release from a Lozenge' showed a decrease in the average response from 3.1 to 2.8. This was due mostly to a few teachers indicating 3='I would have to look at my notes' the second time rather than their initial response of 4='I can teach a lesson on this topic tomorrow' at the end of the program. Again, three of the teachers completed the RTQ a third time toward the end of the school year. The average scores for the 13 topics ranged from 3.5 to 4.0 indicating that at least these three teachers could teach all of the topics even if they had to look at their notes.

Attitudes to Engineering: Teachers completed the Attitudes to Engineering Survey (TATE) at the beginning of the RET program and again a few months into the school year after they had completed the program and had some time in their classrooms. The TATE (20, 21) measures teachers overall attitudes toward engineers and engineering as a career as well as their knowledge of careers in engineering and their self-efficacy for assisting students who might be interested in studying engineering. Teachers' attitudes toward engineers and engineering as a career was found to be fairly high, even at the beginning of the program. All nine teachers agreed that 'skills learned in engineering are useful in everyday life' and disagreed with the statement 'I would not like any of my students to be engineers'. Their average Attitudes to Engineering scores before the beginning of the summer program was 3.9 which increased to 4.2 during the school year.

Most teachers were somewhat informed about how to help prepare students that might be interested in studying engineering. Most agreed they knew 'where to find the necessary information to help their students if they wanted to become engineers' but most disagreed with the statement 'I have all the information I need to help prepare any of my students who may want to be an engineer'. Only a few indicated they knew of summer programs to help students learn more about careers in engineering. Average scores on the items that assess teachers' self-efficacy for helping students who might want to study engineering were low, only 3.0 at the beginning of the program but increased to 4.3 during the school year.

Knowledge of engineers and engineering as a career is measured using a multiple-part open-ended question which asks teachers to 'Name five different types of engineers' and to 'give an example of the work done by each type'. Each type of engineer is coded '1' for correct and '0' for incorrect. Possible total scores range from zero to five. Each example of the work they do is coded '2' for completely correct, '1' for partly correct, and '0' for incorrect. Possible total scores range from zero to ten. At the beginning of the program only five of the nine teachers were able to correctly name five different types of engineers and two of them were only able to name two types correctly. Only one of the teachers was able to give correct or partly correct examples of the work done by all five types of engineers receiving 7 points. One teacher did not give any examples and the rest were only able to give one, two or three partly correct examples. When the teachers completed the survey again a few months later results showed that teachers' knowledge of engineers and engineer as a career had increased. Six of the teachers were able to correctly name five different types of engineers, two teachers named four types and the last teacher named three. All of the teachers were able to give at least some partly correct examples of the work done by the types of engineers they named most scoring at least 5 or 5 points, a few scored 8 or 9 points.

Teachers' feedback on program effectiveness: Periodically during the program teachers were asked to provide written feedback on how they felt the program was progressing. Teachers were asked to rate each activity or learning experience by indicating how useful they felt it was to them as a teacher (2= very useful, 1=somewhat useful or 0=not useful) and the value they felt it had for student learning (2=high value, 1=some value or 0=no value). The average usefulness rating for a majority of the activities was at least 1.5. Two activities, a poster presentation session to share their research experience with others and the mentoring process, had an average rating of 1. Many of the teachers just did not find the poster presentation very useful. Two of the teachers rated the mentoring process as not useful. Unfortunately one of these two teachers reported in additional comments that their mentor had "not been available" during the program. The teachers also found a majority of the activities to have a high value for student learning in their classrooms. Most activities had an average rating of at least 1.6. The activities that teachers did not find useful for their students, scoring only an average of 1 or less were things like tours of laboratories, poster presentations and discussions of on-going research.

Conclusions

Teachers found the RET program useful to them as teachers and found a lot of value in the experience for their students. Many of the teachers expressed an interest in repeating such an experience. Participation in the RET program increased teachers' attitudes towards engineering, knowledge of engineering careers and their self-efficacy for helping students who might be interested in studying engineering. The program is being repeated in 2008 with a greater focus on collecting student data to help evaluate the impact of the program on students as well as teachers.

Acknowledgments
This project is based upon work supported by a grant from the National Science Foundation, ERC Supplement Award for an RET Site, EEC-0540855, and is gratefully acknowledged. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation (NSF).

