

From BEEVT to DLR – NSF Supported Engineering Education Projects at Virginia Tech

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Abstract

This paper briefly discusses the motivating factors that led to formation of an active collaborative group of engineering and education faculty at Virginia Tech. This group is actively pursuing a number of engineering education research activities and has been successful in winning two grants from the NSF in first 12 months of their collaborative efforts. These collaborative activities are targeted at improving engineering pedagogy at Virginia Tech and began with a planning grant from the NSF in September 2003. A 15-month Masters/Licensure program has been developed specifically for licensing engineering graduates in Technology Education. A number of assessment activities have been initiated for analyzing curricular changes beginning with the freshman-engineering program. Use of electronic portfolio in engineering instruction is being explored. The curricula of freshman engineering and bioprocess engineering are being reformulated using a theme based spiral curriculum approach, which is part of a major research grant, under the Department-level reform program of the NSF, that began in September '04. The interdisciplinary group has developed/ is working on a number of research proposals for expanding the scope of ongoing studies. The information presented should be very useful for new engineering educators who are exploring similar collaborative ventures elsewhere.

Background

On May 17, 2004 the Division of Engineering Fundamentals, responsible for teaching freshman engineering courses within the College of Engineering (COE) at Virginia Tech, officially was renamed the Department of Engineering Education (EngE). The EngE department is one of two such departments in the country and continues to offer the freshman (first-year) engineering program, which is also called the General Engineering (GE) program. Students transfer to eleven degree-granting departments after successful completion of the GE program. Although the formal announcement of the creation of EngE department was made in May 2004, engineering education efforts began when Hassan Aref joined the COE as dean in April 2003. His leadership

resulted in two changes: i) Computer Science (CS) Department became part of the COE and ii) More emphasis was placed on engineering education research activities in the COE. While the first change resulted in major changes in the introductory engineering courses in the GE program, the second change brought together a group of faculty members from engineering and education departments to build a collaborative group charged to develop research proposals targeted at improving engineering pedagogy in the COE. This group has already had some early successes in a short period of less than two years. This paper presents information on how the collaboration began, the current status of collaborative activities, and a summary of early outcomes. We believe this information should be useful for new engineering educators interested in pursuing similar collaborative activities elsewhere.

The collaboration startup—bridges for engineering education: Virginia Tech (BEEVT)

In spring 2003, the National Science Foundation (NSF) published a solicitation for their “Bridges for Engineering Education (BEE)” program. This presented a perfect opportunity to EngE faculty to collaborate with colleagues in the School of Education in developing a proposal to initiate engineering education scholarly activities. In their first few meetings together, the education faculty began learning about ABET2000 A-K, and the engineering faculty received a crash course on the intricacies of teacher licensure regulations. The engineering faculty learned of the new *Standards for Technological Literacy*¹, developed by the International Technology Education Association and reviewed/endorsed by the National Academy of Engineering. The education faculty, in turn, learned of the innovative engineering design activities that the EngE faculty were implementing in their first year curriculum, which were similar in nature to those commonly used in secondary level Technology Education programs. As they began to get to know each other, both sides discovered commonalities and common interests. It was the beginning of a new Virginia Tech (VT) engineering/education collaboration that was *completely unfathomable* a year earlier.

Since NSF’s intent with the “Bridges” solicitation was, in part, to improve engineering pedagogy, the group quickly expanded to include two educational psychologists. One was Director of VT’s Center for Excellence in Undergraduate Teaching, who already had working experience with some engineering faculty on issues relating to pedagogy. The other was the Director of the new School of Education. This working group thus had a good balance of engineering and education faculty who were eager to work together on a proposal they felt had great potential for fostering long-lasting collaboration. To start with, the group put together a 2-page prospectus outlining the goal and objectives (see Table 1) of a proposal the group was planning on submitting to the NSF and sent this prospectus to the BEE program officials at NSF. The group then visited the NSF to discuss their ideas with program officials. The group benefited a lot from the NSF visit and ended up re-writing goal/objectives of the project in light of suggestions made by NSF program officials (see Table 2). It can be seen in tables 1 and 2 that the proposal objectives became more focused / meaningful as a result of our discussions at the NSF. Therefore, the authors will strongly suggest new engineering educators to consider discussing their proposal ideas with concerned program officials at funding agencies before spending too much time in developing the detailed proposal.

