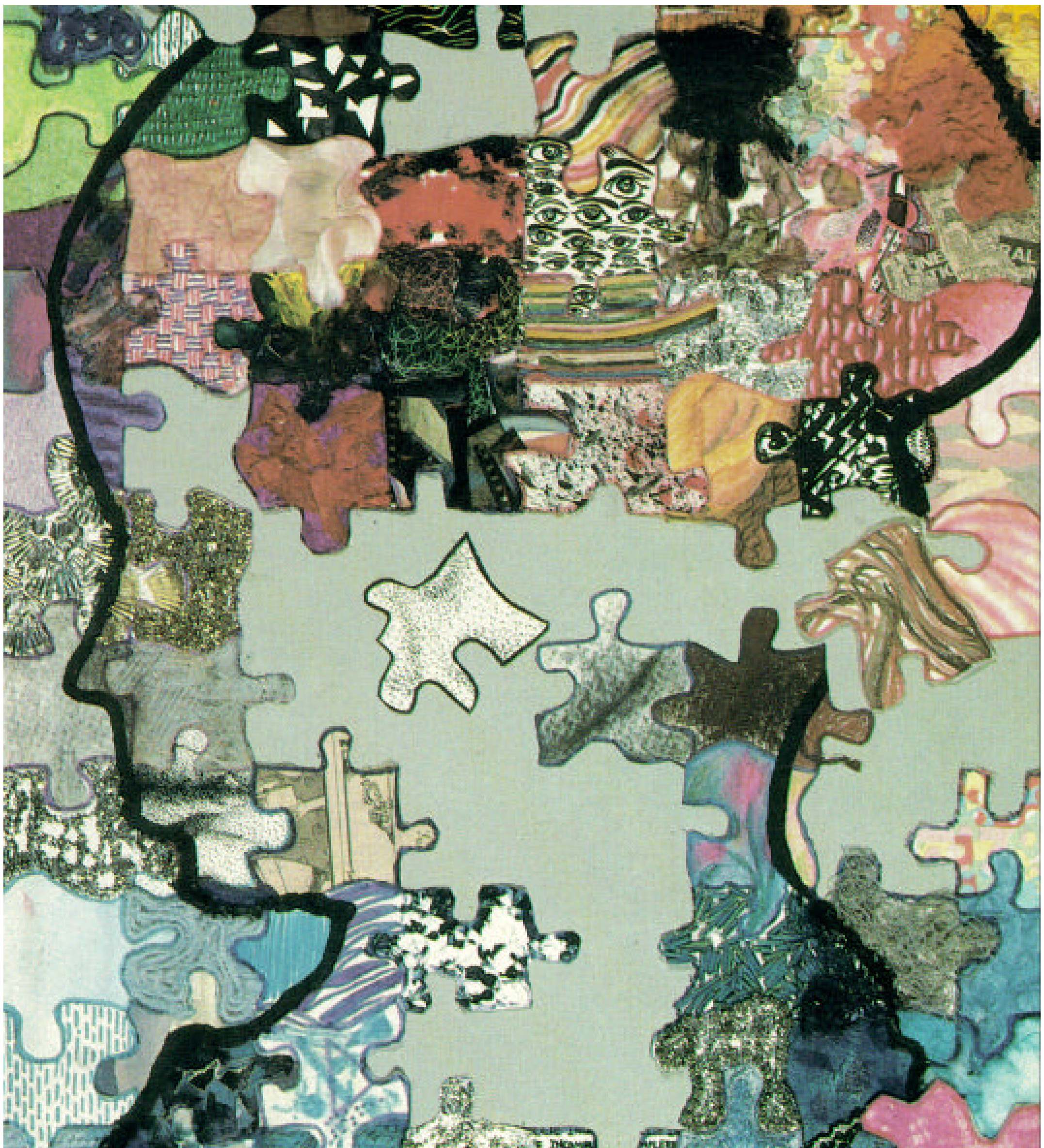
NATIONAL SCIENCE FOUNDATION 1998 ENGINEERING SENIOR DESIGN PROJECTS TO AID PERSONS WITH DISABILITIES



Edited By
John D. Enderle
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FOREWORD

Welcome to the tenth annual issue of the National Science Foundation Engineering Senior Design Projects to Aid Persons with Disabilities. 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 individuals with disabilities. Through the Bioengineering and Research to Aid the Disabled (BRAD) program of the Emerging Engineering Technologies Division of NSF,[1] funds were awarded competitively to 16 universities to pay for supplies, equipment and fabrication costs for the design projects. A book entitled, *NSF 1989 Engineering Senior Design Projects to Aid the Disabled* was published in 1989, reporting on the projects that were funded during the first year of this effort.

In 1989, the BRAD program of the Emerging Engineering Technologies Division of NSF increased the number of universities funded to 22 in 1989. Following completion of the 1989-1990 design projects, a second book was published, describing these projects, entitled, *NSF 1990 Engineering Senior Design Projects to Aid the Disabled*.

North Dakota State University (NDSU) Press published the following three issues. *NSF 1991 Engineering Senior Design Projects to Aid the Disabled* described the almost 150 projects carried out by students at 20 universities across the United States during the academic year 1990-91. *NSF 1992 Engineering Senior Design Projects to Aid the Disabled* presented the almost 150 projects carried out by students at 21 universities across the United States during the 1991-92 academic year. The fifth issue described 91 projects carried out by students at 21 universities across the United States during the 1992-93 academic year.

