2006-1001: ACTIVE TEACHING, ACTIVE LEARNING: INFUSING THE DESIGN PROCESS IN A FIRST-YEAR COURSE

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Abstract
The overall goals of most first-year engineering design courses are to introduce students to the engineering design process through hands-on learning activities, to familiarize them with the various disciplines in engineering, and to inspire and instill an appreciation for the engineering profession, its ethics, and practices—all with the hopes of improved retention. At Northeastern University, our team of instructors has developed a set of classroom activities that illustrate each step of the engineering design process through exercises which dynamically engage the students in each of the progressive course topics. Not surprisingly, students have been very responsive to this approach and emerge from the course with a reportedly higher capability to remember and apply the concepts having been actively involved in simultaneously learning and practicing them. A variety of course assessment measures—both formal and informal—support the notion that students involved in active learning practices regard the instructor as significantly more effective, report to have learned significantly more, and rate the overall course significantly higher relative to students in cohort sections that have not experienced the same level of directed hands-on learning.

Introduction
One of the more challenging aspects of teaching engineering design is to build a course out of activities that are woven around a well-established process in order to allow students to experience design rather than just listen to how it is supposed to work. It is well known through research and practice that incorporating learning activities into a course better facilitates the student learning process as compared with more passive approaches. First-year engineering design courses typically include standard design-and-build projects, design competitions, laboratory projects, and other projects that span many weeks. These projects are active and hands-on, but are often relatively self-contained and separate from the exercises of presenting a design process and becoming familiar with other aspects of successful design. Thus the objective of this paper is not merely to extol the virtues of active learning as that has been well established; rather this work will illustrate the effects of a deliberate introduction of a variety of hands-on experiences that directly map to the steps of the engineering design process. The objective is to instill into the engineering students a natural and applicable progression through relevant and memorable activities. As such the apprentice engineers are no longer compelled to memorize the phases of structured design since they have been directly involved in developing them in a first-hand way.

In terms of academics, a step-by-step method for engineering design is easily proffered to the students, but teaching a process is challenging and requires particular focus on ensuring that links are made among the steps. An introductory study of the engineering design process as a
whole is not typified or represented by cool formulas, problems with trucks on ramps, energy balances to write, circuit diagrams, graphs, or stress-strain curves. The process itself—that is, a set of design stages—can theoretically be taught in a single day. However, the practice of comprehending, carrying out, and understanding when to apply the concepts of each stage is more complicated than providing a simple list; it requires more time and involvement on the part of the individual student. Moreover, we cannot easily teach creativity and innovation, which are also critical elements of the design process that need to be cultivated. How then do we move beyond the surface elements of design and fill a semester with innovation once the steps of the engineering design process have been enumerated?

Over the past 5 years, the team of instructors teaching engineering design to first-year students at Northeastern University has developed an assortment of connected active learning exercises that are sewn into the fabric of the semester. These activities are used to dynamically—and creatively—illustrate, simulate, and stimulate the engineering design process. The introductory engineering design courses use a six-phase design process represented by Voland: Needs Assessment, Problem Formulation, Abstraction and Synthesis, Analysis, Implementation, and Reflection. Along with a design-to-construction project, which is a key component in the course, the students are continuously required to apply the process, innovate, and take advantage of opportunities to reflect on what was learned. This keeps the students involved at every step, and the instructor is rarely lecturing to a sleepy, inert group. This certainly is a desirable outcome. The students, who often work in teams, appear enthusiastic about their numerous projects and activities. Through continuous involvement, the engineering design process becomes integral to the students’ thinking, and they subsequently are more inclined to think imaginatively and proactively to generate engineering solutions and feel more confident to create designs and solve problems. This paper will present some general course information, followed by a comprehensive description of the active learning exercises and projects used at each phase of Voland’s design process. The conception, synthesis and adoption of these activities have been an ongoing process for over 5 years. Assessment in the form of student mid-term and final course evaluations is used to support the inclusion of the numerous learning activities all of which are mapped to ABET outcomes a-k. The rationale behind this paper is to not only outline the learning activities that have demonstrated success in the first-year Introduction to Engineering Design course at Northeastern University but also to provide details and insights for administering and weaving these learning experiences into courses with similar objectives.

