

## **2006-2023: LEVERAGING REHABILITATION NEEDS INTO FRESHMAN ENGINEERING DESIGN PROJECTS**

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Bruce Ankenman received a BS in Electrical Engineering from Case Western Reserve University and an MS and PhD. in Industrial Engineering from the University of Wisconsin-Madison. Prior to his graduate work, he worked for five years as a design engineer for an automotive supplier in Ohio. He is currently an Associate Professor in the Industrial Engineering Department at the McCormick School of Engineering at Northwestern University. His research interests include the statistical design and analysis of experiments. Although much of his work has been concerned with physical experiments, recent research has focused on computer simulation experiments. Professor Ankenman is currently the director of the freshman engineering and design course (EDC) and was awarded the Outstanding Advisor of the Year at McCormick in 2001. He serves as a department editor for IIE Transactions and as an associate editor for Naval Research Logistics.

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J. Edward Colgate received the Ph.D. degree in mechanical engineering in 1988 from M.I.T. He subsequently joined Northwestern University in Evanston, Illinois, where he is currently a Professor in the Department of Mechanical Engineering and holder of the Alumnae of Northwestern Professorship of Teaching Excellence. Dr. Colgate's principal research interests are cobots - collaborative robots - and haptic interface. He has served as U.S. Editor of Robotics and Computer Integrated Manufacturing, and as an associate editor of the Journal of Dynamic Systems, Measurement and Control and the IEEE Transactions on Robotics and Automation. In addition to his academic pursuits, Dr. Colgate is a founder of Cobotics, Inc. (now part of Stanley Assembly Technologies\*) a leading supplier of human interface technologies for the industrial marketplace. From June 1999 until September 2000, Dr. Colgate took a sabbatical leave from Northwestern University to work at Cobotics as the Company's President. More recently, he has been a founder of Chicago PT, LLC, a start-up devoted to developing intelligent assist devices for the physical therapist. Dr. Colgate is also a member of the Board of Directors of Methode Electronics, Inc., a global, diversified manufacturer of electronic components. Dr. Colgate is currently the Director of IDEA - the Institute for Design Engineering and Applications - which is chartered with integrating design education throughout the engineering curriculum at Northwestern.

### **Phillip Jacob, Northwestern University**

Phillip Jacob is the Marketing Coordinator for the freshman engineering and design course (EDC) at Northwestern University. He has been involved in recruiting real world design projects and clients for over five years. In addition to identifying and screening project proposals for the nearly 200 teams per year, he meets regularly with the core faculty to plan curriculum and logistics of the freshman design course. Before joining Northwestern, Phillip completed an internship with an international trade organization and has (and continues to) lead work teams with Habitat for Humanity International. Phillip received a BA from the University of Illinois and also studied at DePaul University and at McGill University.

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Director of the Rehabilitation Research and Training Center on Technology Promoting Integration for Stroke Survivors: Overcoming Societal Barriers, sponsored by the U.S. National Institute on Disability and Rehabilitation Research. He is the Founder and former Director of the Rehabilitation Institute of Chicago's Center for Stroke Rehabilitation and former Associate Director of Spinal Cord Injury Rehabilitation for Northwestern University's Midwest Regional Spinal Cord Injury Care System. Dr. Roth has published more than eighty peer-reviewed papers, book chapters, and other articles in medical rehabilitation. He was named Outstanding Teacher of the Year by the residents in his Department in 1991; one of the Best Physicians in Chicago by Chicago Magazine in 1992, 1996, and 2000; one of Crains Chicago Business' "Forty Under 40" in 1995; one of the Best Doctors in America in 1996; and one of the Best Physicians in Chicago by Castle-Connolly Publishers in 1999, 2000, and 2003. Dr. Roth's academic interests are in the areas of stroke, spinal cord injury, geriatrics, comorbidity, and functional outcomes assessment.

