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An Overview of the National Science Foundation Program on Senior Design Projects to aid Persons with Disabilities*

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This paper provides an overview of the National Science Foundation (NSF) Senior Design Projects to Aid Persons with Disabilities program. In 1988, the NSF started to provide a mechanism whereby student engineers at universities throughout the United States designed and constructed devices for persons with disabilities. This program combined the academic requirement of a design experience with enhanced educational opportunities for students, and improved the quality of life for disabled individuals. Students and university faculty provided, through their normal ABET accredited senior design class, engineering time to design and build the device or software, and the NSF provided funds, competitively awarded to universities, for supplies, equipment and fabrication costs for the design projects. Described in this paper are some experiences at several universities in this program and an annual publication that describes all of the projects carried out in this initiative.

INTRODUCTION

DEVICES AND SOFTWARE to aid persons with disabilities often need custom modification, are prohibitively expensive, or non-existent. Much of the disabled community does not have access to custom modification of available devices and other benefits of current technology. Moreover, when available, engineering and support salaries make the cost of any custom modifications beyond the reach of a person with disabilities.

It has been reported that over 35 million people in the United States have disabling conditions. More than 9 million Americans have significant mental or physical conditions that prevent them from being able to carry out the major activity of their age group (that is, play, attend school, work, or maintain a household). These numbers are rapidly increasing due to advances in medicine that extend life expectancy. Today, the average American spends approximately 12 years of his or her life as a person with disabilities. Besides the enormous suffering experienced by the disabled community, disability imposes an enormous cost to the nation, totaling 6.5% of the gross national product (greater than $170 billion). Aside from the economic cost to the United States due to disabilities, there is the vitally important consequence of the disability to the individual. Every American has either a disability or direct contact with a person with disabilities (that is, a family member or close friend). Disability ranks as America's greatest health problem in terms of the number of individuals affected and the economic impact.

As part of the accreditation process for university engineering programs, students are required to complete a minimum number of design credits in their course of study, typically at the senior level. Many call this the *capstone course.* Engineering design is a course or series of courses that bring together concepts and principles that students learn in their field of study – it involves the integration and extension of material learned in their major toward a specific project. Most often, the student is exposed to system-wide synthesis and analysis, critique and evaluation for the first time. Design is an iterative, decision-making process in which the student optimally applies previously learned material to meet a stated objective.

Design is not a course substitute for the deficiencies that exist in a department's curriculum. It is an approach to problem solving for large-scale, open-ended, complex and sometimes ill-defined systems. The emphasis of design is not on learning new material. Typically, there are no required textbooks for the design course, and only a minimal number of lectures are presented to the student. Design is best described as an individual study course where the student:

- selects a product to design;
- writes specifications;
- creates a paper design which consists of multiple solutions/products;
- analyzes the paper design and selects the optimal design;
- constructs the device;

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- evaluates the device;
- documents the design project.

Typically, the creation of the paper design and analysis of the paper design are contained in one document.

In 1988, the National Science Foundation (NSF) began a program to provide funds for student engineers at universities throughout the United States to construct custom designed devices and software for disabled individuals. Through the Bioengineering and Research to Aid the Disabled (BRAD) program of the Emerging Engineering Technologies Division of NSF, funds were awarded competitively to sixteen universities in 1988 to pay for supplies, equipment and fabrication costs for the design projects. (In January of 1994, the Directorate for Engineering (ENG) was restructured. This program is now in the Division of Bioengineering and Environmental Systems, Biomedical Engineering & Research Aiding Persons with Disabilities Program.) Funding for this program has continued each year since with the goal of this NSF program to enhance the educational opportunities for students and improve the quality of life for persons with disabilities. Approximately twenty universities have been involved with this program on a yearly basis. Students and university faculty provided, through their normal Accreditation Board for Engineering and Technology (ABET) accredited senior design class, engineering time to design and build the device or software, and the NSF provided funds, competitively awarded to universities, for supplies, equipment and fabrication costs for the design projects.

The location of the schools participating in 1993 is shown with black dots in Fig. 1 and is representative of the demographic distribution of the participants since 1988. Note that the participants change on a yearly basis, but most schools are involved for a five-year period.