Table 1: Goal and objectives of BEEVT proposal before visiting NSF

Goal: The goal of the project is to develop long-lasting collaborative relationships among Engineering and Education faculty at Virginia Tech to enhance K-16 engineering education / technology education in Virginia and elsewhere. The specific objectives of the project are to:
<ul style="list-style-type: none">• Evaluate the current status and future potential of engineering–education collaborations intended to promote the use of new pedagogy, assessment, and learning theory in K-16 engineering education / technology education;• Propose ways to increase engineering content in K-12 education;• Identify corporate and other partners in support of these collaborative efforts; and• Develop new curriculum and licensure options for engineering students leading to K-12 technology education teaching opportunities.

Table 2: Goal and objectives of BEEVT proposal after visiting NSF

Goal: The goal of the project is to initiate long-lasting collaborative relationships among Virginia Tech Engineering and Education faculty, K-12 educators, corporations, and policy/decision makers throughout Virginia. The specific objectives of the project are to:
<ul style="list-style-type: none">• develop a new Technology Education Masters / Teaching Licensure option for engineering graduates,• create a contemporary framework for undergraduate engineering pedagogy, beginning with the freshman engineering experiences, and• initiate the Virginia Engineering / Education Collaborative to ensure stakeholders' ownership of project outcomes.”

The group submitted BEEVT proposal in June '03 and was awarded funds in September 2003. The investigators formed subcommittees to address each of the objectives noted in Table 2. A brief description of progress made to date is given in following sections.

Masters/Licensure program

Both EngE and Technology Education saw potential in developing a new masters/licensure program in Technology Education. Because Virginia Tech had decided in Spring 2003 to phase out all *undergraduate* teacher education, the Technology Education program saw a masters/licensure program as its only means of licensing Technology teachers for grades 6-12 in the future. The EngE program felt this fifth year licensure option would help to retain some students who might otherwise leave engineering for another major. A recent survey for prospective Engineering Education graduate students posted on the EngE program Web site seems to validate that notion. Of the 67 respondents to that survey, 39% expressed interest in teaching engineering at the secondary school level. It's estimated there are more than three secondary school level Technology Education positions open for every newly licensed technology teacher, virtually guaranteeing employment for licensed Technology Education teachers^{1a}.

As engineering programs look for ways to “connect” with education programs, collaboration with Technology Education programs on new K-12 licensure programs is an option to consider. Because women comprise the majority of public school teachers in the US, women studying engineering may be more likely to enroll in and complete an engineering degree if an option for Technology Education teaching licensure exists. The idea of graduating engineers who go on to

teach engineering content in grades 6-12, is highly consistent with the long-range goals of engineering education. ASEE's new K-12 Division is further reason why engineering programs and faculty developing new education research agendas should consider entering into this sort of collaboration with Technology Education teacher education programs.

For these reasons, and in accordance with the BEEVT proposal, a subcommittee was formulated to develop a new "Technology Education Masters/ Licensure Program" (TEMLP). This group consisted of one TE faculty member, one Engineering Education (EngE) faculty, one civil and environmental (CEE) faculty, and an educational psychology faculty member (who soon thereafter became Director of our School of Education). The new Technology Education Masters / Licensure Program (TEMLP) that evolved from those discussions is an option to which graduates with baccalaureate degrees in engineering, architecture, design, or physics may be admitted². We believe this to be the first graduate program tailored specifically for licensing *engineering graduates* in Technology Education. As more engineering graduates learn of this new licensure option, we believe it will attract a small, but important, percentage of engineering graduates who are looking for different ways to use their engineering degree. This option will be particularly attractive to engineers interested in making a career change, a group that has always shown interest in TE, but has not heretofore had access to a licensure program tailored to their specific needs. Engineers choosing this option will be ideally suited to carry out the goals and ideals outlined by the mission statement for the ASEE's new K12 Engineering Education Division, as well as those enumerated in great detail in the ITEA's *Standards for Technological Literacy: Content for the Study of Technology*.