**Stacy Benjamin, Northwestern University**

Stacy Benjamin joined IDEA in 2004 as a Senior Design Engineer and Adjunct Faculty. Within IDEA, she is a member of the core faculty to develop and teach the freshman Engineering Design and Communication course (EDC) and the upper level Interdisciplinary Design Projects I & II courses. Stacy also mentors student teams working on IDEA Institute Projects. Prior to coming to Northwestern, Stacy worked for 9 years at IDEO, the world's leading product development firm. She contributed to a range of products including consumer, business and medical devices as a mechanical engineer and Senior Project Manager. Stacy has an MSME from UCLA and a BSME from the University of Rochester in Rochester, NY.

## **Leveraging Rehabilitation Needs into Freshman Engineering Design Projects**

Over the last two years, Northwestern's freshman design course, Engineering Design and Communication (EDC), has partnered with the Rehabilitation Institute of Chicago to provide interesting, useful, and challenging projects for freshman engineers. The goal of the partnership was twofold: 1) To develop innovative products to help rehabilitation patients to accomplish everyday tasks such as tying shoes, reading books, cutting meat with a knife, playing video games, and operating an exercise machine. 2) To have a stable and well supported source of interesting, educational, and challenging projects for 100 student teams per year.

This paper will discuss the strengths, weaknesses, and lessons learned over the two years of the partnership. Having students work with rehabilitation professionals and patients has led to many rewarding experiences for all involved. Many projects have been very successful, with a few being patented and licensed to companies for potential manufacture and distribution. There have also been challenges: too much or too little contact with clients and users, and burn-out for some clients with multiple projects. We have made many adjustments to the system including holding mass information sessions on campus where students have access to the project clients, users, and other stakeholders. One key aspect of the partnership is funding provided by the National Institutes for Disability and Rehabilitation Research (NIDRR) that helps to offset the time commitment necessary for rehabilitation professionals to work with students and help them to understand and interact with rehabilitation patients.

### **Background and Introduction to EDC:**

Engineering Design and Communication (EDC) is an innovative freshman design course at Northwestern's McCormick School of Engineering which integrates the teaching of communication and the engineering design process<sup>1</sup>. The course requires student teams to complete two real-world design projects over a two quarter sequence. The freshman class at McCormick ranges from 350 to 400 students, who work in teams of four. Thus, a typical year of EDC requires nearly 200 design projects since each team must have a project for each quarter. One of the critical requirements of an EDC "real-world" project is that there is both a client and accessible users. A client is a person who has identified a need and is willing to support the design team by answering questions and giving direction throughout the design process. Clients are typically external to the course, but have volunteered their time to work with the students during the project. (Clients are not the course faculty.) Users are people who would actually use the product that the students

are designing. For example, suppose a company wanted the student team to design a book holder to aid stroke survivors in reading. The client would be a company employee who would help the students to understand the product that the company is trying to develop. The users would be stroke survivors who might potentially buy and use the book holder.

In order to properly complete the design process, students need access to users to observe their needs and to test their prototype designs. User feedback must be incorporated into their final design. One of the primary challenges of offering EDC is to find enough interesting projects with clients and accessible users. In this paper, we will first briefly discuss the history of meeting this challenge and then show how, over the last two years, EDC has partnered with The Rehabilitation Institute of Chicago (RIC) to bring high quality, high impact, well-supported design projects into the EDC course. We will also discuss some of the issues that have arisen in the collaboration and how we are working to overcome these problems.

The EDC course was piloted in 1997 with a small group of students. Since 1998, the two quarter course has been required for all incoming students and is typically taken in the freshman year. The first quarter of EDC is the students' first introduction to the design process and we have found that having similar projects (e.g. websites) for all students improves the delivery of this introductory quarter. Since the students all have some experience with the design process by the second quarter of the class, the projects are more eclectic and students take more responsibility for the project management. Second quarter projects typically come from clients on the university staff (e.g. the redesign of office space), the community (e.g. a salesman who needed an office space built in his van), or local industry (e.g. a company wanted their hand assembly operations redesigned for better efficiency).