Course Background

General Background: The Engineering Design course at Northeastern University (NU) is a one-semester 4-credit course which is a requirement for all first-year engineering majors and is typically taken in the fall semester. It is the first of two ‘Introduction to Engineering’ courses—the second offered in the spring is called Engineering Problem Solving with Computation. There are approximately 16 sections of the course taught each academic year with the majority of these classes being taught by a team of five full-time teaching faculty called the Gateway instructors who are a team dedicated to teaching in the freshmen program. The course requires students to work 6 to 10 hours outside of class (3 hours in class) with most of the time allocated to working in groups on their design projects.
**Design Projects and AutoCAD:** This engineering design course has been developed around two design projects and a variety of smaller assignments that are focused on the phases of the design process. AutoCAD is integrated into the course as a graphics communication tool but less than a third of the class meeting time is dedicated to this module. The first design project, called the Minor Project, is typically a construction project that exposes the students to the design process early and gives them a chance to foster creativity and experience a complete construction task. The second “Major” design project does not require the creation of a working prototype and therefore is more focused on assessing the student’s ability to analyze and apply all phases of the design process to a particular topic in greater detail and over a more extended time period than the first project. This is a group project, due at the end of the semester. Both of these projects will be further discussed in the Active Learning section of the paper.

**Assignments and Homework.** In addition to the two design projects, students are required to work on individual assignments that allow for assessment of their proficiency in AutoCAD and Microsoft Excel. Other team assignments include a reverse engineering exercise and poster presentation, a movie scene dissection analysis, presentations on engineering disasters and relevant case histories, and demonstrations of engineering products, devices, and systems.

**Active Learning**

Kolb\(^\text{17}\) proposed a four-phase learning cycle, in which “half” of the effective learning sequence involves passive observing and thinking (cognition). The remaining “half” involves planning, (active experimentation) and doing (concrete experience). When combined iteratively and in balanced proportions, the combination of knowledge-based cognition and purposeful action can result in improved and lasting learning effects\(^\text{17}\).

A focus on Student-Centered Instruction by Felder & Brent\(^\text{6}\) shows that even with the classes in which some lecture is needed, problem solving and group work can be mixed in to keep the students as active participants during the lecture. More recently, Felder and Brent\(^\text{5}\) discuss a number of approaches that engage the students: in-class teams, problem-based learning exercises, group work, and various exercises that involve active learning. These approaches are also advocated by Johnson, Johnson and Smith\(^\text{11}\) because of what they have identified as their lasting effectiveness. In the ExCEEd workshop on teaching (Excellence in Civil Engineering Education), there are numerous examples of class demonstrations and innovative class activities that involve the participants. The text provided with this workshop continues to be invaluable for teaching, along with Wankat and Oreovic\(^\text{19}\) who state “more active involvement by students increases learning because additional stages in the learning cycle are used.”

**Active Learning Works:** For many years, the team of instructors teaching this design course struggled with students learning, appreciating, and applying the engineering design process. As noted earlier, the structure of the process is easily taught and seemed to be just common sense to some of the students. This led to a low perceived course value and comments like, “What do we really do here?”, and “What is this good for?”. The instructors frequently met together, and discussions centered on how to improve the course, so that students would really get excited about engineering design and being engineers. We began to use more active learning and spent time carefully connecting each activity to corresponding pieces of the design process.
These qualitative course changes have brought about changes in the student feedback about the course. The students in general state they are more motivated to participate and the majority of their remarks are otherwise favorable, as evidenced by the sampling of these comments presented later in this paper. The few objections that are raised are mostly limited to the perceived large volume of course work—not an unusual freshman “complaint”—but there are no real adverse criticisms about the course content. Their responses to the projects have improved vastly and they are rightfully proud of good design work as reflected in the way they print, bind, and present their projects with great ceremony and care. In addition, the instructors are enjoying the course much more, and are involved and excited about the students’ projects, presentations and insights, and the enthusiasm is catching.

Active Learning Projects

Projects that require active use of the design process anchor the course, just as any tapestry begins with anchor threads making the framework for the overall design like the “warp” in weaving. Then with assignments and activities the instructors weave more detail into the scene by teaching the process with all of the exercises, while keeping hold of these design “anchor strands”. Figuratively, by diversifying and adding to the number of directed activities, we keep adding new rows to build the fabric of engineering design; this is the “weft” of our tapestry.

Below are examples of projects with their connection to the design process outlined in order to illustrate how we create a firm base of anchor strands so that the entire design process serves as the foundation of the course:

Minor Design Project. This first project is assigned early in the course to individual students or small teams. The same task is given to the whole class. They are to build and demonstrate a device of their design. Past topics have included creating an Airfoil Design, a Ping-Pong Ball Launcher, The Roommate Rise and Shine Device, The Mousetrap Car, Fettuccini Bridge, a Pumpkin Drop Challenge, and a Submarine Design. The students are given access to a workshop where they can find hand tools and basic building supplies. They have several weeks to innovate, plan, and build their projects. Students experience the design process hands-on but with a strong emphasis on the design steps of problem formulation, abstraction and synthesis, and implementation, with some iteration. There are several demonstration days, during which the students can review others’ projects and show the results of their own work. These are lively and memorable days. The students are required to write a report reviewing all phases of the design process, and reflect on the project. Importantly, the Minor Project is subsequently referenced throughout the course as the design process itself is fully presented—its lessons on design are intertwined each day in the students’ minds. Since they physically experienced it, the design process is more real to them which is helpful as they proceed to the more theoretical and comprehensive Major Design Project.