The TEMLP is an intense 15-month program, with full time coursework throughout two summers and the academic year between. Students beginning in May earn a masters degree *and* Technology Education licensure the following summer. Their coursework includes:

- 19 semester hours of Technology Education courses that introduce students to Technology Education's culture, technical content, and pedagogy;
- 18 semester hours of education/pedagogy/research, including courses in curriculum, instructional methods, educational psychology, social foundations of education, and educational research);
- 11 semester hours (300 contact hours) of clinical experiences, including a semester of internship in education and a 10-week student teaching experience;
- Optional Engineering Education graduate coursework

Although the new TE Masters/Licensure Program wasn't advertised until the spring of 2004, five students were enrolled in the program in May 2004. One (design major) left the program mid-summer for an Art Education masters/licensure program. The other four have done very well; three will teach in spring 2005, while the fourth has taken a leave this academic year. Because the demand for licensed Technology teachers is so remarkable, each of these graduates will have an endless number of teaching positions/opportunities from which to select. Virginia's teaching reciprocity with 48 states means this "seller's market" is a nationwide phenomenon.

Contemporary framework for undergraduate engineering pedagogy

BEEVT investigators launched a number of data collection activities with objectives to analyze changes in GE curriculum and develop assessment tools. A brief description follows.

Departmental feedback system

A Web-based departmental feedback system, targeted at receiving systematic and regular feedback from the degree-granting departments regarding the contents of the first three semesters of engineering courses, has been developed³. This system allows a user to design freshman and first semester sophomore engineering courses by choosing topics (programming, communications, ethics, CAD, graphing, design, profession, and problem solving) from an available set and allocate them to one of 42 weeks comprising the first year and a half of the students' education. A group of BEEVT investigators held a meeting with various Assistant Department Heads in fall 2003 and explained the purpose and operation of this feedback tool, which is now available to entire COE faculty through BEEVT web site (www.beevt.ef.vt.edu). All faculty members have been requested to use this online tool to give their feedback.

Analysis of retention and other data for engineering cohorts

At Virginia Tech, students' GPA, retention, graduation, and intra-college migration data are maintained online by the Institutional Research and Planning Analysis department. However, this information is not available in the form that can be readily used or interpreted. Two undergraduate students collected and processed data for several engineering cohorts to analyze GPA trends, graduation rates, and intra-college migration. The processed information is made available through BEEVT web site. Currently, due to the IRB approval limitation, complete details of the analysis are restricted to Virginia Tech users and will be made available to the public in the future. Some conclusions from this analysis include the following. On an average, the rate of graduation from engineering after 6 years of enrollment decreased from 64% for 1994 cohort to 53% for 1996 cohort. The decline is mainly attributed to a group of students that were admitted to the provisional general engineering (PGE) program begun in the fall of 1994 to address the declining enrollments and was discontinued after fall 1999. The PGE students typically lacked math and physics background and did remedial courses before starting regular engineering courses. Further, on an average, 18% of students who enter engineering program have graduated from another college at Virginia Tech after 6 years.

Development of a continual assessment scheme

One of the major weaknesses in the existing GE program has been the lack of appropriate tools that can be used to assess effectiveness of changes in curriculum. In the past, the success or failure of various curricular changes was assessed based on anecdotal evidence. The BEEVT project facilitated collaboration between engineering faculty and experts in assessment and pedagogy for initiating development of appropriate assessment tools. Currently, a number of activities are underway, which are expected to develop scientific assessment tools/databases for assessing changes in the GE program. A brief description follows.

Use of Electronic Portfolio (e-Portfolio)

The beginning of BEEVT project coincided with a university-wide pilot study exploring the use of an electronic portfolio system. A sub-committee of BEEVT investigators, representing faculty members in engineering and education psychology, developed plans for the participation of engineering students, ranging from freshman to graduate levels, in the university-wide Virginia Tech Electronic Portfolio (VTeP) pilot study. VTeP enables students to easily create,

manage, and share Web-accessible electronic portfolios that document their knowledge, skills, and achievements from coursework and from extracurricular activities. Five BEEVT investigators (all faculty in the COE) and 28 engineering students working with these faculty members participated in the pilot in fall 2003⁴. Based on the experiences of investigators in fall '03, guidelines were developed for introducing e-portfolios for all engineering freshmen in fall '04. As a result, the VTeP was integrated into the in fall 2004 first semester Engineering Exploration (EngE1024) course with the goals of helping the students see the relevance of all engineering coursework, providing a foundation for life-long learning through reflection, and setting the stage for the thoughtful collection of artifacts to support both student learning and program assessment. We believe this to be the largest single application of e-portfolios in engineering instruction. A companion paper gives details of e-portfolio experiences in fall '04⁵.