For many years in EDC, all first quarter projects were website projects. Website projects had many advantages for the introductory quarter since many companies and organizations were new to the internet and were seeking help in setting up their website. Clients were plentiful and users relatively easy to find. Also, at that time internet technology was fairly undeveloped and students could produce a reasonably competitive website with little training. In 2002, the solution of using websites in the first quarter broke down. Website technology had advanced to the point where student-designed projects were no longer competitive with professional websites. Also, faculty were weary of websites and felt that they didn't represent many of the engineering fields well.

The following year, all first quarter projects were changed to involve the redesign of interior automotive space. For example, redesign the interior of a pickup truck to accommodate the needs of a carpenter. Another project was to develop a seat for children that would allow them to easily sleep in the back seat of a truck or SUV. The automotive projects were a success in that they took the students into the shop during the first quarter of EDC. Having physical projects instead of virtual (website) projects in the first quarter significantly raised the quality of the projects that were produced for the clients in the

second quarter. However, the automotive projects themselves were not well supported by clients. The intention was to have clients who were employees at a large (but distant) automotive interior design firm. However, these employees simply did not have enough time to work with the 100 teams of students and EDC faculty ended up acting as clients for most of these projects. Students were asked to find their own users which worked well for some projects and poorly for others. Another issue with both the websites and the automotive projects was that they were primarily commercially based, leading some students and faculty to desire projects that were more socially conscious.

The problem for the EDC faculty was now fairly well posed, “For the first quarter of EDC, we want a large group of projects that have similar theme. The projects will allow students to have external, knowledgeable clients and access to a pool of potential users. Finally, the projects will be physical in nature, small-scale, able to be built by freshman in 10 weeks, and preferably have a social benefit.”

### **Introduction to RIC and RRTC**

The Rehabilitation Institute of Chicago (RIC) is the leading rehabilitation hospital in the US (as ranked by *US News and World Report* for the last 15 years). They have a plethora of programs for treatment of complex conditions including cerebral palsy, spinal cord injury, stroke and traumatic brain injury, as well as more common conditions such as arthritis, chronic pain and sports injuries. RIC also provides specialized services such as Assistive Technology, Prosthetics and Orthotics and Vocational Rehabilitation which help individuals of all ages lead more independent and fulfilling lives.

In 2002, RIC and Northwestern received funding from NIDRR to operate research and training projects under the Rehabilitation and Research Training Center (RRTC). The center is focused on finding the technology-assisted solutions for stroke survivors to achieve independence in their home and community environments. Part of the mission of this center is to engage engineering students in the development of novel designs to assist in accomplishing common tasks that prove difficult for stroke survivors. Patients with disabilities present a variety of physical and emotional needs, many of which can be readily addressed by engineers. Stroke causes a number of specific problems. Weakness or paralysis of the arm and leg are the most common effects, but other problems including sensory changes, speech and language disorders, cognitive deficits, swallowing dysfunction, and visual changes, also affect a stroke patient's ability to function. These deficits cause disabilities in daily functioning such as dressing, bathing, and walking. Rehabilitation consists of measures to improve the patient's ability to perform activities of daily living, including dressing, bathing, and walking, through training, supervised practice, counseling, and the use of specialized equipment. The center also is charged with increasing the awareness of the great potential for rehabilitation for stroke survivors. Student design projects can also aid in achieving this second goal since students get first hand knowledge and experience with the effects and rehabilitation of stroke survivors.

## **RIC and EDC collaboration**

In 2004 and 2005, all the winter quarter projects for EDC were rehabilitation-related projects and were supported by clients at RIC. Many of the projects were related to the fact that many stroke survivors have the use of only one hand. Some examples include devices to allow egg cracking, shoe tying, or door unlocking and opening with one hand. For these stroke-related projects, the client was typically an RIC occupational therapist who had experience dealing with stroke survivors and had identified the problem as one that occurred relatively frequently. The therapist served as an intermediary to ask stroke survivors if they were willing and able to participate in the design process with the students. The therapist also helped the students to understand how not to embarrass or offend the stroke survivor (e.g. by asking inappropriate questions or taking photos or video without permission).