The purpose of the NSF program is threefold. The first purpose is to provide an opportunity for practical and creative problem solving in addressing a well-defined problem to students for meeting the required design component of their study. An outcome of this involvement is that an individual with a disability receives a device that provides a significant improvement in the quality of his or her life at no cost to the disabled individual due to NSF funding of the projects. In many cases, development of devices and/or software for an individual may lead to applications for others with similar disabilities. Students are also exposed to a unique body of applied information on current technology in the area of rehabilitation design. The second purpose is to motivate students, graduate engineers and other health care professionals to work more actively in rehabilitation, towards an increased technology and knowledge base, to effectively address the needs of the disabled. This goal assumes greater importance with the implementation of the Americans with Disabilities Act of 1990 (ADA). The third purpose is allowing universities an opportunity for a unique service to the local community. The students participating in this program have been singularly rewarded through their activity with the disabled, and have justly experienced a unique sense of purpose and pride in their accomplishment. Many of the projects carried out in this program have been highlighted in conference publications, national radio, local TV news programs, local newspapers, CNN, as well as the ASEE Engineering Education Magazine [1].

In the past, students were typically involved in design projects that enabled students to improve

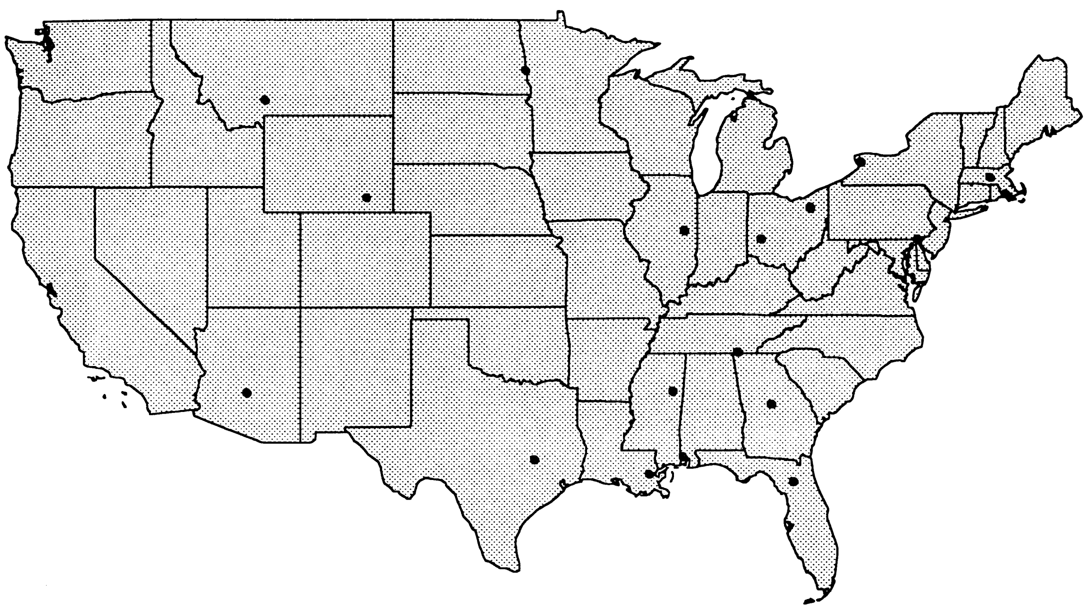

Fig. 1. Location of participating universities in 1993.

the quality of their lives, for instance, by designing and constructing a stereo receiver. Under this NSF program, engineering students at participating universities are involved with designs that result in an original device or a custom modification of a device that improves the quality of life for a person with disabilities. There is no financial cost incurred by disabled persons participating in this NSF program; upon completion, the finished project becomes the property of the individual for whom it was designed. The common practice for the participating universities is for the person with disabilities or their guardian sign a waiver absolving the student, design faculty and staff, and the university of any liability due to the operation of the product. There are no regulations or policies that apply to the functioning of these products since they are one of a kind products built for a specific individual and given as a gift. Also, there is a large degree of variability in product maintenance – some universities continue to maintain the device and others completely build a new product with a new student team. The universities that maintain the products usually hire students during the summer to repair the damaged products with additional funding by the NSF Research Experiences for Undergraduates program.

