A Collaborative Process for K-12 Engineering Curriculum Development

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Abstract

Bringing engineering and technology curricula into the K-12 classroom *as a vehicle for the integration of math and science* can be accomplished with well-developed, interactive engineering lesson plans that incorporate hands-on activities. Through real classroom interactions in elementary, middle and high schools, graduate engineering Fellows successfully bridge engineering subject-area content to age-appropriate education pedagogy. Supported by National Science Foundation (NSF) and Department of Education (DOE)[1] grants, the Integrated Teaching and Learning (ITL) Program has developed extensive and innovative hands-on engineering curricula focused on topics universal to K-12 science, technology and math classes.

Graduate engineering Fellows are key to the successful creation of K-12 engineering curricula, through researching and writing engineering-focused lessons on a wide range of topics, such as energy, laws of motion, and electricity and magnetism. Comprehensive curricular units, comprised of up to 10 stand-alone lessons incorporating low-cost, hands-on activities, are standards-based at the state and national levels. Each curricular unit also contains math components, lesson background concepts, anticipated student outcomes and assessment suggestions.

The collaborative development of engineering curricula that impact K-12 students involves contributions from multiple professionals in the education community, including: research of background and activities by engineering graduate students and K-12 teachers; activity testing by engineering undergraduate students; content review by engineering faculty; math and embedded

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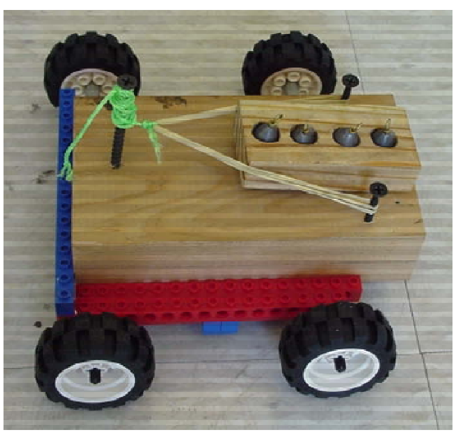
assessment contribution and reviews by qualified individuals; and literacy components, classroom relevance, age-appropriateness, and educational content standards review by certified and experienced K-12 teachers.

This paper examines the planning, research, testing, documentation and assessment process associated with developing standards-based, engineering-focused K-12 curricula. By capitalizing on a partnership comprised of engineering graduate and undergraduate students, engineering faculty and K-12 teachers, a significant impact is made on the K-12 family of teachers and learners.

Introduction

Today, K-12 educators face the challenge of teaching students the skills necessary to flourish in an increasingly technological society. While many students will not pursue careers in engineering or technology, *all* students can benefit from a basic understanding of how social, economic and cultural systems are transformed by the integration of the two[1]. Studies indicate that women and minorities continue to be underrepresented in the fields of engineering and technology and often fail to consider engineering as a viable career choice. For example, in 1999, less than 7% of high school advanced placement computer science test takers nationwide were African American and Hispanic, collectively[2].

A need exists within K-12 education to provide a comprehensive engineering curriculum that can be easily understood and implemented by non-engineering trained teachers. According to the 2002 National Panel Report of the Association of American Colleges and Universities, K-12 schools often do not graduate college-ready students due to various factors, including new accountability demands (standards-based learning), an over-reliance on educational traditions, sub-standard curricula and poor resources[3]. Through a comprehensive K-12 engineering curricular experience, all students, including those typically underrepresented in engineering — women and students of color — can be exposed to the possibilities of engineering and technology as lifelong pursuits.