Major Design Project. This is assigned immediately after the Minor Design project and requires more thorough exploration of each design phase. It is coordinated with the more advanced presentation of each design phase in class. As the students learn about a design phase in their textbooks and in the classroom, they work on that phase of their project as a team. The relevant section of their project is submitted, reviewed, and returned to be incorporated into their final design. This weaves the active learning exercises on the design process into their projects as each
stage is experienced, with practice and feedback. Originally students chose the topics, with suggestions contained in the adopted text by Voland\textsuperscript{15}. Project examples were: innovate a solution to help with demining efforts in war-torn countries, address the depletion of tropospheric ozone, and develop non-wood pulp for paper.

An assortment of self-selected projects relating to student life around the campus also predictably emerged each term. Over the years these projects became less meaningful to the instructors and more importantly, they were even less interesting to the students. These projects often missed the mark of designing to meet the needs of others and society. The course now requires humanitarian and service-based topics such as: Rain Water Collection, Management, and Dispersion System, Mobile Units for Different Disaster Types, Individual Entertainment System for Hospitalized Children, Trash Disposal and Recycling, and Device for Transferring Disabled Persons or Device for Saving Stranded Marine Life. The homework assignments are carefully based around each phase of the design process so that first-year students can steadily develop the major project with careful guidance and feedback from the instructor. More to the point, the homework and related project assignments are designed to actively involve the students in the entire design process.

**Design Deconstruction.** In the last month of the course, the student design teams are required to deconstruct a product or device in order to look back at the design process by “reverse engineering” a product. Much of the inspiration for the addition of this element came from presentations seen in the last few years, and from other instructors. These take-apart activities are much like others we have seen, with a few differences we have created\textsuperscript{4,12,13,20}. We allow the students to select their product with our approval, then they conduct the deconstruction on their own in small teams and prepare a poster presentation. The students are required on a pre-selected day to, assemble in a large hall and display their posters. In our case 70 groups of students presented their posters. We added this element to emphasize the importance of using a poster session as a method for disseminating a large amount of information in a short time to a large population. Another advantage of the poster was that the students had the opportunity to see what other student engineers where doing –how they applied the design process– and they had the chance to evaluate them. Many have commented that they enjoyed this hands-on element of the course and learned a great deal from the guided reverse engineering assignment. It is not only the activity that the students find engaging, but also the presence of a physical device with which to apply their knowledge. This factor of **tangibility** is a critical component in seeing the value of their studies and the activity. Again, every attempt is made to map the experience back to the design process, in this case to the implementation stage.

**The Cross-Threads: Active Learning Applied to Each Phase of the Design Process**

Many activities used in the course illustrate several phases of the Design Process, but are described here in the first design step that applies to them.

1. **Needs Assessment.** The students begin their work with the design process by answering questions such as: What problem does this design solve, who benefits, what human need is met, what improvement can be made? Examples of these assignments and exercises are listed below:
a. Like/Dislike this Design – This assignment is given on one of the first days of class. The instructions are:

“Find an engineered product that you like or dislike to show to the class (unless the product is too large to bring, then it should be easily described, or bring a picture). Review the feature(s) of its design that you like or dislike. Briefly describe on paper this design feature and why it is so desirable or so undesirable. Draw a sketch of an improved product. Hand in your description of no more than one page with a sketch. Be prepared to give a 1-2 minute summary to the class.”

