Development of an Introduction to Mechanical Engineering Design Course

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Abstract
Beginning in the Fall 2001 quarter, a course entitled "Introduction to Mechanical Engineering Design" (IMD) was offered to a group of 16 first year ME students at the Rochester Institute of Technology (RIT) on a trial basis. This course is intended to eventually replace a disjointed three-course sequence taught over the course of the first two years of the curriculum: Materials Processing, Engineering Design Graphics, and Geometric Dimensioning and Tolerancing. All three courses are currently required, as the information they present is certainly all relevant and necessary for graduating engineers. The manner in which it is presented, however, is in need of improvement. In reality, design engineers need to be able to combine and apply the skills learned in these classes to generate complete designs. IMD will teach students the same concepts as the existing courses, only the content will be taught in the context of two design projects spanning two 10-week quarters. In the new 2-quarter, 5-6 hours per week course, students complete one short design on paper and one larger, Rube Goldberg type design where all 16 students work together to design and build a functional system. Since IMD is only offered to freshmen, all analysis is based solely on fundamental physics. In this way, the students are exposed to the entire design process: concept generation; formalized design, analysis, and construction phases; and finally, testing and evaluation of the device(s).

Motivation

The Mechanical Engineering curriculum at RIT suffers from a lack of formal engineering design experience in the early years of undergraduate study. Students are introduced to Mechanical Engineering through a series of courses in Materials Processing, Engineering Design Graphics, and Geometric Dimensioning and Tolerancing over the course of their first two years. While these courses present information that is critical to the design process, the material is presented in a discontinuous method relying on a "you will need to use this later" justification. In addition, these courses are spread out over quarters 1, 2, and 6 in the course sequence, with no actual application to a comprehensive design project until the 11th quarter when they take Senior Design. By teaching the same material integrated with a project, students will immediately see the value of what they are learning, and will have more motivation to retain that knowledge. Since it is impossible to condense 3 quarters of existing course material into two, in addition to adding new material, more responsibility will be given to the students. They can only be presented with the basics in each area; the rest is up to them to discover on their own as the need arises. The ability to learn on their own is an invaluable skill that will serve them well in later ME courses.

ABET has recently placed more of an emphasis on integrating design across the curriculum. RIT's Mechanical Engineering department is responding to this need with the revival of Senior Interdisciplinary Design and the development of an upper-level Integrated Design course. This is in addition to the traditional capstone Senior Design, where students spend 2 quarters designing and building a project for external sponsors. Our first year students need a foundation in design education to prepare them for these courses, where they are given responsibility to design a product for a paying sponsor. In particular, ABET criteria c, e, and h should be addressed before students enroll in a Senior Design class. These criteria state that students should have:

- (c) an ability to design a system, component, or process to meet desired needs.
- (e) an ability to identify, formulate, and solve engineering problems.
- (h) the broad education necessary to understand the impact of engineering solutions in a global and societal context.

Along a similar direction, members of the RIT Mechanical Engineering Industrial Advisory Committee expressed an interest in hiring students who are more self-directed, creative thinkers. The IAC also indicated that RIT's graduates need to improve their communication skills. Some faculty within the department have incorporated small-scale, open-ended design and analysis projects in courses such as Statics, Dynamics, Materials Science, and Mechanics of Materials. However, many students have trouble with these open-ended problems, having been limited strictly to problem solving in their early classes. The students have also had little or no training in technical writing and many have difficulty conveying their ideas in a clear, concise manner. Often times these projects are not included in a particular offering of a course, so a student's exposure to them also depends on the instructor.

A number of other universities have either had a freshman or sophomore level mechanical engineering design course in place for many years or have started one in the recent past. These include Purdue University, Iowa State University, the New Jersey Institute of Technology, and Boise State University [1-3]. These schools have all reported favorable views of their freshman or sophomore design courses with only the minor problems that come from offering a course for the first time. One potential stumbling block could be the lack of new student knowledge about machine components – gearing, nuts and bolts, springs, etc. With the existence of the Freshman Seminar class in RIT's ME department, this will not be a problem as students spend part of that class disassembling and examining various machines. With the foundation in place for students to begin creating their own designs, and with the need for an early course to teach design methodology, this Introduction to Mechanical Engineering Design course will fit well within the ME curriculum.

With the current rate of student attrition in the College of Engineering, and in light of the issues described above, it is in the Department's best interest to attract student interest early and to ensure that these students are well prepared to work as engineers. The proposed course will target students in the first and second quarters of their second year at RIT. It will follow through from the initial problem definition to a final design and teach the required skills along the way in the context of the class design project. Examples of realistic applications-based engineering design problems will give students a taste of what is to come in their later classes – including

Senior Design, the capstone Mechanical Engineering course - and in their future careers. This can be best done by introducing engineering design earlier in the curriculum in a comprehensive course that presents the different components of the design process in one complete package.

