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Developing Creativity and Multidisciplinary Approaches in Teaching Engineering Problem-solving*

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Engineering education is in need of innovative teaching and learning methods to improve the ability of our graduates to solve complex problems and to make explicit the connections between engineering and community or society. Multidisciplinary approaches can provide the synergy and spark the creativity required to develop workable solutions to the increasingly complex problems of today's society. The purpose of this paper is to detail some of the innovative teaching and learning methods in agricultural and biological engineering (ABE) that address these issues, including multidisciplinary problem-solving and tools for developing creativity.

Keywords: creativity; multidisciplinary teams; service-learning; portfolios; engineering poetry

INTRODUCTION

ENGINEERING EDUCATORS during the past 10 to 15 years have been increasingly encouraged to incorporate state-of-the-art teaching strategies into their curricula. Changes in accreditation strategies and the increased emphasis on educational issues through various funding channels have further encouraged the development of creative teaching and learning methods and materials.

In the US, the Accreditation Board of Engineering and Technology (ABET) is the organization responsible for monitoring, evaluating and certifying the quality of engineering (and related) education programmes.

The most recent criteria by which academic programmes are judged represent a shift in evaluation strategies from content-based evaluation to outcomes-based evaluation.

To maintain accreditation, programmes must demonstrate that students have mastered the basic tools of engineering practice and design. Agricultural and biological engineering (ABE) educators have responded to this mandate with significant educational innovations, including assessment strategies for learning across ABE curricula [1, 2, 3], innovative methods and approaches for teaching design [4, 5, 6], innovative design projects including a living laboratory [7, 8], hands-on instrumentation to mimic insect behaviour [9] and live animal habitats [10, 11], learning communities, in which ABE students live in the same dormitories on campus and take the same classes to fully integrate course work with the campus experience [12, 13] and service-learning, a teaching approach that requires students to master their learning objectives by working with a community partner to address a significant community need. For example, ABE students have worked with community partners to design and build playgrounds and outdoor classrooms for public schools [14–16] and to deal with an abandoned hazardous waste site for a local community [17].

Projects at The Ohio State University (OSU) and Louisiana State University (LSU) include:

- Teams without borders, such as
  - Pairing non-engineers from the College of Agriculture with engineering students to address management and design issues involving a local waste management problem;
  - Pairing freshmen and seniors in the same discipline but different universities to address different aspects of a habitat design problem;
  - Pairing engineering students across disciplines in technical writing with biological engineering students to write grant proposals to fund design projects in biological engineering;
  - Pairing student design teams with real-world clients.
- Tools for engaging the creative process in biological and agricultural engineering students, such as
  - A teaching module about engineering creativity following the example of Leonardo daVinci;
  - Student portfolios;

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– Mastering learning using a competency matrix;
– Engineering poetry contest.

CASE STUDIES

Teams without borders

The objectives of each of these student teams were:

(1) to enhance student learning;
(2) to provide a multidisciplinary team experience that replicated the type of work engineers will encounter in the real world;
(3) to address the multidisciplinary teaming educational outcome goal, Criteria 3d, set by the Accreditation Board of Engineering and Technology (ABET).

An additional set of goals in several of these examples was to provide both service-learning opportunities for the students and the local community.

Case study 1: pairing non-engineers with engineering students to address management and design issues involving a local waste management problem.

Courses linked: Food, Agricultural, and Biological Engineering (FABE) 650: Design of Waste Management Systems (OSU) and Agricultural Systems Management (ASM) 550: Pollution Control and Waste Utilization (OSU).

A unique opportunity exists for departments of agricultural and biological engineering which have two separate undergraduate degree programmes: engineering and non-engineering technology management (sometimes called agricultural mechanization or agricultural systems management). This juxtaposition of majors at The Ohio State University (OSU) Department of Food, Agricultural, and Biological Engineering allows implementation of multidisciplinary teaming exercises by building on the different strengths of the two majors.