Creative Learning Press, Inc. has published the succeeding volumes. *NSF 1994 Engineering Senior Design Projects to Aid the Disabled,* published in 1997, described 94 projects carried out by students at 19 universities across the United States during the academic 1993-94 year.

NSF 1995 Engineering Senior Design Projects to Aid the Disabled, published in 1998, described 124 projects carried out by students at 19 universities during the 1994-95 academic year.

NSF 1996 Engineering Senior Design Projects to Aid Persons With Disabilities, published in 1999, presented 93 projects carried out by students at 12 universities during the 1995-96 academic year.

The ninth issue, *NSF 1997 Engineering Senior Design Projects to Aid Persons with Disabilities*, published in 2000, included 124 projects carried out by students at 19 universities during the 1994-95 academic year.

This book, funded by the NSF, describes and documents the NSF-supported senior design projects during the tenth year academic year of this effort, 1997-98. Each chapter, except for the first three, describes activity at a single university, and was written by the principal investigator(s) at that university, and revised by the editors of this publication. Individuals wishing more information on a particular design should contact the designated supervising principal investigator. An index is provided so that projects may be easily identified by topic.

It is hoped that this book will enhance the overall quality of future senior design projects directed toward persons with disabilities by providing examples of previous projects, and by motivating faculty at other universities to participate because of the potential benefits to students, schools, and communities. Moreover, the new technologies used in these projects will provide examples in a broad range of applications for new engineers. 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 their maximum potential for enjoyable and productive lives.

This NSF program has brought together individuals with widely varied backgrounds. Through the rich-

[1] 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.

ness of their interests, a wide variety of projects were completed, and are in use. A number of different technologies were incorporated in the design projects, to maximize the impact of each device on the individual for whom it was developed.

A two-page project description format is generally used in this text. Each project is introduced with a nontechnical description, followed by a summary of impact that illustrates the effect of the project on an individual's life. A detailed technical description then follows. Photographs of the devices and other important components are incorporated throughout the manuscript.

None of the faculty received financial remuneration for supervising the building of devices or writing software within this program. Each participating university typically has made a five-year commitment to the program.

Sincere thanks are extended to Dr. Allen Zelman, a former Program Director of the NSF BRAD program, for being the prime enthusiast behind this initiative. Additionally, thanks are extended to Drs. Peter G. Katona, Karen M. Mudry, Fred Bowman and Gil Devey, former and current NSF Program Directors of the Biomedical Engineering and Research to Aid Persons with Disabilities Programs, who have continued to support and expand the program.

We acknowledge and thank Ms. Shari Valenta for the cover illustration and the artwork throughout the book, drawn from her observations at the Children's Hospital Accessibility Resource Center in Denver, Colorado. We also acknowledge and thank Mr. William Pruehsner for technical illustrations and Dr. Leon Anderson, Ms. Lollie Vaughan, Ms. Leetal Cuperman, Ms. Kirsten Carr, Ms. Carrie Brannon, and Mrs. Jean Hallowell for editorial assistance.

Readers familiar with previous editions of this book will note that John Enderle moved from North Dakota State University to the University of Connecticut in 1995. With that move, annual publications also moved from NDSU Press to Creative Learning Press Inc. in 1997. During 1994, Enderle also served as NSF Program Director for the Biomedical Engineering & Research Aiding Persons with Disabilities Program while on a leave of absence from NDSU.

Brooke Hallowell is a faculty member in the School of Hearing and Speech Sciences at Ohio University. Hallowell's primary area of expertise is in neurogenic communication disorders. She has a long history of collaboration with colleagues in biomedical engineering, in curriculum development, teaching, assessment, and research.

The editors welcome any suggestions as to how this review may be made more useful for subsequent yearly issues. Previous editions of this book are available for viewing at the WEB Site for this project:

http://nsf-pad.bme.uconn.edu/.

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1998
ENGINEERING SENIOR DESIGN PROJECTS TO AID PERSONS WITH DISABILITIES

CHAPTER 1
INTRODUCTION

John Enderle and Brooke Hallowell

Devices and software to aid persons with disabilities often need custom modification, are prohibitively expensive, or nonexistent. Many persons with disabilities do not have access to custom modification of available devices and other benefits of current technology. Moreover, when available, engineering and support salaries often make the cost of custom modifications beyond the reach of the persons who need them.

In 1988, the National Science Foundation (NSF), through its Emerging Engineering Technologies Division, initiated a program to support student engineers at universities throughout the United States designing and building devices for persons with disabilities. Since its inception, this NSF program (originally called Bioengineering and Research to Aid the Disabled) has enhanced educational opportunities for students and improved the quality of life for individuals with disabilities. Students and university faculty provide, through their Accreditation Board for Engineering and Technology (ABET) accredited senior design class, engineering time to design and build the device or software. The NSF provides funds, competitively awarded to universities for supplies, equipment and fabrication costs for the design projects.

Outside of the NSF program, students are typically involved in design projects that incorporate academic goals for solid curricular design experiences, but that do not necessarily enrich the quality of life for persons other than, perhaps, the students themselves. For instance, students might design and construct a stereo receiver, a robotic unit that performs a household chore, or a model racecar.