Based on the feedback gathered and presented above, the objectives of offering a new Introduction to Mechanical Engineering Design course are then:

- to deliver the existing three courses worth of material to the students in a more effective manner, without sacrificing too much content,
- to expose students earlier in their educational careers to the types of challenges that they will confront later in classes, on co-op, and in their future engineering jobs, and
- to present students with techniques that can be used for effectively solving open-ended design problems.

Course Planning

16 students were selected at random from the incoming freshman class and invited to participate. The course size was determined based on computer facility limitations for a partner pilot course [4]. The partner course, Measurements, Instrumentation, and Controls (I and II) was developed to give freshmen experience in the lab, particularly with computer control of experiments and data acquisition. Goals for the course were taken from the curricular needs outlined above. Key points that the course was intended to address beyond what the current program offers were:

- Approaches to effectively solving open-ended problems
- Comprehensive design/design-and-build projects
- Extending basic physics analysis to real-world engineering problems
- Working productively in teams
- Technical writing and presentations

IMD met for two 1-hour blocks and two 2-hour blocks each week. Three texts were chosen for the class. *The Mechanical Design Process* (David G. Ullman) was used as a reference for the design process, *Technical Sketching* (Dale H. Besterfield and Robert E. O'Hagan) was used for classroom and homework sketching exercises and teaching drafting conventions, and *Solid Modeling with I-DEAS* (Sheryl A. Sorby) was used as an instruction reference when the class was learning I-DEAS. IMD met in a lab/classroom, where the students were seated at tables in groups of four. This setup lent itself very well to the team-based approach to in-class activities. Students were given surveys at the beginning of the quarter and asked whether they preferred working in groups or alone, whether they were decisive or indecisive, and whether they tended to think logically and work with facts or to think creatively and worry about the details later. Based on these surveys, four groups of four were assigned so that each had a mix of students with different responses to each question.

The students completed one design on paper only and began work on an extensive design-and-build project. Since this two-quarter course was intended to replace three one-quarter courses while adding more content, it would be impossible to include the same material in the same detail. The overall layout of the first quarter of the course was intended to support the students in their design projects. Topics would be covered in class just before they were needed for the project. The second quarter was intended to cover some of the first quarter topics in more detail, once the students were familiar enough with the basic design process to work on the projects without significant guidance. During the first quarter, the topics shown in Table 1 were covered as outlined. The timing was such that the week before students were required to turn in their design objectives, a class lecture was devoted to methods of defining objectives for your design based on customer needs. In this way, students would get enough of an introduction to topics like the design process, engineering sketching, CAD, dimensioning, and tolerancing to be able to complete their projects. With this introduction, students would have a working knowledge of the general processes. For their projects, they would most likely be required to go into some specifics that were not covered in class in detail; this is good practice for a career where they have not been taught everything, but where they will have enough basic knowledge to learn the specifics on their own as needed. During the second quarter, the lectures will be less structured, allowing for more time to develop the project and more time to explore topics that arise unexpectedly during the project work. An outline of topics planned for coverage in IMD II is given in Table 2.

The first project, design on paper only, is an exercise in following a logical process to learn about an unfamiliar topic, define goals, develop working design options, and select the best one. This project would be one “sponsored” by an organization in the Rochester community. Since there would be no construction, no monetary support was required, but the sponsor would be requested to meet with the class to answer questions and help define the customer needs. By using a community-service type of project, the students would see how their work might one day affect their community. With many classes moving toward Battlebot projects and other engineering activities aimed at making engineering fun, it is important for students to see that their work can have other benefits.

The second project, design and build, was begun with the goal of having the students put their paper designs into a working final product. To emphasize the teamwork aspect of the course, the project would be a Rube Goldberg project. Not only would cooperation be required *within* the groups, but cooperation *between* groups would be critical if all the steps are to work together in the end. The students would be expected to follow the process outlined in the first project, only for this project they would be required to perform analysis and actually manufacture the project. Since the concept of a Rube Goldberg machine is basically a collection of simple machines acting together to perform a task, the project lends itself very well to basic physics analysis: inclined planes, projectile motion, and pulleys, for example.

There was some concern that students would be missing some valuable concepts that would be needed on co-op, particularly where I-DEAS instruction and Materials Processing were concerned. A random selection of 50 5th year student co-op reports were surveyed to determine what sorts of skills were needed for co-op over the course of the 3rd-5th years. At 4-5 co-op quarters per student (depending on their degree option), between 150 and 200 reports were surveyed overall. Very few of these reported using information learned in Materials Processing, while some stated that the Materials Processing *lab* gave them experience that helped on co-op. Some students reported actually using I-DEAS on co-op, but many reported using other CAD programs. In those cases, the students used only their basic working knowledge of CAD in general and had to learn a new program anyway.