Under faculty supervision, students developed specific projects, through their senior design classes, to address the identified needs of particular disabled individuals. Local school districts and hospitals have participated in the effort by referring interested individuals to the program. A single student or a team of students specifically designs each project for a disabled individual or a group of disabled individuals with a similar need. Some of the projects are custom modifications of existing devices, modifications that would be prohibitively expensive to the disabled individual were it not for the student engineer and this NSF program. Other projects are unique one-of-a kind devices wholly designed and constructed by the student for the disabled individual. Projects built in years past include a laser-pointing device for people who cannot use their hands, a speech aid, a behavior modification device, a hands-free automatic answering and hang-up telephone system, and an infrared beacon to help a blind person move around a room. Project selection is highly variable depending on the university, and the local health care facilities. Some universities make use of existing technology to develop projects to aid the disabled by accessing databases such as ABLEDATA. ABLEDATA includes information on types of assistive technology, consumer guides, manufacturer directories, commercially available devices, and one-of-a-kind customized devices. In total, this database has over 23,000 products from 2,600 manufactures and is available from: http://www.abledata.com

More information about this NSF program is available at http://nsf-pad.bme.uconn.edu

The remainder of this paper illustrates three different approaches to the design course experience under this initiative, and also describes an annual publication sponsored by the NSF. At the University of Connecticut (UConn), a WWW-based approach is used in the course for communication among students and clients. At Texas A&M University, the students work on many small design projects during the two-semester senior design course sequence. At North Dakota State University, students work on a single project during the two-semester senior design course sequence in a team-based environment.

UNIVERSITY OF CONNECTICUT SENIOR DESIGN

In August 1998 the Department of Electrical & Systems Engineering (ESE) at UConn received a five-year grant from the National Science Foundation to build devices and software for persons with disabilities (clients) as part of the senior design capstone engineering courses. The NSF project was a pronounced change from previous design experiences at UConn that involved industry-sponsored projects carried out by a team of student engineers. In order to provide effective communication between the sponsor and the student team, a WWW-based approach was implemented [2]. Under the new scenario, students worked individually on a project and were divided into teams for weekly meetings. The purpose of the team was to provide student-derived technical support at weekly team meetings. Teams also formed throughout the semester based on need to solve technical problems. After the problem was solved the team dissolved and new teams were formed.

Each year, twenty-five projects will be carried out by the students at UConn. After the first year, five of the twenty-five projects will be carried out at Ohio University using distance learning (video conferencing) and the use of a web site similar to experiences currently seen in industry.

ESE senior design consists of two required courses, Electrical Engineering (EE) Design I and II. EE Design I is a two-credit hour course in which students are introduced to a variety of subjects. These include: working on teams, design process, planning and scheduling (time-lines), technical report writing, proposal writing, oral presentations, ethics in design, safety, liability, impact of economic constraints, environmental considerations, manufacturing and marketing. Each student in EE Design I:

- selects a project to aid a disabled individual after interviewing a person with disabilities;
- drafts specifications;
- prepares a project proposal;
- selects an optimal solution and carries out a feasibility study;
- specifies components, conducts a cost analysis and creates a time-line;

- creates a paper design with extensive modeling and computer analysis.

EE Design II is a three-credit hour course following Design I. This course requires students to implement their design by completing a working model of the final product. Prototype testing of the paper design typically requires modification to meet specifications. These modifications undergo proof of design using commercial software programs commonly used in industry. Each student in EE Design II:

- constructs and tests a prototype using modular components as appropriate;
- conducts system integration and testing;
- assembles final product and field-tests the device;
- writes a final project report;
- presents an oral report using *PowerPoint* on Senior Design Day;
- gives the device to the person with disabilities after the person with disabilities or their guardian signs a waiver.

Course descriptions, student project homepages and additional resources are located at http://www.ee.uconn.edu/ design/.

Year 1

Because the start of the grant and the beginning of the Fall semester were within days of each other, this created a massive start-up effort involving two academic units at UConn. Due to the overwhelming activity level, a proposed distance learning component of the course involving some student projects to be carried out at Ohio University was not initiated for year 1. This portion of the program will be initiated during the second year.