Under this NSF program, engineering design students are involved in projects that result in original devices, or custom modifications of devices, that improve the quality of life for persons with disabilities. The students have opportunities for practical and creative problem solving to address well-defined needs, and persons with disabilities receive the products of that process. There is no financial cost incurred by the persons served in this program. Upon completion, the finished project becomes the property of the individual for whom it was designed.

The emphases of the program are to:

- Provide disabled children and adults student-engineered devices or software to improve their quality of life and provide greater for self-sufficiency;

- Enhance the education of student engineers by designing and building a device or software that meets a real need; and

- Allow the university an opportunity for unique service to the local community.

Local school districts and hospitals participate in the effort by referring interested individuals to the program. A single student or a team of students specifically designs each project for an individual or a group of individuals with a similar need. Examples of projects completed 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. The students participating in this project have been singularly rewarded through their activity with persons with disabilities, and justly have experienced a unique sense of purpose and pride in their accomplishment.

The Current Book

This book describes the NSF supported senior design projects during the tenth year of this effort during the academic year 1997-98. The purpose of this publication is twofold. First, it is to serve as a reference or handbook for future senior design projects. Students are exposed to this unique body of applied information on current technology in this and previous editions of this book. This provides an even broader education than 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. 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 will serve to motivate students, graduate engineers and others to work more actively in rehabilitation. This will ideally lead to an increased technology and knowledge base to effectively address the needs of persons with disabilities.

This introduction provides background material on the book, elements of design, and highlights the engineering design experiences at three universities that have participated in this effort.

After the introduction, 17 chapters follow, with each chapter devoted to one participating school. At the start of each chapter, the school and the principal investigator(s) are identified. Each 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 key professionals involved in the daily lives of the individual for whom the project has been developed. A brief nontechnical description of the project follows with a summary of how the project has improved a person's quality of life. A photograph of the device or the device modification is usually included. Next, 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 otherwise be fabricated. An approximate cost of the project is provided, 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. Individuals wishing more information on a particular design should contact the designated supervising principal investigator.

Some of the projects described are custom modifications of existing devices, modifications that would be prohibitively expensive were it not for the student engineers and this NSF program. Other projects are unique one-of-a-kind devices wholly designed and constructed by the student for the disabled individual.

Engineering Design

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.[1, 2] Many call this the *capstone course*. Engineering design is a course or series of courses that brings together concepts and principles that students learn in their field of study. It involves the integration and extension of material learned throughout an academic program to achieve a specific design goal. Most often, the student is exposed to system-wide analysis, critique and evaluation. Design is an iterative decision making process in which the student optimally applies previously learned material to meet a stated objective.

There are two basic approaches to teaching engineering design, the traditional or discipline-dependent approach, and the holistic approach. The traditional approach involves reducing a system or problem into separate discipline-defined components. This approach minimizes the essential nature of the system as a holistic or complete unit, and often neglects the interactions that take place between the components. The traditional approach usually involves a sequen-

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[1] Accrediting Board for Engineering and Technology (1999). Accreditation Policy and Procedure Manual Effective for Evaluations for the 2000-2001 Accreditation Cycle. ABET: Baltimore, MD.
[2] Accrediting Board for Engineering and Technology (2000). Criteria for Accrediting Engineering Programs. ABET: Baltimore, MD.

tial, iterative approach to the system or problem, and emphasizes simple cause-effect relationship.

A more holistic approach to engineering design is becoming increasingly feasible with the availability of powerful computers and engineering software packages, and the integration of systems theory, which addresses interrelationships among system components as well as human factors. Rather than partitioning a project based on discipline-defined components, designers partition the project according to the emergent properties of the problem.

A design course provides opportunities for problem solving relevant to 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 the device or system to design
- Writes specifications
- Creates a paper design
- Analyzes the paper design
- Constructs the device
- Evaluates the device
- Documents the design project

Project Selection

In a typical NSF design project, the student meets with the client (a person with a disability and/or a client coordinator) to assess needs and to help identify a useful project. Often, the student meets with many clients before finding a project for which his or her background is suitable.

After selecting a project, the student then writes a brief description of the project for approval by the faculty supervisor. Since feedback at this stage of the process is vitally important for a successful project, students usually meet with the client once again to review the project description.

Projects are often undertaken by teams of students. One or more members of a team meet with one or more clients before selecting a project. After project selection, the project is partitioned by the team into logical parts, and each student is assigned one of these parts. Usually, a team leader is elected by the team to ensure that project goals and schedules are satisfied. A team of students generally carries out multiple projects.

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
or
(800) 227-0216

More information about this NSF program is available at:

http://nsf-pad.bme.uconn.edu

Specifications

One of the most important parts of the design process is determining the specifications, or requirements that the design project must fulfill. There are many different types of hardware and software specifications.

Prior to the design of a project, a statement as to how the device will function is required. Operational specifications are incorporated in determining the problem to be solved. Specifications are defined such that any competent engineer is able to design a device that will perform a given function. Specifications determine the device to be built, but do not provide information about how the device is built. 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 modification should be fully described in as much detail as possible in the specifications. Specific components of the device, such as microprocessors, LEDs, and electronic parts, should be described. Descriptive detail 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 are usually written in a report that qualitatively describes the project as completely as possible, and how the project will improve the life of an individual. It is also important to explain the motivation for carrying out the project. The following issues are addressed in the specifications:

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

Specifications include a technical description of the device, and all of the facts and figures needed to complete the design project. The following are examples of important items included in technical specifications.