At OSU, two professors (one an engineer and the other an environmental scientist) co-developed and co-taught an engineering course (FABE 650, four credit hours) and a technology management course (ASM 550, three credit hours) on the subject of waste management. These two courses attracted students from both departmental majors plus students from other departments (e.g. animal science, environmental science and public health) and working professionals (both engineers and managers) who registered for continuing education unit (CEU) credit or university credit.

Different textbooks were used for each course. Homework assignments, lab reports and exams were geared toward the learning objectives of each course. All students attended the same fundamentals classes; however, the engineering students also attended additional lectures, field trips and problem-solving sessions to learn engineering design aspects of the waste management systems being studied.

Team projects were interdisciplinary with non-engineering students tackling the management, construction and operations aspects while the engineering students handled the design. Projects have included developing waste treatment systems for a small rural community, mobile home park, food processing industry, truck stop, outlet mall, veterinary hospital, racetrack (horse or greyhound), fairgrounds, confined livestock facility (small and large), and companion animal boarding kennel. Each team's deliverable was a poster presented at a reception on the last day of class.

The first two years of offering these courses were challenging due to the different cultures and expectations of the diverse student populations, problems with team dynamics and the difficulty of coordination between two courses and two co-instructors. By the third year, a successful approach had been achieved which included introductory exercises on engineers' and managers' roles, structuring the project work for each course into weekly assignments and encouraging students to share their weekly reports with the other members of their team. Student feedback showed a marked improvement in satisfaction between the first two years of offering and subsequent years. Instructors' own self evaluations reflected much improvement also. Some student comments are as follows:

> '[I learned] how to work well with teams [and] how to work well with non-engineers'

> 'The group project was interesting [and] serves as a reminder to break apart big projects into smaller bits and to delegate different areas to the appropriate experts'

> 'The group project and the last day's poster presentation . . .are great ways of learning and teaching'

> 'The group project illustrated the importance of working in conjunction with other professionals to complement one another's skills'

Case study 2: pairing freshers and seniors in the same discipline but different universities to address different aspects of a habitat design problem.

Courses linked: Biological Engineering (BE) 1252: Biology in Engineering (LSU), and Food, Agricultural and Biological Engineering (FABE) 645: Environmental Controls for Agricultural Structures (OSU).

In the fresher level biological engineering design course, students were introduced to biological engineering through a semester-long design project that emphasized 'big picture' concepts involved in design, including the engineering design method, methods of evaluating decisions, the importance of communication in the design process, and consideration of different perspectives and how they affect a design.

One semester-long design project was to design

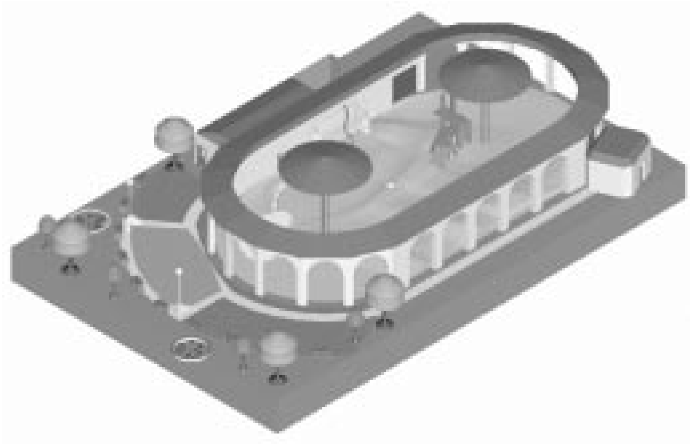

Fig. 1. Student design of tiger habitat

an interactive wildlife habitat for Mike the Tiger, the live tiger mascot that resides on the LSU campus. The ultimate goal of the project was to propose the student design to the university administration for actual construction. This project was introduced to students during the first week of the course; the first half of the semester was spent with instruction on the specific design project and other information gathering exercises such as field trips, library and Internet searches, and speaking with experts. The second half of the semester was spent creating and evaluating student designs with the input of experts, and preparing computer aided design drawings (Fig. 1) and specifications of the habitat, including cost estimates. At the end of the semester, designs were evaluated by expert review panels.