In addition to the projects supported by the NIDRR grant, other EDC winter quarter projects were sponsored by the RIC Sports, Recreation, and Fitness Program. Projects from this program included design of a seat to allow a person with leg disabilities to water ski, a control panel to help the visually impaired to operate a treadmill, a device to allow a person in a wheelchair to safely change the weights on a weight lifting machine. Clients for these projects were typically RIC Sports employees who were coaches or trainers and again acted as both a source of information on the requirements of the design as well as a contact for students to access users for testing of their design ideas.

Most of the projects were highly successful from both an educational and a rehabilitation point of view. Students found the projects compelling and became much more aware of the rehabilitation community. Many prototype devices were turned over to RIC for use and several of the projects were further refined in subsequent quarters of EDC. A few of the designs were patented and licensed to manufacturers.

Despite the great success of these projects, several issues have been raised. One of the biggest issues that we have encountered in this collaboration is the heavy workload that is placed on the RIC clients. They are often serving as clients for several teams and the number of emails, visits and phone calls places a large time commitment on them. When the clients become overwhelmed there are several undesirable outcomes:

1. The students are unable to get the answers they need in a timely fashion.
2. The students are unable to get in contact with users to test their prototypes.
3. Clients become more burdened and less engaged over the course of the term.
4. The RIC clients decline to work with EDC in the following year.

In the next three sections of this paper, we will describe in more detail the collaboration of RIC and EDC over the last two years. The next section we will discuss some of the projects that were taken on by design students at Northwestern and supported by clients and users at RIC. These projects underscore the great benefits that are being seen and show why it is so critical to address any problem areas so that the collaboration can continue. Following the project descriptions will be a section that describes the design

process followed by the students and their interaction with the RIC clients and users. We will discuss some of the issues and challenges that have arisen and how we have begun to address them. The final section will discuss the lessons learned and our plans for continuing this highly successful collaboration between EDC and RIC.

### **EDC/RIC Project Examples**

A complete list of project titles that have been proposed from 2004-2005 is as follows:

<b>WQ04</b>	<b>WQ05</b>
Adapted knife/food stabilizer/utensil holder	Adapted Wet Suit
Button-hook /zipper-pull /shoelace assist	Arm Sling for Water Ski
Cardio Equipment Control Panels	Assisted Softball Glove
Doorknob locking system pull/shoelace assist	*Button-hook/zipper-
Durable book holder or easel	Donning a glove on a tight hand
Kayak Safety Device	Doorknob locking system
One-handed egg cracker	*One-handed egg cracker
Para Pulley – Rock Climbing Device	Retractable Fin for Sit Water Ski
Quad controls for Playstation 2	*Rickshaw Exerciser
Rickshaw Exerciser	*Roller Sled
Roller Sled	*Sandwich Holder
Sandwich Holder	Wheelchair Drinking System
Wheelchair softball	Wheelchair Football

While there has been a wide variety of rehabilitation projects that students have worked on in the past, several of them that have been quite exemplary. For example, on the RIC-Research side over 16 teams of students have worked on the *One-handed egg cracker*. See Figure 1 for a picture of the final prototype. The goal of this project was to devise a way for stroke patients to independently and effectively crack an egg. Each year up to 4 teams have consecutively worked on differing design solutions to address this same problem and in some cases the results have been so successful that several groups were inspired to file provisional patents.