Newton Rocket Car

Students can effectively learn and integrate math and science concepts through applied engineering lessons that incorporate hands-on activities. For example, the Newton Rocket Car activity provides an excellent demonstration of Isaac Newton's 3rd Law of Motion, illustrating in an understandable way that for every action there is an equal and opposite reaction. The rocket car moves with rubber bands attached to nails and pulled taut with string, to slingshot a wooden block filled with lead sinkers (weights). As the rubber band is released, the block moves in one direction, and the car moves in the opposite direction. By repeated trials of this design/build activity, it becomes clear to students that the distance the car travels depends on the number of rubber bands used and the mass of the block being expelled. By adding sinkers to the block, the mass of the block is increased; or by adding rubber bands, the acceleration of the block increases. In both cases (thanks to Newton's 2nd Law: F=ma), the force on the rocket car is increased, and it will travel farther. In this engineering-based activity, students can graph the mass of the block vs. the distance the car travels — an exercise that helps students grasp the engineering connection between math and basic laws of science when designing and building a Newton Rocket Car.

Incorporating hands-on activities, such as the Newton Rocket Car, into a lesson plan and, further, into a multi-week, multi-lesson curricular unit, the ITL Program's goals are to create a practical, hands-on, applied engineering curricula for use in K-12 classrooms. The intended outcomes include a positive impact on K-12 students' content knowledge and career awareness while creating curricular resources that can and will be readily adopted by teachers. Following is a description of the curriculum development process — planning, research, testing, documentation, refining and assessment — that can be readily adapted to other curriculum initiatives.

Overview of K-12 Outreach Program

The ITL engineering outreach program at the University of Colorado at Boulder (CU) is dedicated to the seamless integration of engineering education and experiences into the K-12 community, guided by the following vision statement:

"To create a K-16 learning community in which students, K-12 teachers and the College of Engineering and Applied Science explore, through hands-on doing, the role of engineering and innovation in everyday life. And, to appreciate and apply the art of engineering through designing and building solutions to meet the needs of society[1]."

One component of the ITL's outreach program engages engineering undergraduate and graduate students in elementary, middle and high school classrooms to serve as engineering role models in K-12 science, math and technology classes. This e*ngineering in everyday life* initiative supplements the development of standards-based scientific, mathematic and technological curricula focused on engineering and pre-college mathematics. Additionally, various summer K-12 teacher and student workshops that apply engineering and design principles to "fun" topics — such as air pollution, mechanics, robotics, flight, and invention — offer an inquiry-based approach to teaching both older, and younger, potential engineers.

The preparation and guidance of elementary, middle and high school students — especially those with backgrounds typically under-represented in engineering — towards the university engineering and technology pipeline is an overarching goal of our outreach initiatives. During the course of various summer resident camps focused on design/build projects, students are introduced to the world of engineering and the iterative design/build process, including use of technological tools.

Curriculum Development Partners

Integral to a successful curriculum development process is a diverse team of contributors. We have found that review of lesson and activity background materials, procedures and documentation by someone other than the original author contributes to a higher quality product.

Engineering graduate student Fellows provide the bulk of the research and writing of lesson plans that focus on specific engineering topics relevant to the science and math subjects for which K-12 teachers are accountable. The Fellows work closely with the teachers to develop relevant, age-appropriate hands-on activities and support materials. Engineering *undergraduate students* test activities before they are implemented in classrooms.

K-12 teachers are vital to the curriculum development process. Partnerships with teachers are best formed early in the process to ensure the suitability of the curricular materials. Teachers select the curricular topics to be developed by Fellows, and work closely with the Fellows. In addition, teachers can be helpful in writing and reviewing the literacy, math and age-appropriateness of the curriculum.

University engineering faculty serve as mentors to the Fellows and provide technical content review of the lesson plans and activities.

The *outreach program staff*, including experts in the areas of education assessment, project coordination, classroom teaching and supervision, coordinate and supervise all partners.