Electrical Parameters

interfaces
voltages
impedances
gains
power output
power input
ranges
current capabilities
harmonic distortion
stability
accuracy
precision
power consumption

Mechanical

size
weight
durability
accuracy
precision
vibration

Environmental

location
temperature range
moisture
dust

Paper Design and Analysis

The next phase of the design is the generation of possible solutions to the problem based on the specifications, and selection of 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 product. 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.

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 flowchart. 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. Other situations require that 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. It is far easier to eliminate problems module by module than to build the entire project, and then attempt to eliminate problems.

Design projects should be 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-V 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 client. Ideally, the design project in use by the disabled person should be periodically evaluated for performance and usefulness after the project is complete. 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.

Most universities also require that 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 OrCAD or AutoCAD.

The two-page reports within this publication are not representative of the final reports submitted for design course credit, and in fact, are a summary of the final report. A typical final report for a design project is approximately 30 pages in length, and includes extensive analysis supporting the operation of the design project. Usually, photographs of the device are not included in the final report since mechanical and electrical diagrams are more useful to the engineer to document the device.

The next three sections illustrate different approaches to the design course experience. 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. At the University of Connecticut, students are involved in distance learning and a WWW based approach.

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 six years. The students meet with therapists and/or special education teachers for problem definition under faculty supervision. This program provides very significant “real world” design experiences, emphasizing completion of a finished product. Moreover, the program brings needed technical expertise that would otherwise not be available to not-for-profit rehabilitation service providers. 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.

Texas A&M University's program 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.

The needs expressed by the collaborating agencies often result in projects that vary in complexity and required duration. To meet the broad spectrum of needs, simpler projects are accommodated by requiring 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 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 be responsible for projects that are eagerly anticipated by the intended recipient is the 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 by requiring that the project be revised and reworked until it meets faculty approval.

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 ongoing guidance in the selection of future projects. The faculty also maintains continuous contact with agency personnel with respect to ongoing and past projects that require 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 "oppinionaire" form as well as personal discussion. The objective of the reviews is to obtain students' 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 six 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 community of persons with disabilities to identify potential projects. These organizations are the Fargo Public School System, NDSU Student Services and the Anne Carlson School. NDSU students visit potential dients 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 particular 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 an 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 electrical 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 an individual. This first involves breadboarding the entire circuit to establish the viability of the design. After verification, the students build a 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 client. Each of the student design teams receives feedback throughout the year from the client or client coordinator to ensure that the design meets its intended goal.

Each design team 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 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. Analysis software supported includes Microsoft EXCEL and Lotus 123 spreadsheets, PSpice, MATLAB, MATHCAD, and VisSim. Desktop publishing supported includes Microsoft Word for Windows, Aldus PageMaker, and technical illustration software via AutoCAD and OrCAD. 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 ease in work.

The electrical engineering department maintains a relatively complete inventory of electronic components necessary for 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.

There were many projects constructed at NDSU (and probably at many other universities) that proved to be unsafe or otherwise unusable for the intended individual, despite the best efforts of the student teams under the supervision of the faculty advisors. These projects are undocumented.

University of Connecticut Design Experiences

In August 1998 the Department of Electrical & Systems Engineering (ESE) at UConn, in collaboration with the School of Hearing and Speech Sciences at Ohio University, received a five-year NSF grant for senior design experiences to aid persons with disabilities. This 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.[3] 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 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, 25 projects are carried out by the students at UConn. Five of the 25 projects are completed through collaboration with personnel at Ohio University using varied means of communication currently seen in industry, including video conferencing, the WWW, telephone, e-mail, postal mailings, and videotapes.

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; and
- 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 a design by completing a working model of the final product. Prototype testing of the paper design typically requires modification to meet specifications.

[3] Enderle, J.D., Browne, A.F., and Hallowell, B. (1998). A WEB Based Approach in Biomedical Engineering Design Education. Biomedical Sciences Instrumentation, 34, pp. 281-286.

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 final project report;
- Presents an oral report using PowerPoint on Senior Design Day; and
- Gives the device to the client after a waiver is signed.

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

The first phase of the on-campus projects involves creating a database of persons with disabilities and then linking the student with a person with a 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 Center serves as the link between the person in need of the device and the ESE Design course staff. The 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 client coordinators (professionals providing support services, such as the speech-language pathologists, physical and occupational therapists), the individuals with disabilities (clients), and clients' families.

The next phase of the course involves students' selection of projects. Using the on-campus database, each student selects two clients to interview. The student and a UConn staff member meet 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 writes a brief description for each project. Almost all of the clients interviewed have multiple projects. Project descriptions include: contact information (client, client coordinator, and student name) and a short paragraph describing the problem. These reports are collected, sorted by topic area, and put into a Project Notebook. In the future, these projects will be stored in a database accessible from the course server for ease in communication.

Each student then selects a project from a client that he/she has visited, or from the Project Notebook. If the project selected was from the Project Notebook, the student visits the client to further refine the project. Because some projects do not involve a full academic year to complete, some students work on multiple projects. Students submit a project statement that describes the problem, including a statement of need, basic preliminary requirements, basic limitations, other data accumulated, and important unresolved questions.