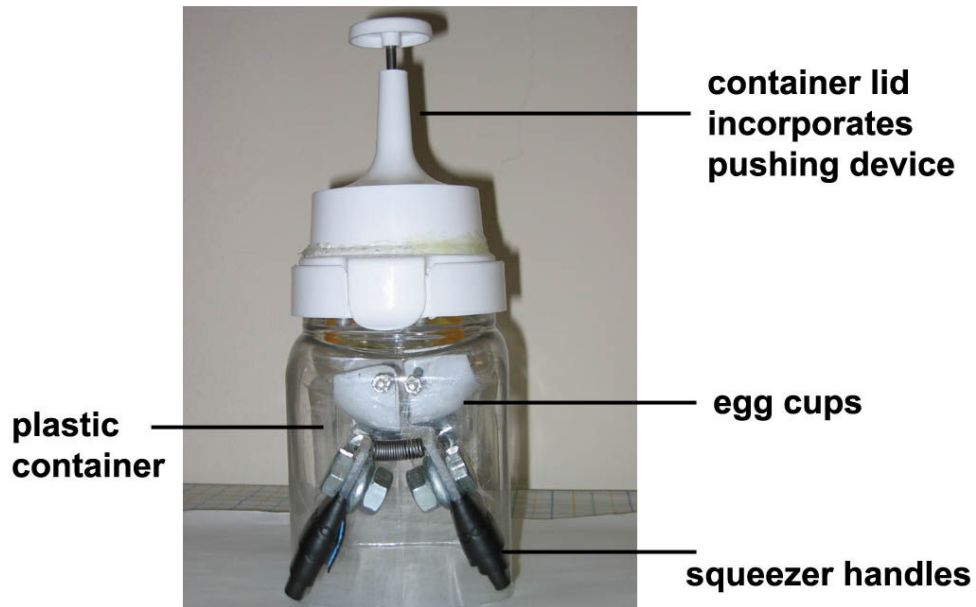


Figure 1. The One handed egg Cracker

In another case on the RIC-recreation side, the wheelchair softball project was met with skepticism when it was first offered in winter 2004 . The objective there was to devise a way for a wheelchair athlete to stabilize the chair while at bat but allow for instant egress upon hitting the ball. Students devised various prototypes and models, but because team members were disperse and rarely available most features were difficult to validate.

Upon further reflection, the project was presented in the spring while the sport is in season and the team members are available for observation and user feedback. So after two years of spring quarter projects the result was a refined and field tested prototype that was actually implemented by the RIC Cubs wheelchair softball team in summer 2005. According to the coach, the design gave them so much of a competitive advantage that they won their national championship and other teams have been requesting specifications of the students' design.



Figure 2. The Wheelchair Softball Batting Device



Not all EDC projects culminate in such tangible success, however, each project has both a practical and an educational benefit to students, clients and users. We feel that the key components in project success are: appropriate projects, cooperative clients, engaged students, available users, helpful faculty, and access to knowledgeable experts.

### **EDC Process and Structure**

The winter quarter of EDC introduces students to the design process in a scripted manner. Over the course of 10 weeks, the students are guided step by step through the initial conceptual stage of product development, as shown in the chart below.

<b>Week</b>	<b>Key activity</b>
1	Introduction to the design process
2	Introduction to RIC projects, begin research
3	Client meetings
4	User observations, brainstorming
5	Design alternatives
6	Mockups
7	Mockups, user testing
8	Design review, begin prototype
9	Design review, prototype, poster & final paper
10	Report, presentation

Each section of EDC has a maximum of 16 students, plus one Engineering faculty and one Communication faculty. The students are divided into four teams of 3 or 4 students each, depending on the section size. All of the teams in the section work on the same project, but the teams work independently of one another. Some projects may be worked on in two sections, resulting in 8 teams, or 32 students interacting with a given client. There are opportunities for collaboration between teams, such as in sharing research results, and for friendly competition, as in the Poster Fair at the end of the quarter.

Since there are so many students interacting with the RIC clients at one time, it helps to have a specific structure in place for the client interaction points.

- **Client meetings**

Experience has shown that allowing the students to contact the clients themselves to arrange the initial client meeting can drastically delay the time of that meeting. Also, traveling to and from the RIC is a barrier to the students, despite the free and frequent shuttle between Evanston and Chicago (10 miles of city driving). Since these meetings are vital to starting the projects, starting in 2005, we decided to arrange these meetings in advance and to have them take place on campus.

To make the meeting itself more manageable, only two members of each team attend. This way, if there are 8 teams working on the project, there are only 16 students present allowing for greater interaction with the client.

- **User observations**

The user observations are more difficult to arrange in advance since the therapists are seeing their patients during the day when the students are typically in class. To address this, (starting in 2006) we ask one of the section instructors to serve as the main section contact to the client. This instructor is responsible for determining several time slots when groups of their students can make it to the RIC. As in the client meetings, only 2 members of each team attend. Also, for therapy sessions, it is typical that the client can accommodate no more than 4-8 students at a time due to physical space constraints. The instructor and client can then determine which time slots will work for the combined schedule constraints.