Curriculum Development Staffing

The curriculum development process is demanding, intellectually intense and time consuming. Recruitment through flyers and posters distributed throughout the college, and/or contacts with college faculty who value K-12 outreach is a proven way to attract top-notch students from all engineering disciplines. Successful selection criteria should include a strong academic record, a commitment to the program as evidenced by a personal statement and experience working with youth[5]. To secure the commitment of engineering graduate students, the ITL engineering outreach program offered fellowship appointments that paid a stipend, tuition and partial benefits. Engineering undergraduate student assistants were appointed for ~10 hours per week at an hourly wage. K-12 teachers with a strong background in math, science, technology and/or engineering were compensated hourly for their contributions, while engineering faculty were paid modest honoraria for their participation in the curriculum development initiative. Lastly, an hourly consulting fee was paid to engage math, literacy and assessment specialists. Many funding sources exist to support K-12 outreach programs, although the funding for any given program is typically quilted together from multiple sources. The ITL's outreach initiative is supported through various funding partners, including NSF and DOE FIPSE grants, a Colorado state *Program of*

Elementary children learning — and enjoying — hands-on engineering activities.

Excellence award, and numerous smaller foundation and private gifts from college alumni.

Recruiting students, faculty and teachers who desire to be part of a systemic pedagogical reform initiative are vital to program success. It is recommend that individuals who possess an interest or track record in education and/or teaching be engaged in the project.

A training program, and clear and timely communication, is key to team-based curriculum development cohesiveness. Training workshops for Fellows provided assistance in educational pedagogy topics, such as assessment, classroom management, learning and teaching styles, and state and national K-12 educational standards. Communication includes weekly group meetings, regular individual progress discussions and weekly reporting by Fellows.

The Curriculum Development Process

An involved, multi-step process was implemented to develop high-quality, meaningful and engaging K-12 engineering curricula for use by teachers. See Table 1 for descriptions of the steps in the process.

Table 1. Summary of the steps in the curriculum development process.

Curriculum Development Process Steps	Brief Description
Develop detailed lesson plan template	Create a structured common template of lesson plan components to assure document consistency.
Select curriculum unit topics	Choose curriculum topics mutually relevant for teachers and students; collaboratively between curriculum developers and K-12 teachers.
Research topics: Curricular Unit → Lessons → Hands-on activities	Investigate conceptual background for unit topics, ensuring the appropriateness of hands-on activities with an engineering context to support each lesson.
Populate document	Populate lesson template with coherent and motivating content under each component.
Review for: • Completeness • Activity testing • Content accuracy • Assessment tools • Math and literacy • Copyright permissions	Complete a multi-faceted review process in which numerous partners contribute to a thorough and independent review for completeness and content accuracy.
In-classroom testing	Test lessons and activities in a K-12 classroom setting.
Revision and refinement	Incorporate changes, improvements and suggestions gathered from in-classroom testing and teacher input; check for technical correctness and final formatting.

Ongoing Sustainability Steps	Brief Description
Teacher training	Teach summer, continuing education workshops to support in-classroom implementation.
On-line curricula	Disseminate curricula (to become available in 2004 through web-based, NSF-funded digital library at *TeachEngineering.com)*.
Engineering Outreach Corps	Offer a yearlong, for-credit technical elective for undergraduate engineering students, using the digital curriculum collection in K-12 classrooms (to be piloted AY 2003-04).

Lesson Plan Template and Contents

The first step in creating useful and engaging hands-on curricula is to define a lesson plan template. This is best done cooperatively between teachers, graduate Fellows and outreach personnel who have experience in the classroom. The template is key to creating consistent lesson plans to which many original authors are contributing. A well-defined template provides the Fellows with structure and enables them to concentrate on research and writing of content rather than on organizational or aesthetic formatting. To clarify expectations, we recommend Fellows be provided with a completed sample lesson plan before they begin to create lessons.

At a minimum, components that K-12 educators agree comprise a standard lesson plan include:
- **Educational standards** that map to lesson content;
- **Anticipated student outcomes** to clarify the learning objectives of the lesson;
- **Introduction/Motivation** for piquing the students' interest in the lesson;
- **Detailed background information** for the teacher to review and understand;
- **Hands-on, inquiry-based activities** that are age-appropriate and interesting to students;
- **Closure** to conclude the activity and encourage rethinking of the process;
- **Embedded assessment** to determine the effectiveness of the lesson plan and to ascertain if the students "got it;" and
- **Extension activities** to provide additional critical-thinking opportunities for the students.