Specific projects at Ohio University are established via distance communication with the co-principal investigator, who consults with a wide array of service providers and potential clients in the Athens, Ohio region.

The stages of specification, project proposal, paper design and analysis, construction and evaluation, and documentation are carried out as described earlier in the overview of engineering design.

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

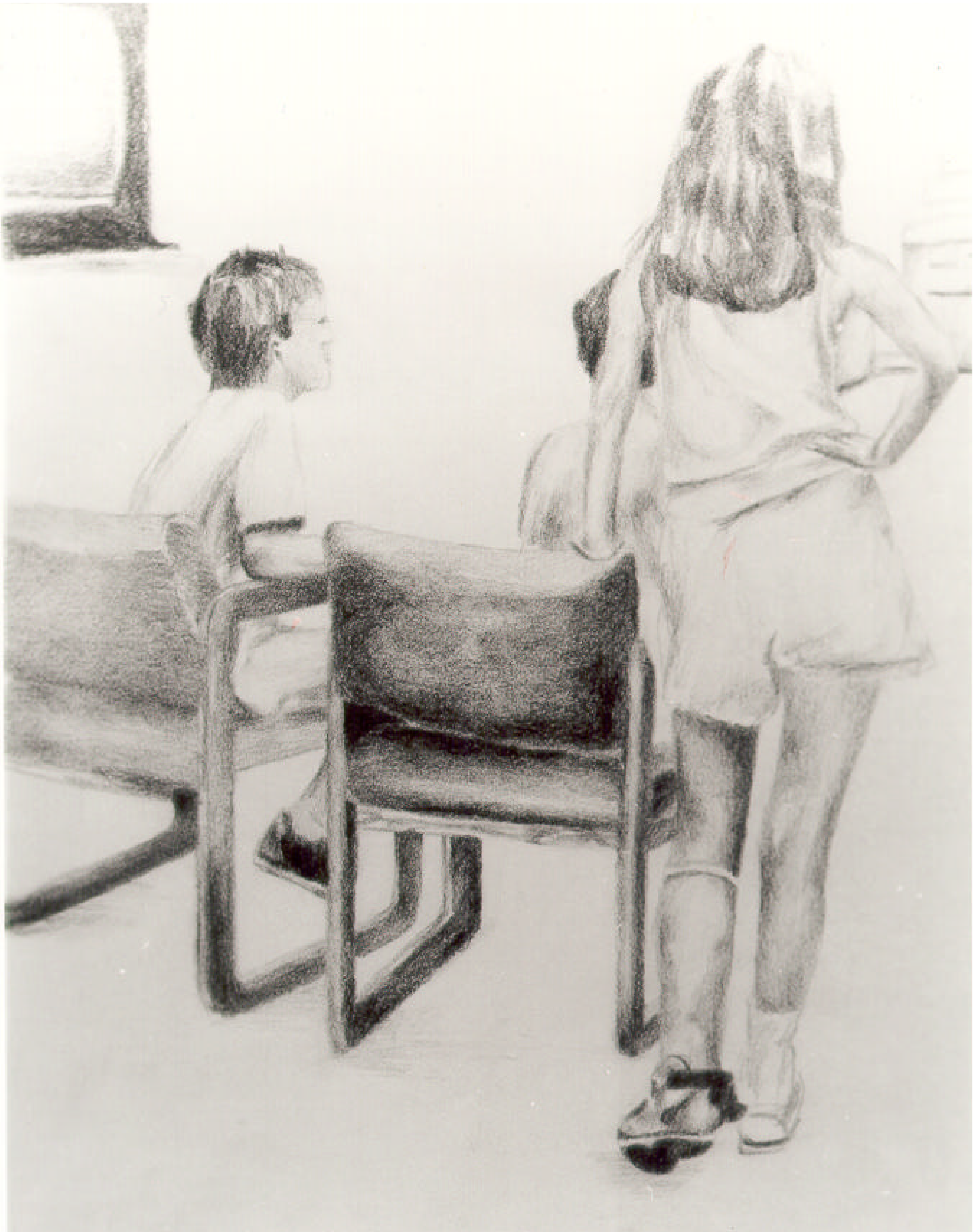
Weekly activities in EE Design I consist of lectures, student presentations and a team meeting with the instructor. Technical and non-technical issues that impact the design project are discussed during team meetings. Students also meet with clients/coordinators at scheduled times to report on progress.

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 at least one graphic. The client and/or client coordinator uses the WWW reports to keep up with project 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.

For the past two years, the student projects have been presented at the annual Northeast Biomedical Engineering Conference.

Other Engineering Design Experiences

Experiences at other universities participating in this NSF program combine many of the design program elements that are presented for Texas A&M University and North Dakota State University. Still, each university's program is unique. 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, 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."



CHAPTER 2
EDUCATIONAL OUTCOMES ASSESSMENT:IMPROVING DESIGN PROJECTS TO AID PERSONS WITH DISABILITIES

Brooke Hallowell

Of particular interest to persons interested in the engineering education are the increasingly outcomes focused standards of the Accrediting Board for Engineering and Technology (ABET).[4] This chapter is offered as an introduction to the ways in which improved foci on educational outcomes may lead to: (a) improvements in the learning of engineering students, especially those engaged in design projects to aid persons with disabilities, and consequently, (b) improved knowledge, design and technology to benefit individuals in need.

