Engineering and Technology Literacy Introduced in Cornerstone Design Courses

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Many first-year engineering students do not have an understanding of the engineering profession or the engineering design process. Their vision of what it means to be an engineer and the engineering design process can sometimes be summed up as brainstorm-build. Many are also unaware of the cyclical process of design-build-test. Most students have also never worked with clients or users. While many students have worked in teams, they have not mastered teamwork, and so they tend to find themselves dividing up the assigned work and trying to put it all together just before deadlines and due dates.

Nearly twenty years ago, Northwestern University’s McCormick School of Engineering and Applied Science changed the first-year engineering curriculum to include a cornerstone design course. It was an opportunity to expose students to the design process prior to their capstone experience. Over the years, the one course grew to two courses- spreading components of the design process over two quarters, and giving the students more responsibility in the second.

The courses have a 50-minute lecture and two 80-minute studio sessions weekly. Students register a lecture and a studio section. The studio sections consist of up to 16 students and include two instructors: one engineering and one communication faculty. Additionally, students form groups of four and are paired with an external client who poses the problem statement. For the first course, there is one project per studio section. For the second course, the majority of the sections have up to four projects- one for each four-student team.

These two cornerstone design courses are designed to help students develop basic engineering and technology literacy through human-centered design, extensive primary and secondary research, and the testing of the team’s ideas building physical mock-ups and assessing them internally and with the client and users. The goal of these courses is to instill empathy in the students through using the user-centered design approach to solve real-world problems by utilizing technology and their engineering skills to develop a design that will improve the daily lives of their clients and users.

This work-in-progress paper will discuss the activities that help students start to develop engineering and technology literacy.
Introduction
Northwestern University’s McCormick School of Engineering and Applied Science requires all Engineering students to take a two-term cornerstone design sequence that focuses on human-centered design. The sequence gets students focused on Engineering Design as both a required tool for engineering systems and as a necessary social function.

Over the last twenty years, this cornerstone design sequence has been the subject of several papers presented at ASEE Conferences. Since the School of Engineering switched to dedicated First Year Advising in 2013, all first year students are strongly advised to take DTC1 and 2 as first year courses. This means that approximately 512 students took DTC1 and 2 AY2015-16 and 487 students in AY 2016-17.

Design-Thinking and Communication (DTC)
Overview
All engineering students at Northwestern University are required to go through Design-Thinking and Communication (DTC), a two-term sequence to learn the human-centered design process. This design process follows six principle phases:

1. Define the problem
2. Conduct primary and secondary research
3. Identifying needs and specifications
4. Generate potential solutions
5. Evaluate, build, and test alternatives
6. Create an initial prototype to demonstrate the design solution.

It is emphasized that this approach is not linear and requires frequent iteration of the phases in order to develop a successful and meaningful solution.

DTC emulates the iterative nature of this approach by following the same process through each quarter of the course: DTC1 and DTC2. In each offering, studio sections are limited to 16 students and are co-taught by one engineering and one communications faculty. Four teams of four students each are formed and assigned a real-world client who poses the initial project scope based on a problem or need they current have. Clients will are paired with a single section in DTC1 and pose the same problem to all four teams. In DTC2, students enroll with new classmates, form new teams, have a new pair of faculty, and work with a new client and design problem. DTC2 provides the opportunity for students to take on more responsibilities throughout the design process, which includes choosing a client and project, coordinating communication and meetings, and setting their team’s timeframe for accomplishing major deliverables. A DTC2 section often has four separate clients, with each team working on a unique problem.
DTC faculty aim to educate students about the design process, advise the students teams, and provide feedback on project deliverables (detailed below) including both communication and engineering topics. Engineering students completing both offerings of DTC receive an engineering design and an English credit towards their degree.

The University has a long-standing relationship with the Shirley Ryan Ability Lab (formerly known as The Rehabilitation Institute of Chicago), so a large number of DTC1 projects are related to improving mobility and access. DTC2 projects are more diverse, and include Whitespace (new product), Human-Centered, Entrepreneurial and University-centered projects.

Project Deliverables

Students are often unfamiliar with the human-centered design approach before attending Northwestern University. Students have required readings to introduce the design process and objectives of each phase. However, the majority of the learning comes from working through and completing the major project deliverables, which are outlined below. Students will develop and enhance their literacy in both technology and engineering principles through these deliverables and the design process.

Defining the Problem and Identifying Needs and Specifications

The initial phase of any design project is to define the stated problem and identify the needs and specifications of what needs to be designed. The needs and specifications will ultimately be used to determine if, and how well, the proposed design adequately address the problem. This phase is often the most difficult and DTC devotes the first 3-4 weeks of a 10-week term to developing a clear defining the scope of the project.