Many additional template components are included in the completed lesson plans developed by the ITL Program, such as vocabulary lists, activity completion time, supplies and equipment lists, costs, activity attachments and worksheets, safety issues, troubleshooting tips, scaling for high/lower level grades, and visual or multimedia elements. For added student comprehension, it is ideal for K-12 engineering lessons to include integrated math and literacy components as well. Responding to teacher input, hands-on activities are best if they are inexpensive for teachers to implement (less than $20/class per activity). Lesson plan examples may be found at http://itll.colorado.edu/teachengineering.

Content in the lesson plan should be straightforward for teachers and engaging for the students. Lesson plans that are too complicated discourage teachers from reading further. The lesson plans must be age-appropriate and relevant to the level of the student as well. For curriculum developers unfamiliar with age-appropriate levels, this relevance can be accomplished by making sure that the lessons are mapped to state and national science, math and technology educational standards, such as the Colorado Department of Education's standards[4], which are created by experts in education and developmental psychology. State educational standards may be found on state Departments of Education web sites. National education content standards for science, developed by the National Committee on Science Education Standards and Assessment, may be found in *National Science Education Standards*[6]. Math standards, created by the National Council of Teachers of Mathematics, can be found in *Principles and Standards for School Mathmatics*[7].

Curricular Unit Topic Selection

Unit topic selection is an important step in the process that can influence whether the curricula will ultimately find a place in K-12 education. We suggest determining which grade levels will be targeted and seeking teacher assistance for clarification. For ease of integration, unit topic selection should enhance what is already required and currently taught in the specific grade-level classrooms. Teachers are an excellent resource for identifying relevant topics; also examine national and state science, math and technology educational standards to learn the grade-specific educational expectations.

Successful unit topics will be mutually relevant to all the partners involved (topics teachers are required to teach, and that engineering students and faculty have the expertise to support), as well as to the underlying outreach program. For example, an engineering-focused unit on rockets, supported by aerospace engineering students and faculty, could meet the need for a six-week Laws of Motion unit for 4th grade students. Such a curriculum would also be suitable for summer teachers' and kids' workshops using the same theoretical background materials and hands-on activities.

Topic Research

Once unit topics are determined, graduate Fellows investigate the broad concepts associated with the topic. From this investigation, a sequential outline of lesson plans is formed, resulting in a multi-week unit that covers a topic in depth. Each unit contains numerous lessons, with supporting inquiry-based, hands-on activities. For example, a curricular unit on the environment might be comprised of 8-10 lesson topics such as natural resources and water pollution, each including numerous hands-on activities. In this fashion, engineering topics provide the context for integrating math and science fundamentals, including energy, laws of motion, electricity and magnetism, and environmental science.

Teachers are the most-informed resource for what will be interesting and useful for their students. Research is necessary to locate existing activities and obtain use permission from copyrighted sources and fill template holes pertaining to the lesson topics. Faculty members can suggest appropriate activities and research resources. The unique value added by engineering students and faculty is an engineering connection that makes theoretical science concepts become "real world" and relevant to K-12 teachers and students, as well as opens up the world of engineering to them.

Creation of Curricular Contents

Once Fellows have completed initial research on a topic, the background and motivating concepts for each lesson plan are composed. This step is followed by populating the remaining template sections. Fellows should add any supporting visual or multimedia elements (photos, diagrams, animations, etc.) that they found during their research — items that will give teachers visual aids for their in-classroom presentation to students.

This curriculum development stage requires creative thinking and effective writing skills to develop a document that is coherent and motivating while completing document sections that may be unfamiliar to the authors (i.e., a section on lesson closure is not usually second-nature for an engineering student).