The first phase involved creating a database of persons with disabilities and then linking the student with a person with disability. The A.J. Pappanikou Center provided a database with almost 60 contacts and a short description of the disabilities in MS Access. The involvement of the Center was essential for the success of the program. The A.J. Pappanikou Center is Connecticut's University Affiliated Program (UAP) for disabilities studies. As such, relationships have been established with the Connecticut community of persons affected by disabilities, including families, caregivers, advocacy and support groups and, of course, persons with disabilities themselves. The A.J. Pappanikou Center serves as the link between the person in need of the device and the ESE Design course staff. The A.J. Pappanikou Center has established ongoing relationships with Connecticut's Regional Educational Service Centers, the Birth to Three Network, the Connecticut Tech Act Project, and the Department of Mental Retardation. Through these contacts, the Center facilitates the interaction between the ESE students, the professionals providing support services such as the speech-language, physical and occupational therapists (client coordinators), the individuals with disabilities (clients), and clients' families.

Project selection and project statement

The next phase of the course involved the student selecting a project. Using the database, the student selected two clients to interview that no other student has visited. The student and a UConn staff member met with the client and/or client coordinator to identify a project that would improve the quality of life for the client. After the interview, the student wrote a brief description for each project. Almost all of the clients interviewed had multiple projects. Project descriptions included: contact information [client, client coordinator, and student name] and short paragraph describing the problem. These reports were collected and put into a notebook, called the Project Notebook, and sorted by topic area. In the future, these projects will be stored in a database accessible from the course server for ease in communication. Twenty-one students were involved in client interviews during the Fall 98 semester and three students during Spring 99 semester. These projects are being presented at the 1999 Northeast Biomedical Engineering Conference. This was a very time intensive activity for the students and staff because of the distances involved, and the time involved in preparing interview questions and carrying out the interview.

Each student then selected a project from a client that he/she has visited, or from the Project Book. If the project selected was from the Project Notebook, the student visited the client to further refine the project. Because some projects did not involve a full academic year to complete, some students worked on multiple projects. The student submitted a project statement that described the problem that included a statement of need, basic preliminary requirements, basic limitations, other data accumulated and important unresolved questions.

Specifications

One of the most important parts of the design process is determining the requirements that the design project must fulfill. Before the design of a project, a statement as to how the device functions is required based on operational specifications. Specifications determine the device to be built, but do not provide any information about how the device is built. Specifications also include a technical description of the device, and contain, usually in tabular format, all of the facts and figures needed to complete the design project.

Prior to the design of a project, a statement as to how the device will function is required based on operational specifications. These specifications determine the problem to be solved. The operational specifications completely describe and define the project. Specifications are defined such that any competent engineer is able to design a device that will perform a given function. If several engineers design a device from the same specifications, all of the designs would perform within the given tolerances and satisfy the requirements; however, each design would be different. No manufacturer's name or components are stated in specifications. For example, specifications do not list electronic components or even a microprocessor since use of these components implies that a design choice has been made.

If the design project involves modifying an existing device, the device is fully described in as much detail as possible in the specifications. In this case, it is desired to describe the device by discussing specific components, such as the microprocessor, displays, and electronic components. This level of detail in describing the existing device is appropriate because it defines the environment to which the design project must interface. However, the specifications for the modification should not provide any information about how the device is to be built.

Specifications written at UConn report qualitatively describing the project as completely as possible, and how the project will improve the life of the disabled person. It also provides motivation for carrying out the project in the specifications. The following issues are also addressed in the specifications:

- What will the finished device do?
- What is unusual about the device?

A table listing all electrical, mechanical, environmental, software specifications and other details are also provided.

Project proposal

Each student writes a proposal whose purpose is to motivate upper management to fund the project. The proposal introduces the project in layperson terms, examines the market place identifying existing products that have similar specifications, and presents a preliminary budget and timeline. Extensive research using previous NSF project publications (for example, see [3]) and ABLEDATA are carried out for completeness. The student presents the proposal using MicroSoft *PowerPoint* to the class. Following this, the student then presents the proposal to the client and/or client coordinator.