Major project deliverables necessary to completing this phase include

- Conducting an initial client meeting
- Restating the proposed problem
- Conducting primary research to understand the project scope, impact, and background
- Conducting secondary research to identify stated and unstated needs
  - Holding user observations
  - Interviewing users and other major project stakeholders
- Creating a project definition document that summarizes findings during this phase

Faculty and students work to identify key questions that need answers in order to drive the project forward. Additionally, classes will prep for meetings and interviews in advance to assure professional standards are met and efficient communication occurs. However, students conduct their own meetings with clients, users, and other stakeholders regardless of whether faculty
attend those meetings. Summaries of each meeting, interaction, and primary research findings are reviewed and compiled to create documentation and justification for each team’s design decisions. These documents are compiled as support materials for each team’s final report.

Generating, Evaluating, Building and Testing Potential Solutions

Faculty lead students through an idea-generation process once the project has been defined and needs identified. Traditional Brainstorming and Brainwriting techniques are utilized to guide the teams through the development of multiple potential design solutions. This often results in 50-100+ ideas, which are grouped by like-category and documented. Ideas are rated by mapping them to the needs each will satisfy and then all ideas are ranked. Students identify the ideas with the most potential (highest ranking) and document their process in an Alternatives Matrix.

All students complete a safety orientation and training on equipment in the McCormick’s prototyping facility (shop). Initial training includes horizontal and vertical bandsaws, sheet-metal shears, drill press, and coverage of basic hand-tools (drivers, hand-saws, and adhesives). Once trained, students have access to the shop and the prototyping specialists who run the shop during standard business hours. Prototyping specialists serve a vital role as they provide guidance on how to manufacture students’ ideas, assist with ordering materials, and provide training for more advanced equipment such as multi-axis and CNC mills and lathes, the water jet, laser cutter, and welding equipment.

Students are encouraged to begin building mock-ups of their top ranked ideas from their alternatives matrix as soon as possible. Each mockup has an associated mock-up sheet that requires the team to identify key questions they need answer to pertaining to their potential design solution and what they plan to build in order to test the questions. Mockups should be quickly fabricated using simple and readily-available materials. Students conduct user testing sessions to gain feedback on their mockups, which is used to further refine and evolve their potential solutions.

Performance testing of key functional aspects of their designs help students to determine quantitative values (specifications) that will meet the identified needs. Performance tests combine engineering analysis and experimental testing to learn the range of values for each parameter that will result in the design solution working as specified.

Building a Working Prototype

Students will have settled on an optimal design solution near the end of the term. A final report and presentation will communicate each teams’ solution as well as the process used to define the problem and justify why and how the solution meets the identified needs of the client and
users. Students will also build a working prototype to demonstrate their design solution and will deliver it to the client along with the report and presentation.

The prototype serves as a proof-of-concept for the team’s proposed solution. While the prototype must work, it also is not production ready and may be made at scale. Each team is budgeted $100 for their prototype and must choose components and materials appropriately.

A student-client understanding form is signed at the start of the project, which states that intellectual property (IP) is owned by the students, but clients have the right to pursue patents and commercialization. Students must be included on any patent filings, and further agreements must be made between students and client regarding how each will be involve and compensated if commercialization is to occur.

Major Course Activities

Given the scope of the course requirements, students have to work in teams. There is too much work for one student to successfully complete alone. The major course activities can be broken down into the following:

- Team formation
- Define the Problem
- Initial Client Meeting
- User Observations
- Conduct primary and secondary research
- Identifying needs and specifications
- Brainstorming
- Alternatives Analysis
- Evaluate, build and test mock-ups
- Prototype
- Design Project Poster
- Final Presentation

There are several team formation techniques used. The faculty assigned to each section decide how they want to form teams. In DTC 1, the section usually has one project, with each team developing its own idea for a final prototyped solution. Usually, two sections have the same project, so a total of eight teams are working towards solutions to the same problem. Most DTC 2 sections have up to four projects, so students may have a choice based on the project description and/or whom they wish to team with. There are not more projects in DTC 2, but projects are spread over two or more sections.
Analysis of DTC using definitions of Engineering and Technological Literacy

Krupczak et al differentiated engineering and technological literacy as follows:

“A person who is technologically literate might have a knowledge of the systems of the systems of an automobile such as engine, powertrain, and brakes along with the basic principles underlying the functioning of these systems. This is knowledge of the product. Engineering literacy would include knowledge or the ability to design, analyze or otherwise create the constituent components of the automobile.” 16,17

If we use Bloom’s Taxonomy, we can apply these definitions to the course phases and activities in DTC 1 and 2. Applying Bloom’s action verbs (remembering, understanding, applying, analyzing, evaluating and creating) 18, we can see that the courses have both engineering and technological literacy components.

