"Hands-On" Engineering Design Projects at N.D.S.U.

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Five years ago the curriculum in Mechanical Engineering at North Dakota State University was long on theory courses and short on experimental or professional learning. At least, this was the consensus of the E.C.P.D. reaccreditation team which gave us the incentive to ultimately organize a 10 quarter-credit hour design program spanning the last five quarters (1, 1, 3, 3, 2 credits sequentially) of the undergraduate curriculum. This format was chosen to accomplish the following objectives:

1. Understand the morphological approach to the design of a complex system (1, 2).*
2. Practice the technique and procedures for innovation by defining a real life problem and developing a practical system for the solution (3, 4).
3. Experience the advantages and difficulties of working together as a design team.
4. Communicate ideas through formal (written) and oral presentation before peers and a panel of professional practitioners.

In a period when the tendency has been to make the engineer a white collar worker dependent on the computer and on theoretical studies, we want to help tilt the balance back in the direction of the all-around engineer - someone with both the theoretical background and the practical knowledge. NDSU is located in an area of sparse industry so we felt we should give our students a "hands-on" learning experience, which emphasizes the practical aspects of the art and science of engineering. Mechanical engineering is an art because to make a piece of machinery function in the real world requires knowledge that reaches beyond book learning.

We wanted our program to extend over five quarters so that our students would learn: that design must overcome misinterpreted objectives and misunderstood problem definitions; that occassionally tests did not control a critical parameter and that results can be invalid; that design is bewilderment and the feeling that you have absolutely no explanation for the results of the last test; that most important comes the realization of what design is not. It is not an individual process. If you read all the books, consider all the discussions with professors, peers and acquaintances that relate in some way to your design and you trace those sources back to their origin, you realize that design is a group effort. It is the summation of all human expertise, which, when combined, acts much like a computer

*Numbers in brackets designate General References at end of paper.

program randomly incrementing. In this case perhaps a more accurate term is "muddling toward a solution." Design is the essence of engineering. It is that one thing which clearly distinguishes engineering from science. The objective of design is to "make useful things", deemed useful by an agent organizing the activity and footing the bill, i.e. the promoter. Whether the creation will improve the human condition is a matter of the promoter's taste, political debate and numerical estimates of performance and side consequences; whether in the long run it improves the human condition is a matter of historical judgment. There are aspects of design education which can be learned as knowledge; there are other aspects which can only be conveyed as understanding; there are yet other aspects which can only evoke, much as poetry (even when devoid of facts and knowledge) evokes moods within us.

Numerous articles have been written on design education, essentially all suggest that the experience include the following:

1. Definition of design specifications from a consideration of human need, side effects and long range consequences.
2. Development of a time and resources schedule.
3. Review of patent and state-of-the-art literature.
4. Selection of the most promising design from among several alternatives.
5. Refinement of the most promising to such a point that its performance (in sum or in part) can be predicted analytically and demonstrated experimentally.
6. Recycling of (5) until the actual and predicted performance converge and satisfy (1).
7. Consideration of economic, manufacturing and marketing factors.
8. Preparation of written and oral reports.

The underlying principles of the program are that inventors and innovators are vital elements of technological change, that creative engineering and innovation can be encouraged, and that an understanding of the innovative process can be taught on a comprehensive basis. A great deal of importance is placed on defining the problem. This is one area in engineering education that has had inadequate attention. Rarely are students required to define the problem they are to solve. They do not recognize that problems are defined by available solutions, that an engineering problem cannot be completely defined until the solution is completely known.

The management of the design project experience is a strong force in determining the quality of the outcome for the student. The outcomes are heavily dependent on the supervisory style and guidance of the faculty. The "chief engineer" role of the faculty is one that is both demanding and satisfying. A colleague relationship develops that is not only valued by both, but is a requisite for learning. There are indications that our program demands more effort than conventional classroom instruction. Originally, the entire design projects program was under the direction of a single instructor. Subsequently, as the enrollment increased, more of the faculty was involved. In any case, we found there was a cadre of loyal opposition which had to be accomodated as part of the design experience.