The students generally choose common objects familiar to everyone and easily present them, because they can keep it short. This breaks the ice by bringing them to the front of the classroom in the first week, and also gets them started on the path to looking at the world around them for design possibilities, design successes and design failures. It is intended to activate their “design antennae”, and can continue throughout the semester with the One-Minute Engineer described below. It also turns the focus to the needs assessment phase, i.e., Why was this device designed?

b. The One-Minute Engineer – This activity gets the students involved in their own learning by having them explore their surroundings and find an engineering topic to present. Each student has approximately one minute to start design class each day with a presentation on a device, a person, a concept, a vocabulary term, or a historical or current event related to engineering. This exercise teaches needs assessment, problem formulation, and implementation, as the students become active investigators and engaging presenters of engineering in practice.²

c. What’s Wrong with this Tool? The instructor brings various tools or products to class, distributes them and gives the students a few minutes to consider ways to improve the object or device. Then the student groups relate what they would do to re-engineer the given item. If possible, the instructor has on hand improved versions of the item to then show the class. An example that most students can relate to is using a spray paint can. When the nozzle is held continuously, it is tiring, the nozzle gets messy, and accuracy is compromised. The students develop and sketch their solutions to the dilemma and then get to see the existing attachment that solves the problem. To rectify the situation, engineers have developed an improved trigger handle that fits over the nozzle to assist the sprayer with a small lever and which keeps the process neater.

d. Tower of Straws – The instructor divides the class into groups of 4-5 students. Each group is given 25 straws, a pile of paper clips and a small wad of modeling clay about 1” in diameter. The instructions are to build the tallest tower structure in 20 minutes using the materials provided. The class discusses the comparison to a real world scenario when they would have resource and time constraints, and must work as a team. Additional challenges are created by having a variety of goals to be met in the same project that may be conflicting. Some additional criteria used as goals are: most creative, earthquake resistant, hurricane resistant, aesthetically pleasing, and any others that the class selects such as cost-effective. Before starting, the goals are ranked, with the point values determined collectively by the class, so the students know which goals their team may try to meet and the weight of those goals. These rankings are used in decision analysis at the end to determine which tower is “best”.

In the Tower activity the class also addresses working as a team, with guidelines that must be met to ensure that all members participate. The teams can select their own location in the room for their tower. The building process provides many learning opportunities to reflect upon during that day and throughout the remainder of the semester. For example, the constraints due to poor materials means that moving the tower is unwise. They learn that once started, there is insufficient time to restart the task; thus good problem formulation, preparation, and planning count. They also learn that although height is the top criteria, if it is not sturdy, one long set of straws will bend and fall over. At the end of the allotted time, they must present their structure and each is tested for compliance with the design criteria. This activity covers all design phases in an abbreviated manner: needs assessment, problem formulation (setting goals), synthesis, analysis, and implementation. Additionally, once the towers have been built, there is also reflection on how the task and approach may have been revised. Reflection time is crucial to review what they have learned about teamwork, constraints and engineering. In addition, this gives the students an opportunity to get to know each other, which helps on numerous future team projects. Since this activity covers nearly all phases of the design process, it may be used at any point in the course. Many instructors choose to implement it in the abstraction phase, since this coincides with major design group formation and it is useful for team-building experiences. It is also an iteration of the Minor Project concept in that it is another chance for the students to construct an item from beginning to end.

e. Newspaper Article Evaluation – The class is divided into a number of groups and each is handed a news article or excerpt reporting a situation that is affecting a large population. The students are asked to identify a number of needs that must be addressed in order to rectify the current situation. The importance of organizing and prioritizing the list is emphasized as well as the difficulty in doing so with the limited information given in the article. The students are also asked to identify the primary and secondary target beneficiaries of any relevant engineering efforts. Recent events such as the Asian Tsunami and Hurricane Katrina are just a couple of examples of possible evaluation topics.

2. Problem Formulation. In this phase, the students explore the problem at hand more thoroughly, considering the goals for the project and possible solution paths, but not solutions per se. They are shown various techniques for revealing defining, and reformulating the problem. Some of the techniques are Duncker Diagrams, Kepner-Tregoe Problem Analysis, Kepner-Tregoe Situation Analysis, and Statement-Restatement Technique.18

a. Using Problem Formulation on Current Events – Similar to 1e above, recent current events are taken from the newspaper; these are problems that do not have one clear solution. The instructor finds 5 or 6 of these articles; they need to be fairly short. An example is a neighborhood problem where a large number of college students moved into a family-oriented neighborhood, causing problems with noise and disruptions on weekends. Copies are made, and then distributed to groups of about 4 students. There should be at least two groups that are given the same problem. Problem formulation techniques are then assigned to be applied to each of the problems. When doing the assignment, the instructor should ensure that the same technique is not used on the same problem. The groups formulate their responses on transparencies for presentation at the end of class. The students practice the problem formulation approach and see all techniques demonstrated.
b. Case History Presentation – Student teams are randomly formed and each team is given a historical topic or case study from the textbook to research and present. They are told the presentation should contain a summary of the case, identification of the important lesson learned concerning engineering design, and a similar example in which comparable principles are illustrated. Topics used in the past have included the two space shuttle disasters, the draining of Lake Peigneur, heart defibrillator development, cleaning up oil spills, airline disasters, how color printing lead to air conditioning, and even the story of Levi Strauss and his riveted jeans.18

c. But I Saw it in the Movies – Teams of three or four students select and analyze a scene from a movie. This was inspired by a 2004 ASEE presentation having students from the US Military Academy find and analyze a movie scene16 as well as work by Di Bella3. Instructions to the students at NU were as follows:

“How you select a movie clip is up to you and your team. Watch the movie and document where the action is, what scene it is in, where it is located. Please select a scene that is tasteful; no nudity, sexual content, or explicit gore, blood, and guts. You will need to describe that scene, and plan to show it to the class. Keep it short. Then, for your analysis of the engineering reality, refer to the following questions:

- What engineering principle was captured or represented?
- What part of that principle is correctly portrayed?
- What part of that principle may not be correctly portrayed?
- If the principle were corrected, what would it look like? Would it still be effective?
- How does this example portray engineers in society?”

Students are required to give a short overview to the class, showing their selected scene and related findings. This is another opportunity to have them research scientific principals, dynamically engage them in public speaking and in organizing an effective visual presentation.

3. Abstraction and Synthesis – This stage of the engineering design process requires the students to creatively generate multiple solution options for the engineering problem at hand. Numerous creativity stimulation techniques are described and defined for the students in class and in their textbook. These techniques are brainstorming, bionics, checklisting, synectics, analogies, adaptation, fresh perspective, inversion, brainwriting, morphological charts, and idea diagrams. While the students are usually familiar with brainstorming, related activities quickly help them learn about and apply the other techniques.

a. Small Groups Solve Problems to Present to Class – The students are divided into small groups, in which they are given a problem and are required to generate as many solutions as possible, using one of the techniques -not including brainstorming- in order to practice a different creativity method. They are given overhead transparencies and markers to use to write their solutions down and present them to the class. Several examples of the problems used are:

*The Putrid Pond:* “A very large (500,000 sq. ft. ≈ 10 football fields) sludge pond is part of a waste treatment plant. The liquid in the pond is very viscous and sticky. From time to time, unwanted floating objects (dead animals, branches, etc.) appear on the pond and must be removed. Unfortunately, covering the pond is not an option. Devise ways to solve the problem.”
I'm Really Steamed: “The Heiss manufacturing company of Germany has been making a steam-producing home appliance, designed to be used to steam milk in the making of cappuccino. Unfortunately for the company, its competitors now incorporate a steam maker right into the cappuccino maker, so that a steamer-only design no longer sells. You have been hired by a liquidator company that has acquired 40,000 of these steamers to write an advertising brochure, describing as many practical uses for this steamer as you can.”

The Dead Hen Dilemma: “An epidemic on a chicken farm created a thousand tons of dead chickens. The local landfill would not accept the dead chickens. It is also against the law to bury the chickens and the local authorities are insisting the matter be dealt with immediately. Suggest ways to solve the farmer’s problem.”

When distributing the problems and creativity stimulation techniques, it is recommended to give the same problems to different groups with different creativity techniques to apply. Also, some techniques work better on some kinds of problems, so some prior consideration is required to determine which techniques suit which problems. The students are often resistant to the “new” techniques but find that they come up with a lot of creative solutions (and laughs) during this exercise. Once the groups have worked on their creative solutions, they typically present their results to the class as noted above; sometimes the instructor works with each team to do this and supplement the learning process.

b. Class Synthesis using Creative Techniques on a Single Problem– A variation on the previous activity is to present the same problem to the entire class, but divide them into small groups and assign different creativity stimulation techniques. The students then compare the variety of solutions generated by using the different methods. This shows the value of teamwork in teaching and trying different techniques, even if they are unfamiliar or new21.

c. Brainteasers and Brainstorming - This approach trains the students in brainstorming by handing out problems that include simple brain teasers or problems relating to current events such as deforestation, cleaning up polluted ponds, waste disposal, or even fictional situations like changing the rules of basketball to accommodate shorter players. The emphasis of this exercise is on proper brainstorming technique -quantity not quality at this phase, and no negativity towards other group members whose ideas you consider infeasible or impractical. Again, this active learning exercise involves all members in the process and gives practice using techniques from the design phase.

d. Tower of Straws: See Needs Assessment item 1d above.

e. Design Teams Apply Abstraction and Synthesis approaches to their Major Design Projects – During class time, the students conduct their synthesis sessions to come up with ideas for the Major Design projects they are working on. This ensures that the instructor can monitor and guide the students through this phase. The discussions can become lively and it is a great opportunity for the professor to have informal and productive dialogue with the students while providing immediate feedback on their projects.
4. Analysis – At this point in the design process, solution options have been generated and students are asked to objectively evaluate the available options according to stated design goals, design features, and other factors bearing on the final decision. They learn to generate rank-order tables and design matrices to aid in complex decision making.