Table 1 categorizes the course phases as either exercises in engineering or technological literacy. Three phases were categorized as engineering literacy- defining the problem; evaluate, build and test and prototyping tend to be mainly exercises in engineering literacy. Since students in DTC also have to build prototypes (when possible), there is technological skill required to build mock-ups, but we are going to include that as part of engineering literacy for the sake of this paper. The other three course phases- conduct primary and secondary research, identifying needs and specifications and generate potential solutions are categorized as exercises in both engineering and technological literacy.

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Table 1: Categorizing DTC 1 and 2 course phases
Defining the problem is usually one of the hardest tasks for students. While students can often give you a problem statement, it is usually in terms of what the clients states she or he needs, not necessarily an engineering problem statement. Students also believe that their problem statement is static, even though their research, and other activities hint (or scream) at something else. This is where student really struggle with the concepts of engineering and technological literacy.

Students have to conduct research on multiple topics. Since they are working on human-centered design problems, they usually have to conduct research on medical conditions and their associated effects on people. The students also have to conduct research on devices, techniques and products that people use as work arounds, so that requires them to look for commercially-available products and develop an understanding as to why these products are not the best alternative for their clients and users. In addition, students have to research any standards or regulations that affect their designs. These usually come up when identifying needs and specifications. Students also have to really become literate in competing technologies associated with different solutions.

When identifying needs, the students rely mainly on information they gather from clients, users and secondary users. Specifications are usually gathered from interviews and primary and secondary research. For example, a team may be designing a table for a user who is coping with Quadriplegia and wants to be able to work at home and eat with her family. The team will learn about the users’ needs by interviewing the client and users, but will have to research materials and calculate the overall weight and size of their prototypes.

In generating potential solutions, students have to determine if an idea is technically sound, meets the client’s/user’s needs and can be engineered using current materials and manufacturing techniques. This requires the teams to work with the Prototyping Specialists, faculty and sometimes outside experts to determine if an idea is worth pursuing. Students are given feedback in a design review. This is the first point where students really demonstrate both technological and engineering literacy with respect to their projects. They may not have fully-formed ideas, but they usually have three or four viable ideas, and use feedback from DTC faculty and their peers to cut the list down to one or two design ideas.

Once the team completes the design review, they build, test and evaluate their ideas. This phase requires them to design user and mock-up tests. A client or user may test multiple ideas, but some of those ideas are simply to evaluate how the user would use a subsystem, such as a handle. Students at this point are focusing on engineering literacy, while the clients and users are focused on whether the mock-up might meet their needs.

Prototyping is all about engineering literacy. Students are trying to synthesize information gathered from numerous sources into a physical representation of their design. Prototypes sometimes form the basis for future work in DTC, as the clients or users want further
development based on using them. For example, a Physical Therapist was a client for a specific type of Knee Immobilizer that is not commercially available. After using several DTC prototypes, the client returned the following year and asked for modifications to strengthen the design. Figure 1 is a prototype for a cup designed for people who have dysphagia, or difficulty swallowing. The DTC team worked with their client and users (client’s patients) throughout the design process. The teams work with the Prototyping Specialists in the school’s prototyping shop. For the Slider Team, 3-D printing was the best option for fabrication. Other designs work well with more traditional manufacturing methods, such as Milling and Casting.

Figure 1: 3-D Printed Prototype of The Slider

Table 2 categorizes the major course activities as either engineering or technological literacy exercises. Since six of these activities are also the course phases, we will address the remaining six in this section. Of the remaining six course activities, three of these are exercises in technological literacy- Initial client meeting, user observations and brainstorming. Two activities are exercises in both engineering and technological literacy- poster and oral presentation. One is neither- team formation.

Team Formation is done in several ways, and is dependent on the DTC faculty assigned to that section. Some faculty assign students before the first class. Other faculty use one of several methods to assign teams. One common method for DTC1 is to assign teams based on where students live (North or South Campus). Students may have the ability to self-select their teams.

The initial client meeting is usually scheduled by the client liaison. This meeting is usually the second week of the quarter. DTC faculty are usually not at these meetings. Most clients are not
Engineers, they are Therapists (Occupational or Physical), Physicians and others. Clients may also be the users, sometimes secondary users, but most are usually not the primary user.