Intuition is somehow considered not quite respectable, possibly because when properly employed it often makes formal demonstration of something seem totally unnecessary. In a book called The Architecture of the Universe, W. G. F. Swann writes: "A scientific researcher (or designer) can be likened to two distinct animals. Ahead there travels a dog with keen scent and not over critical capacity who pokes his nose into every bit of intellectual (or curious) garbage he can find on the wayside. He ferrets out from every conceivable place new morsels which no dog has ever chewed before and gnaws out as much of their content as he can. And behind the dog there walks, clad in the most conventional apparel, a calm and dignified gentleman who views very critically everything the dog picks up, and makes him put it down again if it is found wanting, but pockets it in his immaculate coat if it is of worth. It is not to be forgotten however, that it is usually the dog that finds the bone. The dog's name is Intuition and his master's name is Precise Thought."

In addition to the tendency, in some academic circles, to divorce technical thinking from everyday experience there are cases where people apparently don't really want to clean up a field--that would deprive them a pleasant and secure job. S. B. Batdorf in Research Syndrome tells the story about a young lady who went into a department store to buy some material for a nightgown. She wanted something very soft and gauzy and the saleslady finally found just what she wanted. When asked how much was needed, she requested 20 yards. The saleslady was aghast and said, "My dear young lady, you obviously don't know much about making clothes. All you need for a nightgown is 2½ yards." The sweet young thing replied, "But you don't know my husband. He's a research and development engineer and he would much rather look for something than find it."

A team of the faculty should have supervisiory responsibility for the program. The involved faculty should agree on format, criteria, and procedures and work together to operate and improve the program. The faculty should be rotated on and off the team to increase faculty involvement, assure continuity, and provide variety. One faculty member should serve as coordinator for the program. The number of students per faculty member should be about 8 or 9 (2 to 3 teams). There must be recognition of the faculty role in design/experimental learning activities in the assessment of promotion, tenure, and professional development.

Developing a new program requires substantial effort and dedication on the part of all involved. All of which becomes justified when there is an institutional commitment that provides the necessary support and recognition. An aware faculty is a prime prerequisite for an institutional commitment. Hopefully, this paper will contribute to an awareness of the value and opportunities in design/experimental learning programs.

One of the basic needs in a design/experimental learning program is closure. The supervising faculty must establish a clearly defined procedure for monitoring progress and evaluating achievement. Performance evaluation questionaires should be developed. Each student should submit a self assessment and an evaluation of each team mate. Faculty supervisors who have had an opportunity to observe the teams at work should also submit performance evaluation forms. A final live presentation should be made public for all faculty and students to attend. A panel of faculty, students, and consultants should be chosen to critique the presentation. A final written report should be placed in the department's permanent file. The grade for the design project should be based on well defined and publicized criteria.

Today, there seems to be increasing emphasis on professionalism and a need to be able to address and solve complex, interdisciplinary, social-economic-technical problems. This indicates a need for design/experimental learning activities and a guided internship in the practice of engineering.

In 1976 the author, as a member of the department coordinating committee, initiated a theme directed senior design projects program in mechanical engineering. The general theme provides the students an opportunity to practice engineering by authentically involving them in a solution of relatively open-ended problems similar to those they will encounter in professional life. The class met one hour a week in the winter quarter of the Junior year to hear guest lecturers who generally spoke on energy resource alternatives to oil and natural gas. In the spring quarter, rather than disperse the department's limited monetary and faculty involvement over the full spectrum of alternate energy sources: solar, wind, biological and coal, we restricted our options to the power available in the wind. It seemed particularly appropriate in North Dakota that we should in time be able to harvest the wind as well as we have the prairies.

To some extent this decision reflected my personal bias, wind energy is more subtle and potentially destructive (exciting) than solar energy. Wind energy conversion systems (WECS)* utilize many of the engineering disciplines: machine/structural design, aerodynamics, electrical machinery, controls, etc. Applications of wind energy are unlimited: electrical, mechanical and thermal systems are the most obvious.