Review Process

Once an author has completed populating the lesson plan template, a thorough review process is necessary. We suggest an approach where Fellows document the lesson plans on a shared computer network that allows for access to the electronic files by all partners and reviewers, if possible. Various types of reviews that ensure quality of contents include:

- Initial review to assure template component completeness,
- Activity review and third-party testing,
- Review of contents for scientific and mathematical accuracy,
- Embedded assessment review,
- Math and literacy review, and
- Copyright permissions.

Reviewers must be accomplished in the specific area of the curriculum they will evaluate. For example, we ask an electrical engineering professor to review lessons on electricity and magnetism. Undergraduate Fellows test activities and refine the written activity set-up and procedures. This is a good time to generate photographs and diagrams of the activity set-up and procedures, define supplies and equipment lists, estimate costs and add troubleshooting tips.

Permissions to use copyrighted materials — for borrowed *or* adapted materials — from outside sources must be properly obtained prior to in-classroom testing and final review. It is a good idea to retain proof of permission should questions arise in the future. This review step should include a precise check that for every borrowed and adapted source, permission for use exists.

In-Classroom Testing

Once lessons are complete and have been initially reviewed, in-classroom testing begins. Partnering with K-12 teachers, Fellows test lessons and activities in school classrooms, led by either the Fellow or teacher. Fellows critically observe the lesson implementation and ask for feedback from teachers and students. The opportunity for graduate students to teach the lessons in a real classroom setting can also provide an instructional tutorial for the teachers in the presentation of in-depth content material.

Final Review and Revision

Final review and revision occurs after classroom testing. This stage incorporates changes, improvements and suggestions gathered from in-classroom testing and teacher input. Lastly, the document is reviewed for technical accuracy, copyright permissions and aesthetic formatting.

Ongoing Coordination and Supervision

A demanding component of the curriculum development process is the ongoing supervision of the many partners involved in the creation and review of lesson plans. The outreach staff spends a great amount of time organizing and tracking the progress of individual lesson plans and their associated activities. A complex matrix facilitates tracking of the review progress. Without such coordination and supervision, lesson plan development can languish. Occasionally, individual authors become discouraged and suffer "writer's block," requiring help to jump-start progress. Open communication between project coordinators and Fellows allows for discussion of problems and transfer of knowledge between authors (i.e., share lessons learned while developing curriculum).

Assessment and Evaluation

Assessment of any curriculum development process is essential to inform continuous improvement. To evaluate the usefulness of the overall curriculum for K-12 teachers and students, as well as engineering faculty who want to initiate outreach with their local schools, various assessment tools are available. The ITL Outreach Program employed the expertise of a post-doctoral educational psychologist for development of its initial K-12 assessment components[8], as well as the mastery approaches suggested by Kagan[9]. Some of these assessment strategies help to identify the usefulness of the curriculum development process for teachers.

The ITL held a focus group for participating teachers to determine how the curriculum templates should be designed and what topics would be of most interest to the teachers and students. For example, we learned that the curricular topics must overlap almost completely with those subjects for which teachers are held accountable — e.g., those subjects that meet their district educational standards — in order for teachers to realistically have the time for implementation. Mid-year and year-end surveys were also administered to teachers and principals to determine the effectiveness of the curriculum in classroom settings throughout the year.

To assess student learning within curricular units, embedded assessment tools, such as discussion questions, two-minute response written feedback, and journal entries are incorporated in the assessment component of the lesson plan template. Lastly, student reaction to the curriculum can be measured through pre/post self-rated skills and attitude surveys, pre/post content testing and student focus groups.

To learn whether or not engineering faculty would use the K-12 engineering curriculum to independently partner with their local schools, focus groups or open-ended questionnaires can provide insights. Additionally, pilot initiatives could be evaluated.

To determine a program's success, the impact on the individuals involved should also be taken into consideration. To acquire some of this information, we host a mid-year focus group of participating Fellows to obtain feedback on questions such as: Why did you get involved in the program? What do you feel you are getting out of the curriculum development project? What effect do you think you are having in the classroom? Anonymous surveys are another excellent method for assessing the program's impact on the collaborators.