Brief History

As part of a movement for greater accountability in higher education, US colleges and universities are experiencing an intensified focus on the assessment of students' educational outcomes. The impetus for outcomes assessment has come most recently from accrediting agencies. All regional accrediting agencies receive their authority by approval from the Council for Higher Education Accreditation (CHEA), which assumed this function from the Council on Recognition of Postsecondary Accreditation (CORPA) in 1996. The inclusion of outcomes assessment standards as part of accreditation by any of these bodies, such as North Central, Middle States, or Southern Associations of Colleges and Schools, and professional accrediting bodies, including ABET, is mandated by CHEA, and thus is a requirement for all regional as well as professional accreditation. Consequently, candidates for accreditation are required to demonstrate plans for assessing educational outcomes, and evidence that assessment results have led to improved of teaching and learning and, ultimately, better preparation for entering the professions. Accrediting bodies have thus revised criteria standards for accreditation with greater focus on the "output" that students can demonstrate and less on the "input" they are said to receive.[5]

"Meaningful" Assessment Practices

Because much of the demand for outcomes assessment effort is perceived, at the level of instructors, as a bureaucratic chore thrust upon them by administrators and requiring detailed and time-consuming documentation, there is a tendency for many faculty

[4] Accrediting Board for Engineering and Technology (2000). Criteria for Accrediting Engineering Programs. ABET: Baltimore, MD.

[5] Hallowell, B. & Lund, N. (1998). Fostering program improvements through a focus on educational outcomes. In Council of Graduate Programs in Communication Sciences and Disorders, Proceedings of the nineteenth annual conference on graduate education, 32-56.

members to avoid exploration of effective assessment practices. Likewise, many directors of academic departments engage in outcomes assessment primarily so that they may submit assessment documentation to meet bureaucratic requirements. Thus, there is a tendency in many academic units to engage in assessment practices that are not truly "meaningful".

Although what constitutes an "ideal" outcomes assessment program is largely dependent on the particular program and institution in which that program is to be implemented, there are at least some generalities we might make about what constitutes a "meaningful" program. For example:

> An outcomes assessment program perceived by faculty and administrators as an imposition of bureaucratic control over what they do, remote from any practical implications… would not be considered "meaningful." Meaningful programs, rather, are designed to enhance our educational missions in specific, practical, measurable ways, with the goals of improving the effectiveness of training and education in our disciplines. They also involve all of a program's faculty and students, not just administrators or designated report writers. Furthermore, the results of meaningful assessment programs are actually used to foster real modifications in a training program.[6]

Outcomes Associated with Engineering Design Projects

Despite the NSF's solid commitment to engineering design project experiences, and widespread enthusiasm about this experiential approach to learning and service, there is a lack of documented solid empirical support for the efficacy and validity of design project experiences and the specific aspects of implementing those experiences. Concerted efforts to improve learning, assessment methods and data collection concerning pedagogic efficacy of engineering design project experiences will enhance student learning while benefiting the community of persons with disabilities.

Agreeing on Terms

There is great variability in the terminology used to discuss educational outcomes. How we develop and use assessments matters much more than our agreement on the definitions of each of the terms we might use to talk about assessment issues. Still, for the sake of establishing common ground, a few key terms are highlighted here.

Formative and Summative Outcomes

Formative outcomes indices are those that can be used to shape the experiences and learning opportunities of the very students who are being assessed. Some examples are surveys of faculty regarding current students' design involvement, on-site supervisors' evaluations, computer programming proficiency evaluations, and classroom assessment techniques.[7] The results of such assessments may be used to characterize program or instructor strengths and weaknesses, as well as to foster changes in the experiences of those very students who have been assessed. Summative outcomes measures are those used to characterize programs (or college divisions, or even whole institutions) by using assessments intended to capture information about the final products of our programs. Examples are student exit surveys, surveys of graduates inquiring about salaries, employment, and job satisfaction, and surveys of employers of our graduates.

The reason the distinction between these two types of assessment is important is that, although formative assessments tend to be the ones that most interest our faculty and students and the ones that drive their daily academic experiences, the outcomes indices on which most administrators focus to monitor institutional quality are those involving summative outcomes. It is important that each of academic unit strive for an appropriate mix of both formative and summative assessments.

Cognitive/Affective/Performative Outcome Distinctions

To stimulate our clear articulation of the specific outcomes targeted within any program, it is helpful to have a way to characterize different types of out-

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[6] Hallowell, B. (1996). Innovative Models of Curriculum / Instruction: Measuring Educational Outcomes. In Council of Graduate Programs in Communication Sciences and Disorders, Proceedings of the Seventeenth Annual Conference on Graduate Education, 37-44.

[7] Angelo, T. A., & Cross, K. P. (1993). Classroom assessment techniques: A handbook for college teachers. San Francisco: Jossey-Bass.

comes. Although the exact terms vary from context to context, targeted educational outcomes are commonly characterized as belonging to one of three domains: cognitive, affective, and performative. Cognitive outcomes are those relating to intellectual mastery, or mastery of knowledge in specific topic areas. Most of our course-specific objectives relating to a specific knowledge base fall into this category. Performance outcomes are those relating to a student's or graduate's accomplishment of a behavioral task. Affective outcomes relate to personal qualities and values that students ideally gain from their experiences during a particular educational and training program. Examples are appreciation of various racial, ethnic, or linguistic backgrounds of individuals, awareness of biasing factors in the design process, and sensitivity to ethical issues and potential conflicts of interest in professional engineering contexts.