Stewart Udall, the former U.S. Secretary of the Interior, wrote of the potential of wind power in 1970. "Windmills are much, much more

*See WECS References at end of paper.

than relics. They are symbols of sanity in a world that is increasingly hooked on machines with an inordinate hunger for fuel and a prodigious capacity to pollute. Ecologically, the windmill is one of the few perfect devices. It harnesses a completely free resource to pump water or generate electricity under conditions that respect the laws and limits of nature. Like waterwheels and sailboats, windmills have a Zero Environmental Impact. If we are to meet the challenges, inventors and technicians will have to build machines that use, not abuse, the unearned gifts of nature."

We allowed the students to organize their own teams of seven or eight. Each team elected a "captain" who was delegated the authority to oversee the project and serve as a liaison between the team and the instructor. The team captains met with the instructor once a week to hash out personnel, logistical and acquisition problems. Out of this experience, the consensus evolved that the group's dynamic structure is the single most important key to its' ultimate success.

(After one quarter of general orientation, based on my perception of the class, I now assign 3-4 students to each team hopefully attaining a reasonable mix of scholastic and practical aptitudes.)

The entire class attended weekly lectures on the theory of wind machines and discussed modern applications of wind energy. Each team was assigned a different specific device (e.g., heat pump, air compressor, electrical generator) which was to be powered by any conceivable type of Wind Energy Conversion System. Separately, each team had to present and have approved a detailed proposal and tentative budget by the end of the spring quarter. The proposal listed the individual assignments and tentative deadlines so that the work would not get hung up.

The work assignments paralleled the various subsystems that interact and influence the performance of a small scale (less than 3 K.W.) WECS. The projects were to be evaluated on innovation, economic aspects, an objective hardware test, a written report and an oral presentation. A properly prepared proposal should help the team to think through the critical issues involved and serves as a "road map", letting the team know where it is going. In the last analysis the proposal is a "contract" between the team, the individual members and the faculty. It becomes the criteria against which performance can be evaluated.

All of our earlier systems were mounted on stationary towers. At one time we had four operational wind machines dispersed over the campus. We used the Naval Reserve Tower, two utility pole towers on the edge of campus and the only remaining active tower the 40 foot structure behind the mechanical engineering building. I had no idea how hung up things can get at a University. The Naval Reserve commandant had to have a formal statement from the University president releasing him of any liability. I was informed that I might very well be personally responsible for any adverse consequences. (No wonder innovation and initiative are sparse academic commodities.)

The agriculture college was not eager to let us erect a tower on their farm property. Finally, we prevailed on the building and grounds department to give us a site on the edge of campus and run out water and electric service from the nearest building. (For which, the MEAM department was duly billed!) This rather disturbing "in-house" experience was more than compensated for by the most gratifying service we received from local industry. An erector from Moorhead brought his crane over in the dead of winter (wind chill 35° below zero) to raise a complete 3 KW assembly on the Navy Reserve Tower and two months later to take it down. Northwestern Bell donated two wood utility poles, later set the towers and hoisted the wind machines. Local suppliers donated the steel and poured the concrete for the tower behind the mechanical engineering building.