Sustainability

Creation of effective curriculum does little to assure its ongoing implementation. Therefore, creating a *sustainable* resource should be of utmost importance in any curriculum development initiative. Systemic pedagogical reform can best succeed if a new curriculum is implemented in a sustainable fashion and becomes institutionalized within a school or district.

Teacher training to support in-classroom implementation is therefore an important aspect of the curriculum development process. The ITL Program conducts two-day summer teacher workshops specific to a curricular unit, as a way for teachers to gain confidence in and knowledge of a curricular unit prior to bringing it into their classrooms.

Sustainability can also be assisted via broad dissemination on the Internet, providing "one-stop shopping" for teachers seeking innovative, inquiry-based approaches to integrating the teaching of math and science. Available summer 2004, a searchable, web-based digital library — *TeachEngineering.com* — populated with standards-based K-12 curricula will be available for use by engineering faculty and K-12 teachers to teach engineering in K-12 settings. The university partners creating this NSF-funded digital library collection include the University of Colorado, Tufts University, Colorado School of Mines, Duke University and Oregon State University. Through the *TeachEngineering* resource, K-12 teachers and engineering faculty nationwide will have access to this curricular collection. The contents of the digital library will evolve under the stewardship of the American Society for Engineering Education, with the continual addition of new curricula from other contributors.

Community involvement is vital to promoting the use of a newly developed curriculum, subsequently contributing to its sustainability. The University of Colorado intends to pilot an Engineering Outreach Corps that will be comprised of upper-class undergraduate engineering students who enroll in a yearlong, for-credit, service-learning engineering technical elective. Using the curricula from the *TeachEngineering* digital library, corps students will team with partner teachers to teach engineering in K-12 classrooms on a weekly basis throughout the academic year, serving as engineer role models, and educating today's youth to envision and prepare themselves to pursue a future in science, engineering or technology.

Lessons Learned

We have learned during the past three years that the curriculum development process is much more complex than initially imagined, and requires tenacious monitoring to ensure quality results. Collaborator accountability is essential to keep the initiative on track and maintain a realistic completion schedule.

Solidifying early teacher participation and commitment is essential. Educators are an invaluable link between the vision of an engineering pedagogy reform initiative and the K-12 teaching community, who will ultimately implement the curriculum for years to come. Teachers provide first-hand, expert knowledge of topics, materials and approaches that are relevant for teachers and interesting for students. With vested interest by teachers who are committed to the initiative, the curriculum development process can succeed. To assume that such a project could thrive without input from K-12 teachers would be a catastrophic mistake.

Conclusion

The process associated with developing standards-based, engineering-focused curricula involves a wide partnership of engineering graduate and undergraduate students, engineering faculty and K-12 teachers coupled with a dedicated and motivated project team. The process includes key logistical elements: recruitment of strong collaborators, a well-honed lesson plan template, creative translation of engineering concepts to age-appropriate science and math lessons and activities, a comprehensive and organized review process, meaningful assessment approaches, and a strategy for sustainability.

Well-developed engineering-based curriculum is a modern inquiry-based instrument for integrating science, math and technology in the K-12 setting. Incorporating into a student's K-12 experiences a sound curriculum that demonstrates real-life applications of engineering in everyday life provides lessons important for all future citizens, as well as potential engineers. Through these experiences of hands-on lessons and activities, today's youth become cognizant of a broad range of career options. Just before the abrupt decline in the information technology sector, it was estimated that more than 900,000 (information technology) jobs were unfilled[2]. Additionally, the number of graduating engineers has significantly declined since peaking in the mid-1980's[10]. Clearly, the need exists to make young students aware of technology and engineering career paths. Opening the doors early to alternate educational avenues for young students is vital to the technological progress and economic competitiveness of our nation.

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Biography

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