a. Class uses Decision Analysis on One Problem – The instructor facilitates the use of Kepner-Tregoe Decision Analysis on a chosen problem, such as selecting a place to live next semester. The class first selects goals collectively, and then generates a Rank-Order Matrix to select relative weights for each of the goals. As a group, the students create a list of alternative places to live. On the board or projector, the instructor creates a decision matrix for the problem, with the alternatives across the top and goals along the side. The class works to fill in the values by ranking each alternative against the goals. Students then multiply and add up the results for each alternative, making a class decision on where to live. This creates opportunities to discuss why that alternative was chosen, the subjectivity of the technique and ways to handle the process as a group. Other examples to use are how to select a college or which job to take if you had multiple job offers to consider for Co-op.

b. Film on Engineering Disasters – Students view a film on engineering disasters that often have resulted in the loss of life and property and diminished engineering credibility. Each Major Design Project team is assigned one of the disasters and then is required to further research the technical and ethical issues that were involved. They must summarize any product liability cases that arose out of the disaster and provide an example of a similar type of disaster and liability case. The exercise bring ethics and product liability into their analyses and provides each major design team the opportunity to present together for the first time before having to present their final design projects at the end of the term.

c. Design Teams Apply Analysis Methods to their Major Design Projects – as mentioned in Abstraction and Synthesis, during class time and after Analysis is introduced, the Major Design project groups meet and apply one or more analysis technique to their ongoing project under instructor guidance. Again, feedback is provided on the application of design phase methods.

d. Tower of Straws – See Needs Assessment item 1d above.

5. Implementation – This phase requires the students to investigate, understand, and appreciate the realities of bringing a design to fruition. They review costs, marketing, manufacturing, distribution, and several aspects of what it takes to take the design from paper to production.

a. Reverse Engineering Homework Project - As noted earlier, each major project design team selects a product to deconstruct that must be approved by the professor and should be purchased as a group. This is a common engineering activity in design courses. Examples of acceptable items are: disposable cameras, hair dyers, toasters, doorknobs, space heaters, and any number of multipart toys. Products should contain at least 4 major subassemblies and be deconstructed safely and transported easily. Since evaluation of the packaging is part of the assignment, teams typically purchase a new product. Each team is required to observe, report, and illustrate how a product is constructed by looking at each component of the product through the disassembly activity. The product should be deconstructed into major assemblies first, then
each subassembly should be broken down to its individual parts. The students need to summarize the steps they took in the investigation by writing a report that describes in detail the major subassemblies, contains drawings of the major component assemblies, provides information on how the product is manufactured, estimates manufacturing and packaging costs, and presents a complete parts list. In addition to the report, teams participate in a poster session open to everyone at the university to showcase their work. The poster session is useful because it gives the students facility in another form of presenting their work other than using a PowerPoint slide show.

b. Reverse Engineering Classroom Activity - When time is limited, a single-day in-class Design Deconstruction exercise has been useful. The class activity version of Design Deconstruction has been to reverse engineer the single-use cameras. The students buy cameras and take them apart in small groups under guidance. They answer questions about the operation and manufacturing of the camera, sketch components and then try to reassemble it.

c. Manufacturing processes – After the instructor shows several manufacturing processes on how things are made, a discussion on Design for Manufacturability leads to students working in groups on an exercise. A handout shows two options for design comprised of numerous parts. The students must decide which of the two options is best in terms of the principles taught on Design for Manufacturability. Groups discuss and debate which design is really best; this may become lively since many groups have multiple criteria, or the preferred solution does not appear to be the best design at first glance, and this realization does not materialize until all criteria are considered. The students are responsive to this activity because they are involved in making an operational decision as opposed to receiving a lecture on what the decision should or should not have been.

6. Reflection & Iteration

Since the students themselves have been involved with each phase of the engineering design process and have participated in each step along the way, they have had first-hand opportunities to rethink, review, and consider how they would redo or revise given the opportunities. In many cases, this is not merely a theoretical reflection; the student engineers in fact return to the drawing board or make adjustments to their various designs throughout the semester.