Paper design and analysis

The next phase of the design is the generation of possible solutions to the problem based on the specifications, and selecting the optimal solution. This involves creating a paper design for each of the solutions and evaluating performance based on the specifications. Since design projects are open-ended, many solutions exist, solutions that often require a multidisciplinary system or holistic approach for a successful and useful project. This stage of the design process is typically the most challenging because of the creative aspect to generating problem solutions.

The specifications previously described are the criteria for selecting the best design solution. In many projects, some specifications are more important than others and trade-offs between specifications may be necessary. In fact, it may be impossible to design a project that satisfies all of the design specifications. Specifications that involve some degree of flexibility are helpful in reducing the overall complexity, cost and effort in carrying out the project. Some specifications are absolute and cannot be relaxed whatsoever.

Most projects are designed in a top-down approach similar to the approach of writing computer software by first starting with a flow chart. After the flow chart or block diagram is complete, the next step involves providing additional details to each block in the flow chart. This continues until sufficient detail exists to determine whether the design meets the specifications after evaluation.

To select the optimal design, it is necessary to analyze and evaluate the possible solutions. For ease in analysis, it is usually easiest to use computer software. For example, *PSpice*, a circuit analysis program, easily analyzes circuit analysis problems and also allows printed-circuit board fabrication. Other situations require a potential design project solution be partially constructed or breadboarded for analysis and evaluation. After analysis of all possible solutions, the optimal design selected is the one that meets the specifications most closely.

Construction and evaluation of the device

After selecting the optimal design, the student then constructs the device. The best method of construction is to build the device module by module. By building the project in this fashion, the student is able to test each module for correct operation before adding it to the complete device, composed of previously tested modules. It is far easier to eliminate problems module by module than to build the entire project, and then attempt to eliminate problems.

Design projects are analyzed and constructed with safety as one of the highest priorities. Clearly, the design project that fails should fail in a safe manner, a fail-safe mode, without any dramatic and harmful outcomes to the client or those nearby. An example of a fail-safe mode of operation for an electrical device involves grounding the chassis, and using appropriate fuses; thus if ever a 120-volt line voltage short circuit to the chassis should develop, a fuse would blow and no harm to the client would occur. Devices should also be protected against runaway conditions during the operation of the device, and also during periods of rest. Failure of any critical components in a device should result in the complete shutdown of the device.

After the project has undergone laboratory testing, it is then tested in the field with the client. After the field test, modifications are made to the project, and then the project is given to the disabled person. Ideally, the design project in use by the disabled person should be periodically evaluated for performance and usefulness after the project. Evaluation typically occurs, however, when the device no longer performs adequately for the disabled person, and is returned to the university for repair or modification. If the repair or modification is simple, a university technician will handle the problem. If the repair or modification is more extensive, another design student is assigned to the project to handle the problem as part of their design course requirements.

Documentation

Throughout the design process, the student is required to document the optimal or best solution to the problem through a series of required written assignments. For the final report, documenting the design project involves integrating each of the required reports into a single final document. While this should be a simple exercise, it is usually a most vexing and difficult endeavor. Many times during the final stages of the project, some specifications are changed, or extensive modifications to the ideal paper design are necessary.

UConn ESE Design require the final report be professionally prepared using desktop publishing software. This requires that all circuit diagrams and mechanical drawings be professionally drawn. Illustrations are usually drawn with computer software, such as *VisioPro Technical* or *AutoCAD.*

WWW-based approach

To facilitate working with sponsors, a WWW-based approach is used for reporting the progress on projects. Students are responsible for creating their own WWW sites that support both html and pdf formats with the following elements:

- introduction for layperson
- resume
- weekly reports
- project statement
- specifications
- proposal
- final report.

Weekly schedule

Weekly activities in EE Design I consist of lectures, student presentations and a team meeting with the instructor. Technical and non-technical issues that impact the design project are discussed during team meetings. Students also meet with clients/coordinators at scheduled times to report on progress.

Each student is expected to provide an oral progress report on his or her activity at the weekly team meeting with the instructor, and record weekly progress in a bound notebook and on the WWW site. Weekly report structure for the WWW includes: project identity, work completed during the past week, current work within the last day, future work, status review and with at least one graphic inserted into the report. The client and/or client coordinator uses the WWW reports to keep up with projects so that they can provide input on the progress. Weekly activities in EE Design II include team meetings with the course instructor, oral and written progress reports, and construction of the project. As before, the Web is used to report project progress and communicate with the sponsors.