For the user observation sessions, it is okay if the teams are mixed together. For example, two students from team A may join with one student from team B and one from team C to better accommodate their individual schedules.

- **User testing**

The user testing sessions are set up in a manner similar to the user observation sessions. The key difference is that now the teams can not be mixed together. At these sessions, the students are bringing their physical mockups to show to the users, ideally for the users to try them out, or in the least to provide feedback on the concepts. Because each team will be taking their own approach and will have different mockups, there is not enough time in a therapy session to consider the ideas of multiple teams.

As such, this week (week 7) is the biggest drain for the clients. If a client has two sections, they must participate in 8 of these user testing sessions. Some clients have chosen to have two teams come at once to reduce the total number of meetings.

- **Poster presentation**

At the end of the quarter, all of the sections and teams come together for a Poster Fair to display and celebrate their work. This fair is open to the public and the clients are encouraged to attend. The designs are judged by independent external judges (often from local industry, rehabilitation, or design firms) as well as non-EDC university faculty. The fair closes with an award ceremony to acknowledge the best designs and the best use of the design process. The awards from this competition are separate from the grading which is done by the faculty. However, we have found that the excitement of the awards ceremony and the credibility of external judges adds a great deal to the students' EDC experience.

The students are also required to give their final prototypes to their client at the Poster Fair. In the past, there have been misunderstandings about when and how

project materials are to be delivered. We are working to address these issues by having a more formal prototype check-in procedure. While the details have not yet been determined, the section faculty will ultimately be responsible for making sure that each team has either handed off their prototype to the client or turned it in at a “coat check” to be delivered to the client later.

In addition to the key client interaction points, we also found it necessary to add structure to ongoing client communications. The client therapists do not have a lot of spare time for addressing a barrage of student emails. In the past, we have asked that each team have one client contact person to send emails to ask questions or arrange meetings. The contact students were to identify themselves in every communication with their section and team number. However, this showed only limited success in simplifying the communications.

This year, all of the communications will go through the instructor for winter quarter. Each team will forward their questions to the instructor who serves as the client contact on a weekly basis. The instructor will combine and forward these questions to the client. In this way, the students will still get some practice in forming a memo to a client, but there will be a single channel to the client. In the spring quarter when there is a broader group of clients, each student team will be responsible for their own communication with their client.

All of this structure is aimed at accomplishing two things – preventing client burnout by streamlining the client’s work as much as possible; and minimizing student confusion to allow them to focus on the design process. Since the students get to repeat the process in Spring quarter with considerably less structure, they have the opportunity to learn more of the logistics with a basic understanding of the process.

## **Conclusion**

The collaboration between Northwestern and RIC has proved to be very beneficial for both parties involved and has enriched the lives of people with disabilities, therapists, students and faculty. It has served to both educate students and to develop novel solutions to difficult rehabilitation issues. The primary challenge has been to spread and reduce the workload on the clients through controlling the communication between clients and students. This year we have also limited the number of student teams that first-time clients can take on. Of course this requires more clients and thus a system of reward or incentive for clients is under consideration. In 2006, we have instituted a one time payment to clients to make the initial client visit to campus as this is typically not during work hours. We are also investigating methods for compensating clients for the time that they need to handle the email and telephone communication. Another approach to reducing client burnout is increasing the pool size of clients. By involving other departments and units within RIC we feel that we can spread the load and thus ease the burden on each individual client.

User observation and user testing is less of a time issue since therapists are already spending scheduled time with the users. However it is a scheduling issue and one of limiting the number of students that are observing or conducting testing with the users. Selecting a small number of contact students for these activities seems to have much relieved this issue. An added educational benefit to this solution is that it underscores the necessity of the contact students to communicate well with the other team members that were not able to observe the users first hand.

Both RIC and Northwestern are committed to nurture this mutually beneficial relationship and we hope to establish a sustainable system that will allow students, faculty, clients and users to continue to benefit from rehabilitation design projects for many years to come.

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