Assessment

Midterm Survey. The College of Engineering at Northeastern University performs a midterm assessment survey of the first-year students taking Calculus, Chemistry, and Engineering Design by having them rate the teaching of their instructors on a scale of 1 being unsatisfactory to 5 being best. The instructors receive a summary of all the results as well as comments from their class. This is done to review teaching, not active learning, so it is significant that the students mention active learning when they comment on the course. The results showed an average rating of 4.6 for those instructors choosing to use active learning as a substantial component of their courses, with very few ratings of 3 and very few negative comments. The chart in Figure 1 shows an analysis of the comments. The data for this analysis only addressed direct or indirect positive comments about the course itself or how the instructor involves them in activities. It does not include positive or critical comments about the instructors themselves beyond the
activities. Also counted in this assessment are students who left the survey comment section blank. This chart shows that 40% of the students who made comments that were included in the selected data pool described above mentioned they liked aspects of the class that involved active learning, and 10% of this group mention a specific active learning exercise used in class. The other favorable comments focused on the instructors and the course, which are not applicable here. Examples of the few negative comments were typical of most students: “gives too much work” or “lot of projects to manage”. The feedback on the workload and number of projects notwithstanding, results demonstrate that students are responding in an generally positive manner to the use of the previously described active learning exercises.

![Comment Summary](image)

**Figure 1. Analysis of selected midterm assessment survey comments.**

**Examples of Student Comments.** Feedback from students indicates that active learning approaches help facilitate their learning, as well as keep their interest in the class elevated. The following are some comments from these midterm feedback assessments. These comments support why they liked the class and the fact that the instructor kept it engaging:

“Fun and lively class, very hands-on”, “classes are amazingly fun”, “lots of hands-on activities”, “classes are entertaining along with educational”, “goes over the main points and utilizes class-time to do group work and practice”, “projects get students involved”, “very good at involving the class in the lesson”.

Some comments from the course evaluations at the end of the semester are:

“Combines note taking perfectly with classroom activities to maximize learning”, “…divided lectures and activities to make class interesting”, “in-class activities are interesting ways of learning”, “made the material enjoyable to learn”, “made class fun and enjoyable”.
Course Evaluations: The end of course student evaluations for Engineering Design provide further supporting evidence for active learning. Figure 2 below compares instructors that use little or no active learning with the instructors that use a high level of active learning. The level of active learning was established by asking past and present instructors how many of the activities listed were used over the last 6 years and discussing how they teach the course and what they have been using in terms of classroom techniques. We found that most instructors are using some active learning; out of the 19 activities described above, the cohort instructors use 3 to 6 of them and reportedly no others. In comparison, the authors use from 13 to all 19 of the listed activities. The course ratings are on a 5-point scale with 5 being a rating of most effective. The three measures are Overall Rating of Instructor Effectiveness, How Much was Learned, and Overall Course Rating. Figure 2 shows the averages of 45 sections of the course from 1999 to 2005 for each set of instructors. The means were compared using a t-test comparison of means assuming equal variances. The resulting p-values were all less than .0001, showing statistically significant better evaluations of the courses that use more active learning elements. Most notable is the difference in students’ ratings of amount learned, from 3.4 for traditional classes to 3.9 in the experimentally-based course sections.

![Comparison Between Instructors' Level of Active Learning on Course Ratings](image)

**Figure 2: Comparison of instructor course evaluations according to level of active learning.**

Another assessment of the effects of active learning is to hold the instructor variable constant, and review the results over time. Two of the instructors (authors) have been teaching this course for 8 years. On average each year an additional 1 to 2 active learning approaches were introduced with there being a significant increase over and above this after 2000 as more knowledge of and motivation for applying active learning was acquired. Much of this knowledge is credited to attendance at teaching workshops and ASEE.

Figure 3 shows the student course evaluation results for the early years of our teaching in contrast to more recent years, with the major change in our teaching being the increase in active
learning exercises. Each category shows a statistically significant increase. The \( t \)-test of means shows \( p \)-values <.04 for Overall Instructor Effectiveness, \( p \)-.01 for Amount Learned and \( p \)-.001 for Overall Course Rating. It should be noted that the increase is not merely a function of improving as instructors, as we were experienced teachers prior to these course changes. We did not begin this teaching without previous classroom experience. In fact, even as part-time teachers, our early ratings were exemplary. We were hired as full-time teaching faculty because of our experience in teaching and commitment to improvement.

The Final Product: How do we as instructors, assess what the students have learned about the design process? Although there is an exam given after the first year to look at the level of fundamental knowledge retained by the students, its examination content does not include the Engineering Design course. The reason is because of the difficulty of testing what the students have learned about the design process, with much of the learning being experiential. Assessment in this case must therefore look to the quality of their work. In this instance we look at the impact of using the design process in a quantitative fashion (13-19 activities), and the final quality measure being the presentation of the Major Project. As noted earlier, students create Major Design project reports as the final culmination of the semester work. In addition to the related activities and assignments described above, the projects are done in teams, in which the students also rate their peers. The project reports contain chapters covering each of the design process phases. In classes this year, there were no projects that received failing grades even if individual students did poorly on some independent assignments. The students are able to clearly show facility with the design process and its application and they produce interesting and creative solutions to problems during their first semester of engineering.