References

1. American Society of Engineering Education (2004), Engineering in the K-12 Classroom: An Analysis of Current Practices & Guidelines for the Future. ASEE. Washington, D.C.
2. American Society of Engineering Education. Engineering Education and the Science & Engineering Workforce. Public Policy Internet Website. http://www.asee.org.
3. National Academy of Engineering (2002), Raising Public Awareness of Engineering. The National Academies Press. Washington, D.C.
4. National Science Board (2004), Science and engineering indicators 2004, Arlington, VA: National Science Foundation, Washington, D.C. (NSB-00-1).
5. New Jersey Commission on Higher Education (2001), Higher education outcomes and high-tech workforce demands. The fifth annual system wide accountability report. NJCHE, Trenton, NJ.
6. Kimmel, H., John Carpinelli, J., Burr-Alexander, L. & Rockland, R. (2006), "Bringing Engineering into K-12 Schools: A Problem Looking for Solutions?," Proceedings of the 2006 ASEE Annual Conference. Chicago, IL,. June .
7. Guskey, T.R. (1986) "Staff Development and the Process of Teacher Change". Educational Researcher, Vol. 15, pp. 5-12.
8. Joyce, B. & Showers, B. (1988) Student Achievement Through Staff Development. Longman. New York.
9. Zarske, M., Sullivan, J., Carlson, L. & Yowell, J. (2004), "Teachers Teaching Teachers: Linking K-12 Engineering Curricula with Teacher Professional Development". Proceedings of the 2004 ASEE Annual Conference, Salt Lake City, UT, June 20-23,.
10. Kimmel, H. & Rockland, R. (2002), "Incorporation Of Pre-Engineering Lessons Into Secondary Science Classrooms". Proceedings of the 32nd ASEE/IEEE Frontiers in Education Conference, Boston, MA, November 6-9,
11. Kimmel, H. & O'Shea, M. (1999) "Professional Development and the Implementation of Standards". Proceedings of the 29th ASEE/IEEE Frontiers in Education Conference, San Juan, PR, November 10-14.

12. Anderson-Rowland, M., Baker, D.R., Secola, P.M., Smiley, B.A., Evans, D.L. & Middleton, J.A. (2002), "Integrating Engineering Concepts Under Current K-12 State and National Standards." Proceedings of the 2002 ASEE Annual Conference, Montreal, PQ, Canada, June 16-19.
13. Schaefer, M., Sullivan, J. & Yowell, J. (2003), "Standards-Based Engineering Curricula as a Vehicle for K-12 Science and Math Integration." Proceedings of the 33rd ASEE/IEEE Frontiers in Education Conference, Boulder, CO, November 5-8.
14. O'Shea, M. & Kimmel, H. (2003) "Preparing Teachers for Content Standards: A field Study of Implementation Problems". Proceedings of the American Association for Colleges of Teacher Education, New Orleans, LA, January 25.
15. Miller, B. and Winter, R.M. (2006), "RET Site: Inspiring Educators in Rural America through Research." CD 2006 AIChE Annual Meeting Conference Proceedings. New York, NY, AIChE.
16. Orlich, D, Zollers, R, and Thomson, W. (2006). "Introducing Engineering at the Middle School and High School Level." Proceedings of the 2006 ASEE Annual Conference, Chicago, IL,. June 2006.
17. Conrad, L., Conrad, E, and Auerbach, J. (2007). "The Development, Implementation and Assessment of an Engineering Research Experience for Physics Teachers." Proceedings of the 2007 ASEE Annual Conference, Honolulu, HI,. June 2007.
18. Kimmel, H. & Cano, R.M. (2003) "Model for a K-12 Engineering Pipeline", Proceedings of the 2003 ASEE Annual Conference, Nashville, TN, June 22-25.
19. Carpinelli, J., Burr-Alexander, L., Henesian, D., Kimmel, H. & Sodhi, R. "The Pre-Engineering Instructional and Outreach Program at the New Jersey Institute of Technology." Proceedings of the International Conference on Engineering Education (ICEE 2004), Gainesville, FL, October 16-21 2004.
20. Hirsch, L., S., Kimmel, H., Rockland, R. and Bloom, J. (2005). "Implementing Pre-engineering Curricula in High School Science and Mathematics". Proceedings of the 35th ASEE/IEEE Frontiers in Education Conference, Indianapolis, IN., October 2005.
21. Hirsch, L., S., Kimmel, H., Rockland, R. and Bloom, J. (2006). "Using Pre-engineering Curricula in High School Science and Mathematics: A Follow-up Study". Proceedings of the 36th ASEE/IEEE Frontiers in Education Conference, San Diego, CA, October 2006.
22. National Research Council. Systems for State Science Assessment, 2005. National Academic Press. Washington, DC.
23. Tell, C.A., Bodone, F.M. & Addie, K.L. "A Framework of Teacher Knowledge and Skills Necessary in a Standards-Based System: Lessons from High School and University Faculty". Presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA, April 24-28, 2000.
24. Rothman, R., Slattery, J. B., Vranek, J. L., and Resnick, L. B. Benchmarking and Alignment of Standards and Testing. CSE Technical Report 566. National Center for Research on Evaluation, Standards, and Student Testing, UCLA, Los Angeles, CA, 2002.
25. Rutherford, F.J. and Ahlgen. Science for All Americans. 1991. Oxford University Press, New York, NY
26. Hall, G., E., George, A., A., and Rutherford, W., L. (1980). "Stages of Concern about the Innovation: The Concept, Verification, and Implications". Distributed by Southwest Educational Development Laboratory, Austin, Texas.