The distinction among these three domains of targeted educational outcomes is helpful in highlighting areas of learning that we often proclaim to be important but that we do not assess very well. Generally, we are better at assessing our targeted outcomes in the cognitive area, for example, with in-class tests and papers, than we are with assessing the affective areas of multicultural sensitivity, appreciation for collaborative teamwork, and ethics. Often, our assessment of performative outcomes is focused primarily on students' design experiences, even though our academic programs often have articulated learning goals in the performative domain that might not apply only to design projects.

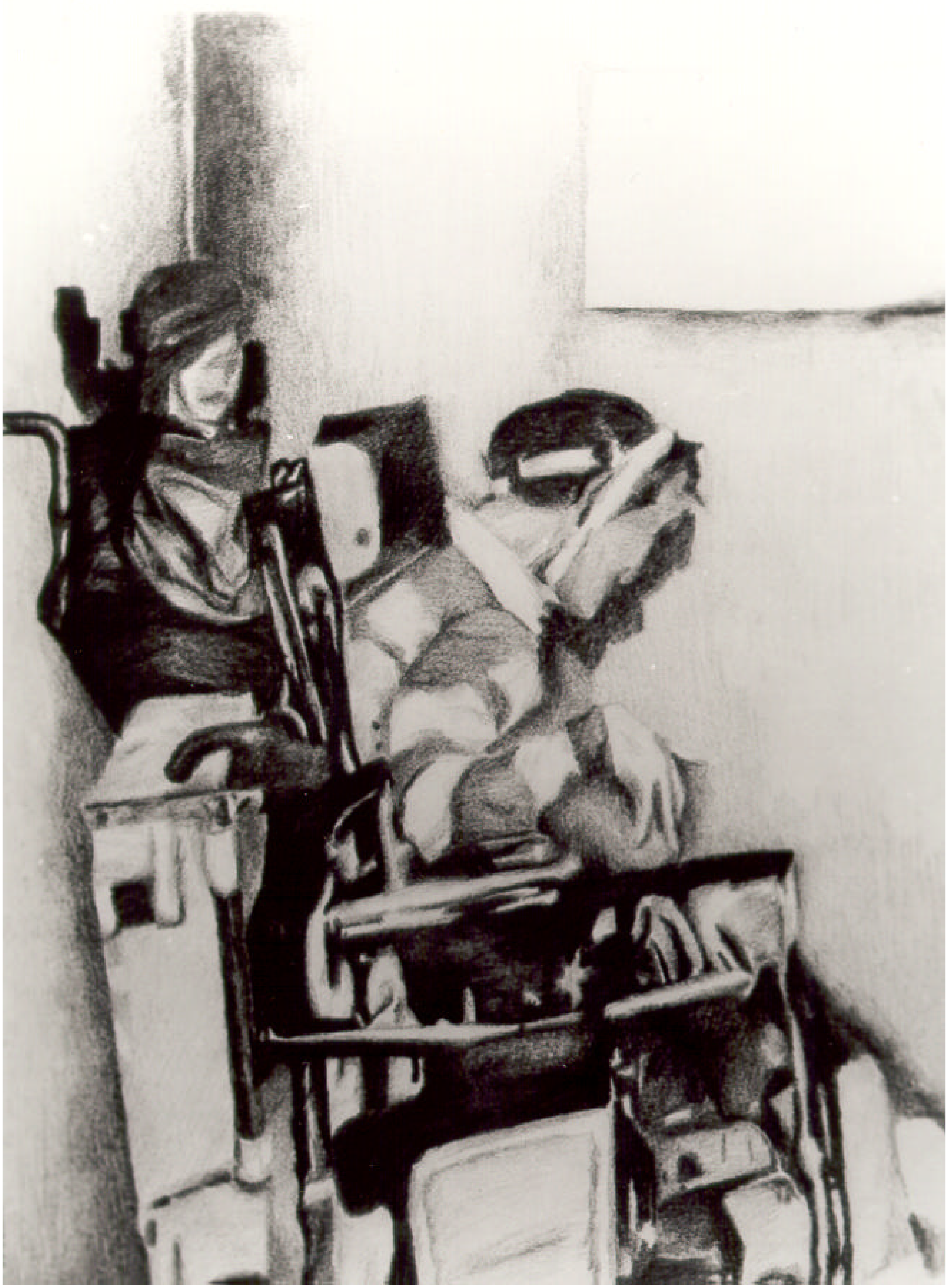
Faculty Motivation

A critical step in developing a meaningful educational outcomes program is to address directly pervasive issues of faculty motivation. Faculty resistance is probably due in large part to the perception that outcomes assessment involves the use of educational and psychometric jargon to describe program indices that are not relevant to the everyday activities of faculty members and students. By including faculty, and perhaps student representatives, in discussions of what characterizes a meaningful assessment scheme to match the missions and needs of individual programs, and by agreeing to develop outcomes assessment practices from the bottom up, rather than in response to top-down demands from administrators and accrediting agencies, current skeptics on our faculties are more likely to engage in assessment efforts. Additional factors that might give faculty the incentive to get involved in enriching assessment practices include:

> Consideration of outcomes assessment work as part of annual merit reviews; provision of materials, such as sample instruments; or resources, such as internet sites; to simplify the assessment instrument design process; demonstrate means by which certain assessments, such as student exit or employer surveys, may be used to [a] program's advantage in negotiations with … administration (for example, to help justify funds for new equipment, facilities, or salaries for faculty and supervisory positions); and notice and reward curricular modifications and explorations of innovative teaching methods initiated by the faculty in response to program assessments.[5]

With the recent enhanced focus of on educational outcomes in accreditation standards of ABET, and with all regional accrediting agencies in the Unites States now requiring extensive outcomes assessment plans for all academic units, it is increasingly important that we share assessment ideas and methods among academic programs. It is also important that we ensure that our assessment efforts are truly meaningful, relevant and useful to our students and faculty.