Because this was a first year course, students did not possess the technical expertise to create a well-developed, detailed design. Nor did the ABE department at LSU offer a course in heating, ventilation and air conditioning (HVAC). Thus, a combined senior and fresher-level biological engineering design project was crafted. Senior students at OSU designed the HVAC system for the campus mascot enclosure. Though the new habitat was open air, the hot summer climate in Louisiana was anticipated to cause areas of heat build up within the enclosure. Additionally, an environmental control system was needed for the enclosed off-exhibit area that included an office, storage area and two animal dens. Each student team submitted a different design approach, based on that team's set of engineering assumptions. A conference call was held during the seniors' class period to discuss design considerations and to clarify objectives. Each team submitted a short memo summarizing the design recommendations with all supporting calculations. These were incorporated into the freshers' tiger mascot habitat design.

The design was submitted to higher administration and was merged with other designs proposed by professionals. The new habitat was built in 2005, and aspects of the students' original design are reflected in the actual design. The technical design created by the students has been published [10].

Case study 3: pairing engineering students across disciplines in technical writing with biological engineering students to produce grant proposals for funding design projects. Courses linked: BE 1252: Biology in Engineering (LSU) and ENGL 3002: Technical Writing (LSU).

A linked project model was used in which a service-learning design project in biological engineering was linked with a service-learning writing project in a technical writing course offered by the English department. Service learning is defined [18] as 'a credit bearing educational experience in which students participate in an organized service activity that meets identified community needs and reflect on course content with a broader appreciation of the discipline and an enhanced sense of civic responsibility'.

The service-learning project in BE 1252: Biology in Engineering involved working with the McMains Children's Developmental Centre to design a therapeutic playground for children with special needs. Additional learning objectives for this project included the development of interpersonal communication skills and civic responsibility.

The technical writing course was intended to teach students the 'writing basics' of technical disciplines, for example, technical reports, resumes, covering letters and memorandums. The course included two students also enrolled in the biological engineering course and majors from several other engineering and technical disciplines. The service-learning project for this course involved writing grant proposals to the Baton Rouge Area Foundation to fund the playground being designed by the biological engineering students.

Students in each class followed the same approach. The biological engineering students based their designs on the input of all stakeholders and on a list of activities and equipment required by physical and occupational therapists, but paid special attention to the drawings of 'dream playgrounds' completed by the children at McMains. The technical writing students investigated the target community, educated themselves about children with disabilities, researched requirements set forth by the Americans with Disabilities Act of 1990, and learned about the products to be used in the proposed playground. Their sources included their classmates in the biological engineering course and, by extension, the children and their parents; the director and staff of the McMains Children's Developmental Centre; and websites for the funding agency, playground equipment and products used in the playground project.

Students in each course worked in groups of 3–5 people, and each group was responsible for creating a separate design or grant proposal. At the conclusion of the semester, the designs were presented to the children, parents, therapists, staff and executive director of McMains, and the grant proposals were presented to the executive director of McMains, the community and a programme (funding) officer of the Baton Rouge Area Foundation (BRAF). After viewing the grant proposal presentations, the funding officer instructed the executive director to use the information that both student groups had created to apply for $65,000 in grant funds to construct the therapeutic playground. Eventually $50,000 was secured from BRAF, and volunteers from both classes helped to construct the playground using these grant funds. This project enabled students in both courses to understand what was, for many, an abstract idea before the project began—that equal access is a right of all citizens.

Case study 4: pairing student design teams with real-world clients. Linkage: FABE 625: Modelling and Design of Biological Systems (OSU) and community partners.

Student projects that are real, relevant and are undertaken with input from practicing professionals are vital to educating future engineers. Direct interaction with the community partner, customer and/or client gives students a more realistic experience of design and better preparation for their professional careers. Industry has been critical of universities producing graduates who are deficient concerning design practices in industry, lack communication skills, and cannot deal with open-ended problems [19]. Interacting with real clients is an effective way to improve the education of our students, to address the concerns of industries, and to enhance ties between industry and academia [20].

Students in the senior-level FABE 625 class participated in a site investigation at an abandoned Superfund hazardous waste site, the Uniontown Industrial Excess Landfill in Stark County, Ohio [17]. The purpose of including this project as a component of the overall course was to provide a real-world design experience for the students and to assist the township. Students visited the site, developed and executed an environmental sampling plan (Fig. 2), met with township trustees and the local media, and proposed alternative designs to remediate the site or to have prevented the pollution from occurring in the first place. The results were a series of reports which were delivered to the township. The project provided a deeper understanding for the students of the environmental, political, and ethical constraints of design.

Fig. 2. Students performing environmental sampling and monitoring down gradient from an industrial excess landfill

During other years, the projects have included performing preliminary environmental site assessments at local sites including the following in Ohio:

- Acid mine drainage site in the Wayne National Forest;
- Military truck parts salvage yard in Akron;
- Commercial hazardous waste landfill in Oregon;
- Barrel and drummed waste landfill in Tremont;
- Manufacturing site with solvent spill in Yellow Springs.

Using real-world projects yields a number of benefits including increased student enthusiasm and buy-in. Additionally, the students are exposed to aspects of engineering professionalism and the use of standard business practices, including interacting with clients, preparing presentations, writing business memos, participating in conference calls, working within teams and coordinating between them. The designs can be and often are used by industrial and community clients; thus, students can see their work implemented, stronger ties can be built between the university and industry and faculty can enhance their own growth and credibility with their student and professional counterparts. Another benefit is that engineering students discover that communication and investigation skills are important in their future, and that as professionals they will spend a considerable amount of time communicating with clients, defining problem-solving objectives, and obtaining the information needed to develop those solutions. Also, many of the issues that will drive the final outcome will be legal, economic, social and/or political. Using real-world projects is an excellent way to promote a hands-on student centred approach to learning, to motivate students, to prepare them for their future careers, and to develop their sense of professional and civic responsibility.

TOOLS FOR ENGAGING THE CREATIVE PROCESS

Although engineering is a creative profession, principles of creativity are not always taught or demonstrated to students explicitly. The purpose of this section of the paper is to discuss methods that have been used to engage ABE students in creative endeavours through their engineering studies. Several methods are detailed, including instruction on creativity, student portfolios and a departmental poetry contest.

Instruction on creativity

Principles of creativity are taught in BE 1252, a fresher level biological engineering design course. This approach encourages students to use their creativity in a general sense and as it applies to engineering problem-solving.

Students are required to read the book *How to Think Like Leonardo da Vinci: Seven Steps to Genius Every Day* [21]. This text frames creativity in terms of seven principles:

1. **Curiosita**: an insatiably curious approach to life and an unrelenting quest for continuous learning
2. **Dimostrazione**: a commitment to test knowledge through experience, persistence and a willingness to learn from mistakes
3. **Sensazione**: the continual refinement of the senses as a means to enliven experience
4. **Sfumato**: a willingness to embrace ambiguity, paradox and uncertainty
5. **Arte/Scienza**: the development of the balance between art and science, imagination and logic.
6. **Corporalita**: the cultivation of grace, ambidexterity, fitness and poise
7. **Connessione**: a recognition and appreciation for the interconnectedness of all things and phenomena.

Students are required to complete exercises to develop their creative talents in each of these seven areas. In addition, students participate in a 'creativity laboratory', in which they rotate through four different stations. This laboratory is held early in the semester, when students have already been assigned to groups for their semester-long-service learning project, but have not worked together for more than two weeks. The purpose of the exercise is for students to practice the creative skills they have been taught in class, to apply these techniques to their design projects and to develop team camaraderie. The four creativity stations are as follows:

- **Creating an affinity diagram**. This exercise enables each group to systematically develop a "big picture" perspective on their design project.
- **Developing a team name, a team slogan, and a team logo**. This activity helps to build team unity and exercises the students' creative skills.
- **Playing Cranium™.** Two student groups play one another in teams of 2–3 per team (sometimes members of the team play against each other if their teams are large enough). The game requires creative thought and cooperation, and builds team unity.
- **Completing brainstorming activities.** Students are required to complete a set of brainstorming activities that help to develop more detailed ideas about specific aspects of the design project.

Approximately 80% of the students reported that the most engaging part of this exercise was playing Cranium ™. The authors believe that instruction on principles of creativity and providing avenues for students to practice their creative skills and enables them to become more confident in using such skills.

Student portfolios

Student portfolios have been defined as 'a purposeful collection of materials capable of communicating student interests, abilities, progress and accomplishments in a given area' [22]. Portfolios cause the student to engage in the creative process of selection, reflection and description regarding what they have learned. Student portfolios encourage active learning strategies and can be used to address accreditation issues. Although fields such as art, journalism, language arts and architecture have long used portfolios to document student achievement, their use in engineering has been a relatively recent phenomenon.

Christy and Lima [1] detailed portfolio methods designed to enhance and assess student learning in ABE courses. Lima *et al.* [23] and Christy *et al.* [24] further described portfolios and their potential for enhancing industrial ties in the classroom within the ABE discipline. These studies demonstrated that learning is enhanced by students engaging in the process of selection, self-evaluation and reflection that are inherent in the portfolio method. This helped shift the students' emphasis toward quality work, encouraged use of their evaluative and creative skills and allowed them to take more control of their own learning. In exit surveys performed over several years, 76% to 88% of the students reported that the portfolio method had enhanced their learning. Employers were impressed by the creativity and professionalism exhibited by many of the portfolios. Students have received job offers based on their portfolios, and many of the recruiters who hire from the department now ask to see students' portfolios during their on-campus interviews.

Mastering learning using a competency matrix

A major portion of the student portfolio involved the creation of one or more competency matrices (e.g. Fig. 3). The goal was for the students to demonstrate mastery of core concepts and competencies. These competency areas had been previously identified through interviews with future employers and current professionals, by accreditation boards (ABET), and discussion between the instructor and the students. The competency matrix makes explicit the idea that learning is not a binary operation of ignorance versus full knowledge, but a dynamic, progressive process. Modified from Bloom's taxonomy [25] and the Newcomb and Trefz model [26] regarding the learning process, four levels of learning were presented in ascending order: (1) Information, (2) Knowledge, (3) Application and analysis and (4) Wisdom. As students progressed through the levels of learning for each competency topic, they referenced one or more examples of their work which demonstrated that they had achieved the stated level of mastery. These examples were drawn from completed assignments or any other appropriate items a student chose to include. These materials, along with the completed matrices, were organized in the student's portfolio. This method makes explicit the life-long nature of engineering education. It also provides the student with creative licence to demonstrate her or his proficiency. As students are given more proactive roles in their learning process, they better comprehend engineering concepts and their future roles as practicing engineers.

Departmental Poetry Contest

Poetry is a very compressed form of creative writing which incorporates concrete language, complex imagery, sensory details and a freshness of voice. The act of composing poetry can benefit engineering students by enhancing their ability to communicate through the written word and by giving them permission to exercise another side of their creativity. A poetry contest was recently inaugurated in an ABE department and subsequently expanded to an intercollegiate event [27]. The objectives of the contest were to:

1. provide the opportunity for students to improve written communication skills;
2. enhance students' creativity;
3. expand their appreciation for the interconnectedness of all aspects of their college education, especially the arts and humanities.

A student assistant helped organize and publicize the contest which was open to undergraduates, alumni, faculty, staff and graduate students. Judges were recruited from the English department based on their poetry credentials and teaching reputations. All judges, including the university's poet laureate, were very enthusiastic and supportive of this project. The contest was held during spring quarter 2004–2006. Four categories were awarded: students vs. non-students and technical subjects vs. non-technical. Prizes in all categories included rosette ribbons and participant certificates. Cash awards were made to the student winners in both technical and non-technical subject areas. In a department of over 400 potential poets, there were 29 poems submitted the first year. The second year, the contest was opened to both the College of Engineering and the College of Agriculture, and 240 poems were submitted. One judge commented that he was impressed with the quality ('exceptional') and range of topics. Another stated that some of the ABE poetry 'could stand on its own outside this kind of modified contest'. Winning entries were read aloud at an evening poetry gathering in the student lounge which included live music and fine art selections provided by students, staff and faculty.

Other universities have also explored using poetry in the context of an engineering programme. The University of Michigan's college of engineering offers three major writing awards, one of which is for the Roger M. Jones Poetry Contest, established in 1977 to encourage engineering students to write poetry and develop their creative skills. Winning poems are awarded up to $1,000. Michigan State University (MSU) has for several years hosted an annual poetry contest within its college of engineering [28]. The goals were to initiate more focus on communication

FABE 650: Design of Waste Management Systems

Technical Competency Matrix

Topic	Competency	Level of Learning				Portfolio Reference
		#1 Information	#2 Knowledge	#3 Appl./ Analysis	#4 Wisdom	
Fundamentals	Waste impacts					
	Engineering properties of waste					
Sampling	Planning and design					
	Statistical analysis					
Treatment processes	Physical					
	Chemical					
	Biological					
Siting & operational limitations	Soil characteristics					
	Variable waste flows					
	Skilled labor availability					
	Energy conservation					
Non-technical issues	Regulatory issues					
	Political issues					
	Community acceptance					
	Economic issues					
System design	On-site domestic systems					
	Small community systems					
	Manure management systems					
	Septage & sludge systems					
	Food processing waste systems					
Unit design	Septic tank					
	Soil adsoprtion system					
	Mound system					
	Sand biofilter					
	Lagoon					
	Composting					
	Nutrient removal systems					
	Disinfection systems					
	Wastewater irrigation systems					
	Land application systems					
Other skills	Multi-disciplinary teamwork					
	-					
	-					
	-					

Fig. 3. Example of competency matrix

skills, to showcase the students' creativity and to encourage students to write for enjoyment. Initial resistance both within and outside the college was gradually broken down as students embraced the contest and exceeded expectations with the quality of their creative work. Craig Gunn, the director of the Communication Programme in Mechanical Engineering at MSU and founder of their college engineering poetry contest, wrote:

> Students were not only interested in submitting work but experiencing what others had written . . . It was especially interesting to see students reading those works that were deemed winners in the contest when they were displayed in the lobby . . . Some students were even heard to ask other students 'to quiet down so they could truly enjoy the reading.' Poetry had become something that was not the property of those liberal education majors on the other side of campus. Poetry was part of engineering as much as math and science. The depth of understanding and ability to present ideas improved [28].

At Drexel University, the fresher E^4 programme (Enhanced Educational Experience for Engineers) integrates humanities, especially communication and composition skills, with math, science and engineering components. Creativity is enhanced by introducing literature, poetry and journal writing [29–30]. Concurrent assignments in engineering and humanities classrooms allow the students to explore creative self-expression through writing poetry about engineered objects such as a CD-ROM, laser printer, radar, suspension bridge, or calculator. Harriet Millan, the director of the University Writing Programme at Drexel University, wrote:

> Perfect exam scores will not prepare our students to become the professional who is adaptive and creative, able to cope with both success and failure or loss. Making connections, thinking symbolically, preserving contradictions, exploring conflict are keynote skills inherent in writing poetry, whereby our students can experience the vulnerability that may in fact be their greatest creative asset [30].

CONCLUSIONS

Engineering education is in need of innovative teaching and learning methods to engage students' creativity, to improve the ability of our graduates to solve complex problems and to make explicit the connections between engineering and the society which it serves. Student projects that feature teams without borders and that favour multidisciplinary approaches provide student-centred learning opportunities and help prepare students for their future. The world itself becomes their classroom. Professional development, social responsibility and lifelong learning become their goals. Tools for the creative process are important because engineering is ultimately a creative profession, yet there is little engineering curriculum explicitly teaching this process. Establishing and using such tools will allow students to develop their own creativity thereby enabling them to solve complex problems, much like those they will encounter when they graduate from our ABE programmes and enter the engineering profession.

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