As mentioned above, students often have problems defining the Engineering problem because they are usually presented with a human-centered problem. They are told and shown a difficulty that someone is facing (a Stroke Survivor that only has use of her right arm, but wants to paint her nails on both hands), and sometimes have trouble developing its engineering equivalent. Since many of the students have not taken an engineering course (some have participated in Project Lead the Way and other Engineering Outreach Programs), they have no engineering literacy associated with an engineering design process.

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Table 2: Categorizing DTC 1 and 2 course activities

Even though students have been introduced to a problem description (Week 1) and met with their clients (Week 2), it’s not usually until they get to observe their users (Week 3) that they start to develop a real sense of the engineering problem with which they have been assigned. Since the teams can start some research Week 1, and ask questions of their client Week 2, they
usually have some understanding of the problem by the time they are conducting user observations. At this point, the students are still developing their technological literacy about the problem and possibly some potential solutions.

Brainstorming is an exercise in technological literacy. In DTC 1, student teams are mixed and groups are encouraged to develop a large quantity of ideas, with the goal of thinking up several viable ideas. Brainstorming is focused solely on creative methods for solving the problem, so evaluating the ideas at that time is discouraged. So an idea such as training a Seal to paint our user’s nails is an acceptable idea during brainstorming, because we are just focusing on how to complete a task, and not how viable or how to design a solution.

The project poster documents the problem and solution visually. In a 24 x 36 inch poster, the teams explain their solutions, components and associated benefits. Teams are expected to use the poster as part of their final presentation. Some teams use their posters to highlight both the engineering and technological literacy required to arrive at their solution. Figure 2 is an example of project posters produced for both DTC 1 and 2. The Sensing Stroller team developed this poster to highlight the problem they were attempting to solve (baby strollers tipping and injuring children) and key features of their solution.

![Figure 2: Project poster for the Sensing Stroller Team](image)
The final presentation is an opportunity for a team to summarize the technological and engineering literacy it required to produce a prototype solution for a human-centered design problem. The DTC1 presentation involves a demonstration of the prototype to an audience that includes the client, users, faculty, staff, students and community at the Fall or Winter Design Expo. These Expos are part of the Design Institute’s Fall and Winter Expos that showcase the work of students in multiple Graduate and Undergraduate design courses and clubs. The DTC2 presentation involves a demonstration of the prototype to a smaller audience including the client, user(s) and other teams that are working on the same project. Unlike DTC1, DTC2 projects are distributed to one team per section and across two to four sections. In both DTC1 and 2 presenting is an opportunity for students to develop an appreciation for how much their technological and engineering literacy on a specific topic has changed over an academic term. In both courses, the expectation is for teams to develop physical prototypes unless their project does not support one. Figure 3 is the Sensing Stroller prototype shown in the project poster shown in Figure 2.

![Sensing Stroller Prototype](image)

Figure 3: Sensing Stroller Prototype

Figure 4 shows one of the Touch Tank teams, Team Roll N Wash, presenting its solution to a DTC1 Judge. The judges are external volunteers (Product Designers, outside University and High School Faculty and Industry) that agree to judge teams from two sections. The teams are judged on their design and communications skills. The judging is a test of a team’s ability to communicate their Technological and Engineering Literacy to people who have not been involved with their projects. One team from each of the two sections is awarded a small prize for
either Communications or Design. As part of the presentation, the teams use both their posters and prototypes to demonstrate and explain their problem and design solution.

![Figure 4: The Roll N Wash Team presenting to a Design Expo Judge](image)

**Conclusion**

DTC 1 and 2 are designed to teach students about the engineering design process, communications, teamwork and human-centered design. It also raises the technological and engineering literacy of students. The DTC experience is one of the few lower division experiences that gets mentioned in capstone design or in senior exit surveys.

How the DTC sequence affects student retention in McCormick and particular major is not clear. The last study of how DTC affected student outcomes was published in 2005. This study looked at confidence, not retention. This is partially due to very high school retention. The school retains 89% of First Year students through graduation. In 2013, a small retention study was included in a memo to the dean. The results of a name/student id match concluded that since 2008, 89% of students that entered McCormick graduated with an Engineering degree from the school. This represents an increase in retention from 81% prior to 2008. Of the 11% that left the school, 55% graduated from the University and the remaining 45% left the University. DeCosta outlined efforts to better understand first year student performance, but there has not been a study of how DTC affects persistence in Engineering.

The experience is powerful, and demand for the courses from students outside of Engineering. The decision was made to develop DTD- Design, Thinking and Doing, a non-engineering version of DTC. This decision was made partially to respond to demand from students in other schools who wanted to take DTC, and partially to spread the design experience across the
university. DTD is not unique, as Virginia Tech launched a similar course in Citizen Engineering. \(^\text{19}\)