The next chapter serves as an invitation to readers of this book to join in collaborative efforts to improve design experiences, student learning, and design products through improved assessment practices. Future annual publications on the NSF-sponsored engineering design projects to aid persons with disabilities will include input from students, faculty, supervisors, and consumers on ways to enhance associated educational outcomes in specific ways. The editors of this book look forward to input from the engineering education community for dissemination of further information to that end.



CHAPTER 3
AN INVITATION TO COLLABORATE IN USING ASSESSMENT TO IMPROVE DESIGN PROJECTS

Brooke Hallowell

In Chapter 2, we discussed educational outcomes assessment, emphasizing ways in which clearer foci on educational outcomes may lead to improvements in the learning of engineering students, and, consequently, improved knowledge, design and technology to benefit individuals in need. We described concerted efforts among accrediting agencies, including the Accrediting Board for Engineering and Technology (ABET), to improve the accountability of educational institutions through improved assessment practices. We discussed how a "meaningful" emphasis on educational outcomes helps overcome bureaucratic hurdles in academe, and enhances our educational missions in specific, practical, measurable ways by improving the effectiveness of training and education. This chapter serves as an invitation to readers to join in collaborative efforts to enrich meaningful educational outcomes assessment efforts associated with NSF-sponsored design projects to aid persons with disabilities.

A look at ABET's requirements for the engineering design experiences in particular[8] may give us further direction in areas that are essential to assess in order to monitor the value of engineering design project experiences. For example, the following are considered "fundamental elements" of the design process: "the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation" (p. 11). Furthermore, according to ABET, specific targeted outcomes associated with engineering design projects should include: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions. The accrediting board additionally stipulates that it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact. ABET's most recent, revised list of similar targeted educational outcomes is presented in the Appendix. We encourage educators, students and consumers to consider the following questions:

- Are there outcomes, in addition to those specified by ABET, that we target in our roles as facilitators of design projects?

- Do the design projects of each of the students in NSF-sponsored programs incorporate all of these features? How may we best characterize evidence that students engaged in Projects to Aid Persons with Disabilities effectively attain desired outcomes?

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[8] Accrediting Board for Engineering and Technology (2000). Criteria for Accrediting Engineering Programs. ABET: Baltimore, MD.

- Are there ways in which students' performance within any of these areas might be more validly assessed?
- How might improved formative assessment of students throughout the design experience be used to improve their learning in each of these areas?

Readers interested in addressing such questions are encouraged to send comments to the editors of this book. We are particularly interested in disseminating, through future publications, specific assessment instruments that readers find effective in evaluating targeted educational outcomes in NSF-sponsored engineering design projects. Basic terminology related to pertinent assessment issues is presented in Chapter 2. Cognitive, performative, and affective types of outcomes are reviewed briefly here, along with lists of the types of assessments that might be shared among those involved in engineering design projects.

Cognitive outcomes are those relating to intellectual mastery, or mastery of knowledge in specific topic areas. Some examples of these measures are:

- Comprehensive exams
- Items embedded in course exams
- Pre-post tests to assess "value added"
- Design portfolios
- Student self evaluation of learning during a design experience
- Alumni surveys
- Employer surveys

Performative outcomes are those relating to a student's or graduate's accomplishment of a behavioral task. Some performance measures include:

- Evaluation of graduates' overall design experience
- Mastery of design procedures or skills expected for all graduates
- Student evaluation of final designs, or of design components
- Surveys of faculty regarding student design competence
- Evaluation of writing samples
- Evaluation of presentations
- Evaluation of collaborative learning and team-based approaches
- Evaluation of problem-based learning
- Employer surveys
- Peer evaluation; e.g., of leadership or group participation

Affective outcomes relate to personal qualities and values that students ideally gain from their educational experiences. These may include:

- Student journal reviews
- Supervisors' evaluation of students' interactions with persons with disabilities
- Evaluations of culturally-sensitive reports
- Surveys of attitudes or satisfaction with design experiences
- Interviews with students
- Peers', supervisors', employers' evaluations

We welcome contributions of relevant formative and summative assessment instruments, reports on assessment results, and descriptions of assessment programs and pedagogical innovations that appear to be effective in enhancing design projects to aid persons with disabilities.

Please send queries or submissions for consideration to:

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APPENDIX: Desired educational outcomes as articulated in ABET's new "Engineering Criteria 2000" (Criterion 3, Program Outcomes and Assessment)

Engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs

(d) an ability to function on multi-disciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (p. 38-39).

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[9] Accrediting Board for Engineering and Technology (2000). Criteria for Accrediting Engineering Programs. ABET: Baltimore, MD.