Engineering Education New Student Survey

The Engineering Education New Student Survey is a locally-developed, on-going study of students' academic backgrounds prior to enrolling at Virginia Tech as well as the experiences that they have had involving technology. One of the main purposes of this survey is to determine what behaviors are most likely to lead to student success and failure in engineering courses. All engineering freshmen completed this survey in fall '04.

Student Computer Attitudes Survey

The Student Computer Attitudes Survey is adapted from one developed by an external group⁶ of researchers with whom EngE faculty are collaborating. It gathers data on student attitudes towards computers and related technology and has the potential to identify attitudes, which might predict success in engineering in general and particularly in those courses or course segments focused on computing. This survey was also administered in fall '04.

Student Background Data survey

The Student Background Data survey is adapted from another instrument developed by our collaborators⁶ and focuses on demographics and some experiential variables, again with the intent to use both to predict academic performance using non-academic independent variables as predictors. Engineering freshmen completed this survey too in fall '04.

Alice Surveys

Starting fall '04, Alice, an object oriented programming language, available freely from Carnegie Mellon University (www.alice.org), is being taught in the first semester "Engineering Exploration, EngE1024" course at Virginia Tech. Alice replaced MATLAB, a procedural programming language, in this introductory course. A Programming Concepts Examination is adopted from our Alice collaborators to test the effectiveness of Alice instruction⁶. This Alice concepts examination, consisting of 19 Alice related multiple-choice questions, was administered as a pre- and post-test in fall '04. Analysis of results of this survey is in progress at the time of this writing. This is the first time a pre- and post-test strategy was employed by EngE faculty to test the effectiveness of engineering instruction in a freshman year course. Also, a survey of all instructors who taught Alice in fall '04 was done to obtain their feedback regarding Alice's

potential in teaching programming to engineering freshmen and problem solving concepts. Interested readers are advised to see a companion paper for details on Alice instruction⁷.

Development of proposals for implementing activities planned in BEEVT

A year and a half since its formation, the engineering-education group continues to meet several times/month working on the aforementioned goals, a variety of additional project proposals, and some very new and creative collaborative ideas. The level of activity in this new collaboration is very significant, with more than a handful of faculty from each side typically involved in the conversations and activities. A number of joint proposals targeted at implementing and extending engineering education research activities have been / are being funded/developed by the group since the beginning of BEEVT. A brief description follows.

Department-level reform (DLR) proposal

In January 2004, NSF published a request for proposal (RFP) for its department-level reform (DLR) program. Following the successful example of BEEVT, a group of BEEVT investigators put together another 2-page prospectus that identified goals, objectives, and activities planned under BEEVT and sent it to DLR program officials at NSF (see Table 3). The group then visited the NSF to discuss the proposed goal and objectives. During the meeting the group quickly realized that the DLR program was meant to reform entire engineering curriculum of an engineering discipline (say, civil engineering) and proposing reformulation of only freshman year program, which is what the investigators had proposed in their prospectus, would not meet RFP's requirements (see table 3). The investigators were advised by NSF officials to modify the proposed approach by including curriculum of one of the engineering departments along with freshman-engineering curriculum. The faculty of Bioprocess Engineering option within Biological Systems Engineering (BSE) department expressed interest in working with BEEVT investigators and the goal and objectives of the DLR proposal were revised to reformulate GE and bioprocess engineering programs (see Table 4). Again, information listed in tables 3 and 4 further emphasizes the importance of getting in touch with program officials to make sure what's being proposed fits the goal and objectives of the funding program. The DLR proposal was submitted in March 2004 and in September 2004, the EngE-BSE-Education group received almost a 1-million dollars award (Sep. '04 – Aug. '07) from the NSF to reformulate the GE and bioprocess engineering curricula.