TEXAS A&M UNIVERSITY ENGINEERING DESIGN EXPERIENCES

The objective of the NSF program at Texas A&M University is to provide senior bioengineering students an experience in the design and development of rehabilitation devices and equipment to meet explicit client needs identified at several off-campus rehabilitation and education facilities. Texas A&M has participated in the NSF program for more than five years. The students meet with therapists and/or special education teachers for problem definition under the supervision of the faculty. The type of design experience offered in this program provides very significant real-world design experiences, emphasizing completion of a finished product. Moreover, the program brings needed technical expertise to the not-for-profit rehabilitation service providers that would otherwise not be available to them. Additional benefits to the participating students involve their development of an appreciation of the problems of disabled persons, motivation toward rehabilitation engineering as a career path, and recognition of the need for more long-term research to address the problems for which today's designs are only an incomplete solution.

The engineering design experience in the bioengineering program at Texas A&M University involves a two-course capstone design sequence, BIEN 441 and 442. BIEN 441 is offered during the Fall and Summer semesters, and BIEN 442 is offered during the Spring semester. The inclusion of the summer term allows a full year of ongoing design activities. Students are allowed to select a rehabilitation design project, or another general bioengineering design project.

The faculty at Texas A&M University involved with the rehabilitation design course have worked in collaboration with the local school districts, community rehabilitation centers, residential units of the Texas Department of Mental Health and Mental Retardation (MHMR), community outreach programs of Texas MHMR, and individual clients of the Texas Rehabilitation Commission and Texas Commission for the Blind.

Appropriate design projects are identified in group meetings between the staff of the collaborating agency, the faculty, and the participating undergraduate students enrolled in the design class. In addition, one student is employed in the design laboratory during the summer to provide logistical support, as well as pursue his or her own project. Each student is required to participate in the project definition session, which adds to the overall design experience. The meetings take place at the beginning of each semester, and periodically thereafter as projects are completed and new ones identified.

Faculty feel the needs expressed by the collaborating agencies which often result in projects of varying complexity and time to completion. To meet the broad spectrum of needs, simpler projects are accommodated by requiring their rapid completion, at which point the students move on to another project. More difficult projects involve one or more semesters, or even a year's effort; these projects are the ones that typically require more substantial quantitative and related engineering analysis. Projects are carried out by individual students or a team of two.

Following the project definition, the students proceed through the formal design process of brainstorming, clarification of specifications, preliminary design, review with the collaborating agency, design execution and safety analysis, documentation, prerelease design review, and delivery and implementation in the field. The execution phase of the design includes identifying and purchasing necessary components and materials, arranging for any fabrication services that may be necessary, and obtaining photography for their project reports. Throughout each phase of the project, the faculty supervises the work, as well as the teaching assistants assigned to the rehabilitation engineering laboratory. These teaching assistants are paid for with university funds. The students also have continued access to the agency staffs for clarification or revision of project definitions, and review of preliminary designs. The latter is an important aspect of meeting real needs with useful devices. In addition to individual and team progress, the rehabilitation engineering group meets as a group to discuss design ideas and project progress, and to plan further visits to the agencies.

One challenging aspect of having students responsible for projects that are eagerly anticipated by the intended recipient is the sometimes variable quality of student work, and the inappropriateness of sending inadequate projects into the field. This potential problem is resolved at Texas A&M University by continuous project review, and the requirement that the project be revised and reworked until it meets approval by the faculty.

At the end of each academic year, the faculty and the personnel from each collaborating agency assess which types of projects met with the greatest success in achieving useful delivered devices. This review has provided an ongoing guidance in the selection of future projects. The faculty also maintains continuous contact with agency personnel with respect to ongoing projects, and past projects, that requires repair or modification. In some instances, repairs are assigned as short-term projects to currently participating students. This provides an excellent lesson in the importance of adequate documentation.

Feedback from participating students is gathered each semester using the Texas A&M University student opinionnaire form as well as personal discussion. The objective of the reviews has been to obtain the student's assessment of the educational value of the rehabilitation design program, the adequacy of the resources and supervision, and any suggestions for improving the process.