![Figure 3: The effect of adding active learning within same instructors in a span of several years.](image.png)
We can also review how the course meets outlined objectives and if the objectives match ABET desired outcomes. The following list is taken from the Engineering Design course syllabus:

**Course Objectives:**

- Learn and apply all of the steps of the engineering design process in proposing and building working devices or models in design projects.
- Design and construct a working device or model that meets preset constraints and specifications.
- Design a product or engineer a solution by applying the engineering design process steps and documenting and reporting on each phase (not including build and implementation).
- Describe the scientific principles and technical background required for the proposed design project;
- Outline the patents related to the proposed design and evaluate their pertinence to the solution.
- Generate a report for the design project that reflects work completed in each step of the design process and presents technical drawings that apply to the approved design.
- Review and evaluate engineering failures and successes for their relationships to engineering design problems, solutions, and processes.
- Apply the engineering principles revealed in class exercises on teamwork, creativity, problem solving, and on evaluation, selection, and implementation of solution alternatives.
- Develop and apply drawing and sketching skills to communicate design and engineering information graphically. Apply the principles of orthographic projection in engineering design.
- Learn and practice technical drawing and engineering graphics communication using AutoCAD. Apply skills of technical drawing to specific engineering projects.
- Formulate engineering problems for numerical solutions, conduct relevant computations, analyze, organize and present results using Excel software.
- Create and deliver individual and team presentations on engineering design projects and topics.

The active learning exercises meet most of these objectives by providing classroom practice for the students in each phase and in many classes and lessons. The course objectives reveal emphasis on application; it is a key word in 5 of the 8 objectives. The activities described here also represent applications of the principles and assist the students in learning how to apply the design process.

**Accreditation Board of Engineering and Technology (ABET):** This work also maps to the ABET outcomes a – k. By developing and analyzing solutions to problems, demonstrating and presenting the solutions, working in teams, and participating in the class activities described above, the students visibly demonstrate progress in the referenced ABET outcomes: (a) an ability to apply knowledge of math, 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, (g) an ability to communicate effectively, and (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. Further, ABET outcomes (f) an understanding of professional and ethical responsibilities, (h) broad education necessary to understand the impact of engineering solutions in a global and societal context and (i) a recognition of the need for, and an ability to engage in life-long learning, are easily woven into the case study exercises and presentations as outlined above.
Conclusions
Teaching Engineering Design, and indeed any educational course, has many dimensions to the needs and requirements of the course. As educators we are not only striving to find ways to instill in our students the contents of the course syllabus, but we also have to ensure that they are capable of comprehending and successfully applying the course precepts. This is necessary to help them in their ongoing engineering education and employment and so that we can provide reliable assurances to their employers as to their suitability as engineers.

Incorporating activities into the Engineering Design course not only helps students understand and apply the stages of engineering design, but also gives us as educators many views of the students' capabilities. The projects we have assigned to the students have been selected to enable them to become participants in their own education. They have the inspiration to create and we acquire the ability to evaluate and assess their proficiencies in the more innovative elements of their work. The course structure we have outlined above was designed for (1) creating diversity in the students' activities to capture all stages of engineering design, (2) providing sufficient iteration to stimulate retention of the concepts, and (3) supporting creativity through selected problem sets and ongoing practice. The assignments and activities go well beyond simply identifying the six stages of design for the students; they experience them.

As educators we have found that it has helped our individual classes to call upon the ideas and inspiration of our colleagues to add new textures to our syllabus, and through a combined patchwork and meshing of ideas we have made our classes more relevant to our students' needs and the class elements are ever evolving to maintain their interest. We began using more active learning and spent time carefully connecting each activity to a piece of the engineering design puzzle. In providing the outlines set out in this paper we hope to provide similar inspiration to fellow colleagues in this field.

The instructor team discussions on the course are now mostly focused on cosmetic changes, additions, and administrative improvements in implementing the course activities. With so much in the course already that works, it becomes difficult to decide what to take out in order to try something new. However, that dilemma does not imply we are done searching for improvement opportunities. Each semester brings new areas and ideas that require evaluation, review, and revision as we look for new threads of activity to work in to maintain the vitality of our course and the panorama that results.

References:


