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Viewpoint-The Problems of Teaching Practical Design To Today's Engineering Students—the Agricultural Engineering Experience*

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In our department, senior design is a two semester sequence intended to comply with the capstone requirements of ABET criterion 3(c) and criterion 4. The primary requirement of senior design students is to select a project and through a series of steps, carry it through construction to testing. By their senior year, students are quite capable of using the sophisticated engineering skills and software learned in previous courses but are woefully unprepared to produce even the simplest practical designs and prototypes. When recently we have taken the time, either in or out of class, to provide students with practical instructions in tools, materials and techniques, the results have been very encouraging. Rather than rejecting the hands-on aspects of engineering design, students have enthusiastically embraced it in some unusually creative ways. This paper discusses the growing realization of our educational pedagogical deficiencies and the steps, some implemented and some anticipated, needed to correct this problem.

INTRODUCTION

FEW SERIOUS OBSERVERS would dispute the notion that the profession of agricultural engineering has significantly changed in the last few decades. Of course, all types of engineering are continually changing. The problems confronting engineers have evolved as well as the tools used to solve these problems. The changes to agricultural engineering seem more extreme because it is supremely an exercise in applications. For most of the 100 years since the profession was formally established in the US [1], it has been primarily dedicated to the application of engineering principles to agriculturally related problems. In a very practical sense, this has meant the application of engineering principles to solve on-farm problems. Historically, a great portion of successes in agricultural engineering have been dedicated to the lessening of the hard physical work related to farming and preserving the renewable resources of rural agriculture.

Until recently, agricultural engineering may have been unique in that a large portion of students entering the profession had direct experience with the class of problems they would confront professionally since they, for the most part, grew up on farms. Few occupations require the broad range of practical skills or the total involvement of family members, even from a young age, than life on the family farm. Among agricultural engineers who graduated in the decades just after World War II and are now retiring, there is a pervasive sense they entered the profession with a duty to 'the folks back home'.

Although a certain portion of agricultural engineering still involves solving on-farm problems, in many ways agricultural engineering has moved off the farm. A great majority of agricultural engineering graduates nowadays find work either with regulatory agencies, consulting firms or industry. And though this work may have significant impact 'down on the farm', the nature of the work is often such that it simply does not have the emotional connection it once did. The recent shift in emphasis has been away from production agriculture and especially away from two of the traditional areas of agricultural engineering—power and machinery and structures and environment—and towards biological and bio-process engineering. This has had the effect of encouraging non-farm students into the curriculum which has been a very good thing for many agricultural engineering departments struggling with declining enrolments. It has, however, had the effect of fundamentally changing the student body. There is now a growing realization of our educational pedagogical deficiencies and the steps, some implemented and some anticipated, needed to correct this problem.

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ENGINEERING AS DESIGN

A review of enrolment figures in the Department of Biological and Agricultural Engineering at North Carolina State University indicates that as late as the mid 1980s, the majority of undergraduate students were white, male and rural [2]. The students entering our department from a rural/farm background often came equipped with significant hands-on experience and practical ability that greatly complemented their engineering education. To a degree, this was true of other engineering disciplines as well. Almost all types of engineers who were undergraduates in the 1950s and 1960s can fondly recall working on automobiles, building model airplanes and constructing short wave radios -all hobbies that provided creative outlets and honed practical skills [3, 4]. For all practical purposes, these and very few other hands-on creative outlets are available to most students today.

In response to a declining enrolment in the traditional areas of agricultural engineering and a growing student interest in human engineering, our department added a biomedical engineering concentration in the early 1990s. By the autumn of 1996, the large majority of our students were urban and choosing the biomedical engineering concentration with the intention of pursuing a career in medicine or medical research but not necessarily engineering. Because of broadening opportunities in the environmental regulatory area, most of the non-biomedical students were choosing the soil and water engineering concentration. This concentration attracted significant numbers of urban students interested in such areas as urban storm water management—an area drawing on the technology of traditional agricultural engineering but historically outside its purview. Few of our students were interested in power and machinery with fewer still interested in structures and environment.

Within the constraints imposed by accreditation and core content, it is no secret that curricula and courses often reflect the interests of students. In recent years, with few of our students coming from agricultural backgrounds and with most having little hands-on experience, many biomedical students and some soil and water students objected to the use of practical 'agriculturally' related examples in their biological engineering classes. In response, our instructors began to alter their courses to de-emphasize the practical execution of engineering such as fabrication, remove most references to agriculture and to replace these with more simulation and computer related exercises. The result has been to practically eliminate any time spent acquiring the practical design skills students lacked from the beginning.

The de-emphasis of practical design skills is not just confined to agricultural engineering. Quite a few graduate students coming into our department from other engineering disciplines have indicated that the main attraction is the perception we are more application orientated than other disciplines. As a student with an undergraduate degree in electrical engineering explained, 'I spent four years in EE and never once had my hand on a soldering iron. Maybe while in grad school in agricultural engineering, I will finally get my chance'. The excellent level of technical school education in the US may be that part of the reason for the move away from the hands-on aspects across engineering disciplines. Two year technical schools that grant associate degrees in engineering are almost by definition orientated to the hands-on aspects of engineering and they are very good at it. To differentiate ourselves from two-year schools, four year schools have reduced or eliminated hands-on laboratory time in favour of more of the esoteric aspects of engineering. Promoting a dichotomy between those who 'know how' (the tech school graduates) and those who 'know why' (the engineering school graduates) serves neither the students nor society well.

Even more troubling has been the perception by faculty that we are graduating students with engineering degrees—often with outstanding undergraduate records—who are still not capable and creative engineers. This perception is more than hallway talk, it is often a recurring, if not official, theme at teaching symposia and faculty retreats. Engineering can be a dirty job. Occasionally, faculty complain that students do not want to get away from the computer and get their hands dirty. Employers complain bitterly that recent graduates are not able to apply their engineering education to real-world problems. We have often been shocked to hear good engineering students admit they really don't want to be engineers—they like the challenge and rigour of the engineering curriculum but the degree is more a trophy than an occupational decision [5]. What seems to be missing here is the thing that brought past generations of students into engineering in the first place. Those of us who have practiced engineering know it is the scientific curiosity and creative outlet that is the ultimate payoff and essence of engineering. Engineering is the practical application of science and is really about design. What a shame for the students, and ultimately for society, to have them finish the race without receiving the prize. Unfortunately, they don't receive the prize because they don't realize there is a prize. As educators, we do a disservice if we do not inculcate our students with the rush that comes from engineering creativity.

SOME CLASSROOM EXPERIENCES

In our department, senior design is a two semester course sequence intended to comply with the capstone requirements of ABET criterion 3(c) and criterion 4. Like many engineering departments, ours devotes substantial faculty time and departmental resources to senior design. In addition to the usual course content, senior design is promoted as a social and professional experience designed to transform engineering students into engineering professionals.

The primary requirement of senior design is for students to select a project and through a series of design steps, carry it through construction to testing and ultimately, delivery to a client. By their senior year, students are quite capable of using the sophisticated engineering skills and software learned in previous courses to solve a multitude of problems as long as the problems are closed ended and clearly defined. However, the usually ambiguous nature of real-world engineering design problems stops many senior design students in their tracks. This ambiguity coupled with a profound unfamiliarity with materials, tools, processes and simple hardware can frustrate the most motivated of students. If this is design and design is the essence of engineering, then it is no wonder they are ready to abandon their engineering careers just as they are about to begin.

As taught in our department, the senior design class meets for one 50 minute lecture each week plus a formal two hour afternoon lab during the autumn and two weekly lectures and a three hour lab in the spring. Covered in lecture are engineering design topics such as ethics, engineering disasters, forensics, intellectual property, creativity, reverse engineering, scheduling and technical communications. Students have very little difficulty with the material presented in lecture. However, students are also required to self select teams of four or five members and pick a project from a list presented at the beginning of the term. The list is compiled from suggestions by faculty both inside and outside the department as well as government and industry. Student teams enthusiastically select a project at the beginning of the term and spend the first weeks scheduling the various project tasks. Somewhere in the mix of tasks is included the heading 'design'. Although cautioned otherwise, student teams assume that the design phase will be completed quickly and without difficulty. This is almost never the case.

Over the last 20 years, students' attitudes concerning design have changed remarkably. In the past, students would have a design formulated almost from the beginning and would occasionally race to the shop before doing any research, calculations or drawings. The results, of course, were often poor but the students eventually learned the value of deliberate preparation in engineering without dampening their enthusiasm for design. Nowadays, the opposite is mostly true. Students will spend much effort on interviewing clients, scheduling, literature review, the patent search but put off design as long as possible. Although all students are capable of using engineering graphics software, when compelled, they often reluctantly produce poorly rendered sketches. It is astounding that what was once viewed as the most rewarding aspect of engineering—creative design—is now dreaded by students.

Even worse, when the design drawings are finally produced, they are often exercises in futility. Engineering students with no practical experience will design parts that cannot be made or, more often, spend days pouring over the design for a simple part that can be purchased at any hardware store. More often than not, by the end of the project, the design experience, meant to be gratifying, has turned into an ordeal for students and faculty. Moreover, with the encouragement of ABET and university administrators, senior design projects nowadays often contain a 'societal component' which means 'service learning' [6, 7]. Service learning is an excellent idea that involves students and faculty with clients in the community and their problems. Service learning clients get the benefits of enthusiastic students and students get to sample problems in a real-world context. Unfortunately, what starts out with high hopes by client, students and faculty often ends in deep disappointment for all involved. It is not surprising some engineering seniors don't want to be engineers.

An illustrative example of a design problem undertaken by a group of our senior design students was to redesign a small 1950's vintage tractor to be used by a person who had lost leg use after a spinal injury. Because the tractor was a much prized family heirloom, the client had stipulated it not be modified in any way that prevented it from being returned to its original condition. The students were given five weeks to thoroughly research the problem and develop a suitable design including drawings and bill of material. A preliminary progress report at the end of four weeks included a huge amount of research on the nature and statistics of spinal injuries, data and specifications on the tractor in question, patents on clutches and brakes, numerous references on assistive technology and a vague one-page drawing of a pair of massive electrical solenoids. When we suggested they consider, as an alternative, the cable actuator common on most automobile emergency brake systems, they were astonished that such marvellous technology already existed.

Another group spent several weeks designing an elaborate systems of levers to effect a short high-force displacement as part of a larger design. When we suggested they consider instead an inexpensive bottle jack, all but one admitted they had never seen nor heard of such a device.

Once, a group set out to design a welded metal frame to be used as a mobile bridge. The finished design consisted entirely of square bar, they being ignorant of rolled shapes like channel and I-beams.

DISCUSSION

It is fortunate that senior design in our department is a two-semester sequence. With a new semester comes a new project and a new opportunity to succeed. Undoubtedly, some students are turned off by the design experience of the autumn term and consequently view the second period as an ordeal to be survived rather than the gratifying experience it is intended to be. Although some teams produce excellent projects, until recently, most teams just managed to muddle through, learn from the mistakes made in the autumn perriod and produce acceptable spring design projects.

When recently we have taken the time, either in or out of class, to provide students with practical instruction in tools, materials and techniques, the results have been very encouraging. Rather than rejecting the hands-on aspects of engineering design, students have enthusiastically embraced it in some unusually creative ways. For example, a casual demonstration of fastening sheet metal with pop rivets, a technology most students never dreamed existed, elicited wonder and awe and a later attempt to rivet plastic sheets and canvas! The observation has been that students have so few practical tools of creative design that when they acquire one, they will use it in numerous ways, appropriate or not. Finally given the means to create something with their hands that once only existed in their head, (or on a computer screen), some students are so turned on by engineering as to wish they were beginners again!

As engineering educators, allowing our students to muddle through something as important as engineering design just because they lack the practical skills that were second nature a generation ago is unacceptable [8]. It is easy enough to blame society, computers or our urban environment for this shortcoming. We **owe** our students, and society, to provide or teach the tools necessary to be productive professionals. As important, we should **want** our students to finally and fully experience the thrill of creative design that will make them desire a career in the profession. Based upon the application of science, engineering is the profession where individuals can exercise their creative potential for the benefit of society. Engineering design is a noble undertaking needed now more than ever. There is no doubt that the background of students in engineering is different from a generation or two ago. While they are bringing to school far less practical ability, to dismiss them as without curiosity or creative talent is a great disservice to them and us.

SUGGESTIONS TO ENHANCE STUDENT DESIGN SKILLS

1. We should realize that to be productive, engineers must possess a balance of theory and practical skills. For the most part, students coming into engineering schools today have not been exposed to the range of practical skills possessed by past generations. As engineering educators, it is our responsibility to provide this through lectures, labs, demonstrations or whatever means necessary. We should not be deterred by complaints that 'the local community college should teach that'. Further, the reduction in required class hours and the inclusion of more humanities courses has left no room to spare in the curricula for the practical application of engineering.
2. We should recognize that we live in a material world. Engineering, whether agricultural or biomedical, is fundamentally about making things. A competent engineer should have a familiarity and appreciation of how things are made and why they are made that way. Although the term 'reverse engineering' carries negative connotations, when used in a structured and positive way, it can teach some very powerful lessons about the motives of creative design. Every engineering student should be given the opportunity to take things apart to see 'what makes them tick'.
3. Every sphere of human endeavour has its own unique language. A major part of mastering any profession is becoming familiar with its terms and the names of its concepts, tools and apparatus. Just as the basic concept and term 'free body diagram' is familiar to all engineers, so should be the names of basic tools (e.g. box end wrench, centre punch) and basic apparatus (e.g. street elbow, hex socket set screw). We should make an effort to integrate tool and hardware identification into undergraduate engineering classes whenever possible. Nothing gives a student a sense of mastery better than knowing the correct name for something.
4. For a variety of reasons including time constraints and liability, field trips in engineering classes are becoming less common. This is unfortunate because being mostly visual learners, many engineering students will never again have the opportunity to see injection moulding, metal machining, welding, casting and dozens of other fabrication techniques in a learning environment. As educators, we should make every effort to expose our students to as broad a range of practical engineering creativity as possible. In many ways, creative engineering is about the synthesis of different ideas, materials and technologies into useful products.

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