NORTH DAKOTA STATE UNIVERSITY ENGINEERING DESIGN EXPERIENCE

North Dakota State University (NDSU) has participated in this program for more than five years. All senior electrical engineering students at NDSU are required to complete a two-semester senior design project as part of their study. These students are partitioned into faculty supervised teams of four to six students. Each team designs and builds a device for a particular disabled individual within eastern North Dakota or western Minnesota.

During the early stages of NDSU's participation in projects to aid the disabled, a major effort was undertaken to develop a complete and workable interface between the NDSU electrical engineering department and the disabled community to identify possible projects to aid the disabled. These organizations are the Fargo Public School System, NDSU Student Services and the Anne Carlson School. Mechanisms are in place so that NDSU students visit disabled individuals or their supervisors to identify possible design projects at one of the cooperating organizations. All of the senior design students visit one of these organizations at least once. After the site visit, the students write a report on at least one potential design project, and each team selects a project to aid a disabled individual.

The process of a design project is implemented in two parts. During the first semester of the senior year, each team writes a report describing the project to aid a disabled individual. Each report consists of an introduction to the project establishing the need for the project. The body of the report describes the device; a complete and detailed engineering analysis is included to establish that the device has the potential to work. Almost all of the NDSU projects involve an electronic circuit. Typically, devices that involve an electric circuit are analyzed using *PSpice,* or another software analysis program. Extensive testing is undertaken on subsystem components using breadboard circuit layouts to ensure a reasonable degree of success before writing the report. Circuits are drawn for the report using *OrCAD,* a CAD program. The *OrCAD* drawings are also used in the second phase of design, which allows the students to bring a circuit from the schematic to a printed-circuit board with relative ease.

During the second semester of the senior year, each team builds the device to aid the disabled individual. This first involves breadboarding the entire circuit to establish the viability of the design. After verification, the students build printed-circuit board(s) using *OrCAD*, and then finish the construction of the project using the fabrication facility in the electrical engineering department. The device is then fully tested, and after approval by the senior design faculty advisor, the device is given to the disabled individual. Each of the student design teams receives feedback throughout the year from the disabled individual (or their client coordinator) to ensure that the design meets its intended goal.

Each of the design teams provides an oral presentation during regularly held seminars in the department. In the past, local TV stations have filmed the demonstration of the senior design projects, and broadcast the tape on their news show. This media exposure usually results in viewers contacting the electrical engineering department with requests for projects to improve the life of another disabled individual, further expanding the impact of the program.

Design facilities are provided in three separate laboratories for analysis, prototyping, testing, printed-circuit board layout, fabrication, and redesign/development. The first laboratory is a room for team meetings during the initial stages of the design. Data books and other resources are available in this room.

There are also twelve workstations available for teams to test their design, and verify that the design parameters have been meet. These workstations consist of a power supply, waveform generator, oscilloscope, breadboard, and a collection of hand tools.

The second laboratory contains Intel computers for analysis, desktop publishing and microprocessor testing. The computers all have analysis, CAD and desktop publishing capabilities so that students may easily bring their design projects from the idea to implementation stage. A scanner with image enhancement software and a high-resolution printer are also available in the laboratory.

The third laboratory is used by the teams for fabrication. Six workstations exist for breadboard testing, soldering, and finish work involving printed-circuit boards. Sufficient countertop space exists so that teams may leave their projects in a secure location for easing work.

The electrical engineering department maintains a relatively complete inventory of electronic components necessary for these design projects, and when not in stock, has the ability to order parts with minimal delay. The department also has a teaching assistant assigned to this course on a year round basis, and an electronics technician available for help in the analysis and construction of the design project.

OTHER ENGINEERING DESIGN EXPERIENCES

Experiences at other universities participating in this NSF program combine many of the design program elements that are presented for UConn, Texas A&M University and NDSU. In addition to the design process elements already described, the State University of New York at Buffalo under the direction of Dr Joseph Mollendorf, requires that each student go through the preliminary stages of a patent application. Naturally, those projects worthy of a patent application are actually submitted. Thus far, a patent was issued for a 'four-limb exercising attachment for wheelchairs' and another patent has been allowed for a 'cervical orthosis'.

The senior design projects constructed by these students have proved beneficial to the student, the disabled individual, the community, and the university. The impact of these grants on the student is felt not only during the time of project construction and afterwards in the project's use by the disabled individual, but also in the involvement of these students into community-minded service.

NSF ANNUAL PUBLICATION

Since 1988, the NSF has also funded a book series, published annually entitled, *NSF Engineering Senior Design Projects to Aid the Disabled,* reporting on these design projects. These books are available for viewing at http://nsf-pad.bme.uconn.edu. Each annual publication describes and documents the NSF-supported senior design projects during the preceding academic year. The introduction provides background material on the book, elements of design, and illustrative engineering design experiences at universities that participated in this effort. After the introduction, each chapter that follows is devoted to one participating school. These chapters begin by completely identifying the school and the principal investigator(s). Following the chapter introduction for the school, each senior design project description is written using the following format. On page one, the individuals involved with the project are identified, including the student(s), the professor(s) who supervised the project, and the many professionals involved in the daily lives and education of the disabled individual. A brief nontechnical description of the project follows with a summary of the impact on how the project has improved the quality of life of the disabled person. A photograph of the device or the device modification is usually included. Following this, a technical description of the device or device modification is given, with parts specified only if they are of such a special nature that the project could not be fabricated without knowing the exact identity of the part. A circuit and mechanical drawing is usually provided in each report. An approximate cost of the project is given for each project, excluding personnel costs. Most projects are described in two pages. However, the first or last project in each chapter is usually significantly longer and contains more analytic content. The last chapter in the each book contains an index so that projects can be identified by type and technologies used.

Individuals wishing more information on a particular design can contact the designated supervising principal investigator. The information in these publications is not restricted in any way. Individuals are encouraged to use the project descriptions in the creation of future design projects for persons with disabilities. The NSF and the editors make no representations or warranties of any kind with respect to these senior design projects, and specifically disclaim any liability for any incidental or consequential damages arising from the use of this publication.

Purpose of the publication

The purpose of this publication is twofold. One obvious purpose is to serve as a reference or handbook for future senior design projects. Students are exposed to a unique body of applied information on current technology in these books. This provides an even broader education typically experienced in an undergraduate curriculum, especially in the area of rehabilitation design. Many technological advances originate from work in the space, defense, entertainment and communications industry are made known to students in their undergraduate curriculum. Few of these advances have been applied to the rehabilitation field, making the contributions of this NSF program all the more important. Secondly, it is hoped that this publication serves to motivate both students and graduate engineers, and others to work more actively in rehabilitation, leading to an increased technology and knowledge base to effectively address the needs of persons with disabilities. Finally, it is desired that this publication act as a reference for individuals dealing with implementing the Americans with Disabilities Act of 1990.

The following lists the number of chapters and pages in each edition of the book series:

- 1989 Edition: 18 Chapters, 317 pages
- 1990 Edition: 22 Chapters, 388 pages
- 1991 Edition: 21 Chapters, 292 pages
- 1992 Edition: 22 Chapters, 319 pages
- 1993 Edition: 20 Chapters, 240 pages
- 1994 Edition: 21 Chapters, 247 pages
- 1995 Edition: 21 Chapters, 314 pages
- 1996 Edition: 14 Chapters, 250 pages

The books were published by NDSU Press from 1989–1993 and Creative Learning Press from 1994 on. The reports in the books may be freely reproduced and distributed as long as the source is credited. New features in the forthcoming 1997 edition will be chapters on a WWW-based approach to design, outcome assessment and design best practices.

CONCLUSION

This paper provides an overview of the NSF Senior Design Projects to Aid Persons with Disabilities program, experiences at three universities and the annual NSF-sponsored publication *Engineering Senior Design Projects to Aid the Disabled,* reporting on these design projects. This NSF program combines the academic requirement of a design experience with enhanced educational opportunities for students, and improved the quality of life for the person with disabilities. The objective of the NSF annual publication is to enhance the overall quality of future senior design projects directed toward persons with disabilities by providing examples of previous projects, and to motivate other universities to participate because of the potential benefits to the student, school, and community. The ultimate goal of both this publication and all the projects that were built under this initiative is to assist individuals with disabilities in reaching toward their maximum potential for enjoyable and productive lives.

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