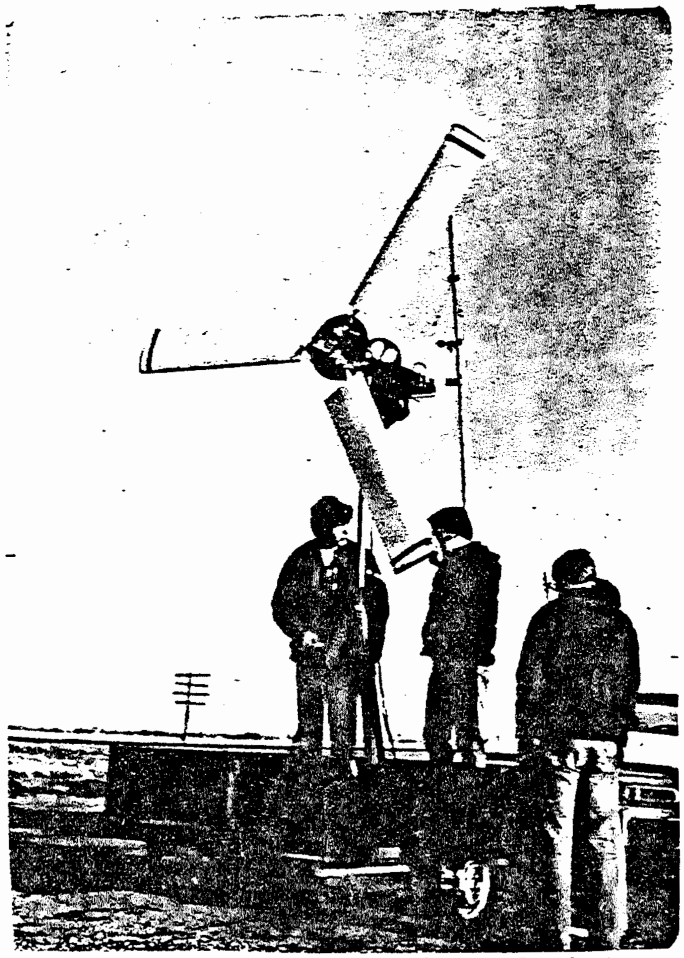
Gratefully, the mechanical engineering department provided the considerable funds necessary to purchase the instrumentation and monitoring equipment which we continue to use year after year. All told, over 70 students have participated in 14 different WECS senior design projects over the past four years.

The following list identifies some of the Wind Energy Conversion Systems: designed, fabricated, tested and evaluated by senior mechanical engineering students at NDSU.

Project 1. Three-bladed vertical rotor "Giromill" coupled to a 3 horsepower mechanical water agitator to provide hot water.
Project 2. Three-bladed horizontal axis sailwing rotor coupled to a freon compressor in a heat pump system.
Project 3. Two-bladed horizontal axis fiber glass propeller coupled to an alternator supplying power to an electric resistance heating system. (One of the participants in this group was subsequently awarded a $18,000 DOE grant to extend the project.)
Project 4. Darrieus ("Eggbeater") vertical axis machine coupled to a permanent magnet generator.
Project 5. Two-bladed segmented (variable twist) propeller coupled to an electric alternator and mounted on a stub tower attached to a trailer towed by an automobile to simulate wind tunnel conditions.
Project 6. Fiber glass propeller with honeycomb core. The trailer mounted system was evaluated as an electric power source in the two-bladed and three-bladed configuration.

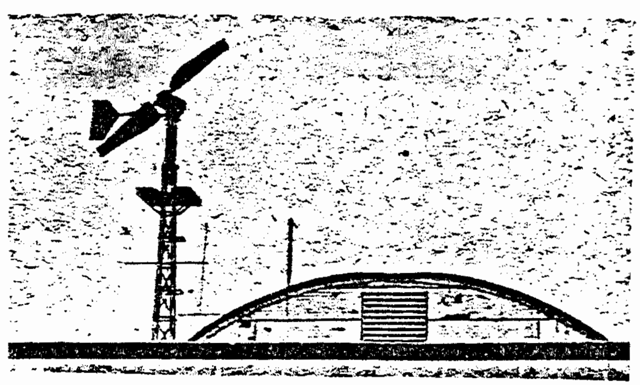
To date, the MEAM department has contributed close to $10,000 toward the purchase of equipment and supplies. The University shop technicians provided supervision and assistance amounting to several hundred hours. The business/industrial community of Fargo-Moorhead donated materials, services and equipment conservatively worth $8,000.

A wind-driven heat pump demonstration unit.



Trailer mounted experimental wind driven electric generator.

A vertical axis giromill drives a stirrer to produce hot water.



Student-built three kilowatt wind turbine mounted on the Naval Reserve Tower on the campus of North Dakota State University.

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