Table 3: Goal and objectives of DLR proposal before visiting NSF

The major goal of this implementation proposal is to enhance the engineering program offered by the Engineering Fundamentals division at Virginia Tech. In support of the goal, the specific objectives are to:

1. Reformulate the existing freshman engineering curriculum by: (i) introducing modern learning practices, (ii) incorporating new laboratory experiences, (iii) integrating powerful software tools using an object oriented approach in engineering design, (iv) incorporating research experiences including use of National Scientific Digital Library (NSDL) to promote inquiry based learning outcomes, and (v) emphasizing communication and interpersonal skills,
2. Develop an assessment scheme to assess the effectiveness of the enhanced program, and
3. Develop a Master in Engineering Education program

Table 4: Goal and objectives of DLR proposal after visiting NSF

<p>The goal of this implementation proposal is to undertake department level reform of the General Engineering (GE) and the Bioprocess Engineering option within the Biological Systems Engineering (BSE) at Virginia Tech. The specific objectives are to:</p> <ol style="list-style-type: none">1. Reformulate the existing General Engineering and Bioprocess Engineering curricula using theme-based spiral curriculum design and improved pedagogical methods,2. Train faculty in the use of learning centered pedagogical techniques,3. Develop a continual assessment plan to measure the impact of the reformulated curricula, faculty improvement activities, and student learning, and,4. Disseminate the results of the curricular reformulation and pedagogical changes to peers within and outside Virginia Tech.

This DLR proposal aims to develop crucial linkages between the GE curriculum and the curricula in engineering departments using the concept of spiral curriculum. Six EngE faculty and seven faculty members in the Biological Systems Engineering (BSE) department collaborated with experts in educational psychology and academic assessment and three faculty members in other engineering departments to develop this proposal. The Bioprocess Engineering option within BSE was selected because it is a relatively new program in the emerging field of biotechnology. Since the creation of the Bioprocess Engineering option about five years ago, the student enrollment in this option has increased in size from about 5 students to 20 students and it is expected that enrollment will double within the next few years. This rapid growth has provided the faculty with new educational challenges and a perfect opportunity to collaborate with the ENGE faculty to work on curriculum reforms. The proposed reforms include adopting the concept of spiral curriculum for linking GE curriculum with the Bioprocess Engineering curriculum. The twentieth century psychologist, Jerome Bruner, proposed the concept of the spiral curriculum in his classic work “The Process of Education.”⁸ Bruner advocates that a curriculum as it develops should revisit the basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them. Further, he proposes structuring a curriculum around the great issues, principles, and values that a society deems worthy of the continual concern to its members. In the proposed GE – BSE curricula reformulation, a theme of sustainability has been selected to provide a contextual framework. The supporting principles of design, ethics, and a systems approach and cross-cutting skills of communication, teamwork, life-long learning, research experience, and lab experience will be woven throughout the curricula. In the reformulated GE and Bioprocess Engineering curricula, students will apply the supporting principles of engineering (design, ethics, systems approach, etc.) to problems related to sustainability. During the freshmen year in GE program, theme related problems would be dealt with on a lower level or using simulation models like the Alice system and laboratory exercises that do not require upper level curriculum knowledge. As the student progresses through the curriculum, the same and new sustainability problems will be addressed with increasing sophistication using more recently acquired skills and knowledge from engineering and other courses.

The DLR investigators have already had eight meetings in first three months of the project to discuss the proposed spiral approach. In order to identify possible spiral threads between the freshman year engineering courses of GE program, offered by the EngE faculty, and the bioprocess engineering courses, offered by the BSE faculty, details of all courses have already

been discussed by the entire group. Three sub-groups of the investigators have been formed to initiate activities proposed in the project. For example, one sub-group is focused on determining use of e-portfolios in the bioprocess engineering curriculum. Another sub-group is considering various approaches to bring research-based activities in the freshman-year EngE1024 course. Three research problems from bioprocess program have been identified for introducing basic bioprocess related research issues to engineering freshmen in spring '04. In the 2nd week of January '05, the entire DLR group held a spiral curriculum work session, led by the educational psychologist of the group, to begin the process of developing theme based spiral curriculum. A theme of sustainability has been selected to provide a contextual framework for the proposed reformulation of the GE and BSE curricula. A faculty member, from Geological Sciences department, who is leading an active curriculum project that is based in part on the spiral concept, was invited to share her experiences. In preparation for this session, the educational psychologist of the group sent a memorandum to all investigators about a month in advance of the session asking a few specific questions so that all investigators are prepared for the discussion along with required supporting material like syllabi, projects, existing curriculum maps, etc. Some questions quoted from this memorandum are: "What is the scope of the academic domain that we have to work with? By this I mean the total number of credit hours and the existing courses and/or experiences that will be reshaped," "What is sustainability? What does it contain in terms of sub-themes? In what sense can it be used as the organizing framework for curriculum development?" "How can we engage students with the theme, beginning with authentic problems and problem situations that will be suited to students just beginning to explore the degree track they have selected?" "How are we going to track, document and report student progress?" This is for the first time faculty members in the EngE and BSE departments are examining their curricula with the assistance of experts in educational psychology and assessment. Successful implementation of this theme based spiral curriculum will be used as a model for incorporating similar reforms in other engineering departments in the College.

IGERT Proposal

Several BEEVT investigators (both engineering and education faculty) submitted a preliminary proposal for the Integrative Graduate Education and Research Traineeship Program (IGERT) of the NSF in April 2004. The primary objective was to develop an interdisciplinary doctoral program in engineering education. Although the proposal didn't get invited for final submission, it received very encouraging comments from the reviewers. A group of BEEVT investigators have already met with a couple of IGERT officials at NSF in Nov. '04 to discuss the re-submission plans. A proposal to develop an interdisciplinary Ph.D. program between the College of Engineering and the School of Education was submitted in February 2005.

TPC Proposal

The engineering-education group developed/submitted a proposal to NSF's Teacher Professional Continuum (TPC) Program in September '04. That proposal brought the group together to explore an entirely different set of ideas. It focused on four research questions that addressed issues of learning and pedagogy associated with engineering design activities and problem-solving instruction in engineering and technology education classes. Technological problem solving (AKA engineering design) has become the hallmark of the Technology Education curriculum in grades 6-12 over the past two decades. Similarly, engineering has increasingly

embraced design activities as a component of the curriculum. We therefore saw this common ground is an ideal venue for collaborative engineering/education research.

The TPC proposal connected us with a prominent cognitive scientist from another university—one of the premiere experts on problem solving in the country. When he learned how parallel our ideas were with the Science of Learning Center proposal he was directing (collaborative problem solving in the context of engineering design), he invited the VT Engineering/Education group to join the large international team he was assembling for that proposal writing effort.

Subsequently, he recruited one of our VT Engineering/Education team members to serve as one of the four Co-PIs on that proposal, to be submitted in Spring 2005. At the time of this writing, the group members are working on another proposal to be submitted to the ROLE program of NSF in first week of March 2005.

Summary

The paper presents useful information for any new engineering educators who are interested in collaboration with education faculty. The engineering / education collaboration at Virginia Tech that primarily began with BEEVT project in 2003 is yielding significant results. This interdisciplinary group has already submitted eight research proposals and contributed four conference presentations^{2,3,4,9} on their collaborative activities. Two investigators (one from engineering and another from education) are organizing two technical sessions on ‘engineering-education collaboration’ and ‘assessment in engineering education’ at an international conference that will be held in Taiwan in March ’05. They will also present a paper on their collaborative data collection and analysis work at this conference¹⁰. The group has received a major 3-year engineering education research grant from the NSF to improve engineering pedagogy using research in cognitive science and learning theory. It’s expected that this early success will encourage faculty members in other engineering and education departments to consider collaborative research with EngE faculty for improving engineering education. In fact, in November ’04 a group of DLR investigators were invited by the faculty in Aerospace and Ocean Engineering for developing the ‘education and outreach’ component of a preliminary proposal for setting up an Engineering Research Center at Virginia Tech. The proposal is currently under consideration at NSF.

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