In addition to the co-op reports, anecdotal evidence from conversations with upperclass RIT ME students indicated overwhelmingly to “lose the lecture, keep the lab”. In Materials Processing lab, students make a small hammer with the RIT insignia on one end. Many second generation students have the hammer that one of their parents made when they were ME freshmen – this tradition is a difficult component of the class to drop. A compromise was reached, where the students would make a slightly simplified version of the hammer that would take only five weeks instead of the full 10 week quarter. During the first five weeks of the second quarter, the students will spend one day per week in the machine shop making their hammers, leaving a full five weeks plus out-of-class time to do any machining that needs to be done for their Rube Goldberg projects. In addition, during the last two weeks of IMD I, the students were in the shop building a device needed to run one of their experiments in MIC I. This served not only as an introduction to the machine shop, but also as a way to show the students how their classes were related to one another – what gets designed and built in one class gets tested and analyzed in another.

Finally, the grading in this class was to be based mainly on project work and homework, not on formal exams. The students were also required to keep a design notebook, which was to be a record of all work done on the design projects – this was collected periodically and checked to ensure that the students were making regular entries. 45% of the final grade was based on project work, and an additional 30% was based on the students’ homework and design notebooks. The remaining 25% was based on attendance, class participation, and a mid-term exam.

Table 1: Week-by-week course outline for IMD I.

Week	Topics	
1	Design Process, defining problem, library and online resources; disassembly exercises	
2	Defining objectives and criteria; engineering sketching	
3	Work on design project; case study: Challenger disaster and statistics in engineering	Project 1: Design only
4	Technical writing; evaluating design alternatives	
5	CAD work (I-DEAS): new drawings, parametric modeling, dimensioning	
6	Continue CAD work; learning to read engineering prints	
7	Engineering analysis; in-class design, analyze, and build project	
8	Work on design project; introduce dimensioning and tolerancing	Project 2: Design & Build
9	Begin machine shop project; work on design project; dimensioning and tolerancing	
10	Finish machine shop project; work on design project; dimensioning and tolerancing	

Table 2: Outline of topics to be covered for IMD II.

Project-related topics	PERT Analysis and the Critical Path Outsourcing Purchased Components Fabrication and Assembly Issues
CAD-related topics	Use of symmetry and arrays Boolean operations Sweeps Parametric modeling Assemblies and Libraries
Manufacturing-related topics	Cost of tolerance Cylindrical parts / features Rectangular parts / features Odd geometries Casting Powdered / amorphous materials Fasteners Surface finishes

Achievements to Date

The achievements of the course to date are evaluated based on the four primary objectives outlined in the course and based on student response to in-class surveys.

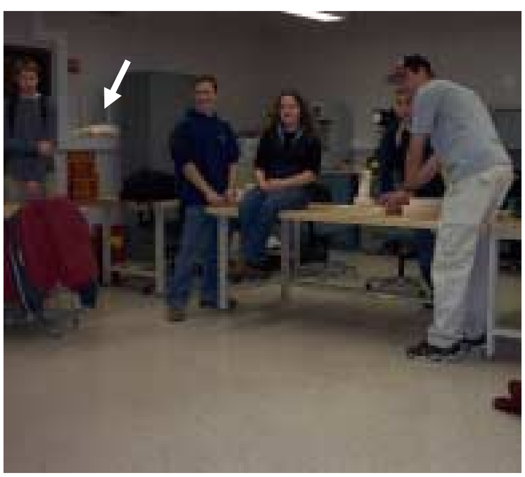
Solving open-ended problems, comprehensive design/design-and-build projects

The design on paper only was set up in cooperation with Monroe Community Hospital, a local rehabilitation hospital/nursing home. Suggestions were solicited from the Physical Therapy Department, prior to the start of the quarter, for a "wish list" of devices they would like to see made available for their patients. Students were presented with this list at the start of the quarter and allowed to select the project of their choice. One group chose to design an alternate propulsion system for wheelchair-bound patients who lacked the mobility to reach down and turn the wheels of their chair. The other three groups, working independently chose to design an emergency brake system for wheelchairs. The brake system was to automatically engage when the patient stood up. This was intended for use with, for example, Alzheimer's Disease patients who might forget to engage the brakes before trying to rise from their wheelchairs. Students were given the opportunity to either interview or give a written survey to the Director of Physical Therapy to help define their specific project goals. They used techniques learned in class to (1) set forth specific objectives, (2) brainstorm design concepts, (3) weigh the pros and cons of each concept, and (4) select one to be developed to the point of engineering sketches. The final report included the results of all four steps, plus the engineering drawings and relevant part drawings.

The extensive design-and-build project was begun successfully, but the construction has not yet begun. The students are working as a class towards building a Rube Goldberg project according to the rules of the National Rube Goldberg Machine Contest [5]. The project requires students to design a device that secures, raises, and waves an American flag using no less than 20 steps. During the second half of IMD I, the students met as a class to determine how the various machine steps would be broken up between groups. They also developed a preliminary proposed design. Each group designed their individual steps and the groups worked together to determine the interfaces between each team's cluster of steps. The culmination for this project in IMD I was a 20 minute oral presentation by each group explaining their design concepts and how their steps would pass the ball, so to speak, to the next group.

Extending basic physics analysis to real-world engineering problems

A one week in-class design-and-build project was done during the 7th week of the quarter. Students were presented with a plan to design, analyze, and build a projectile launching device to shoot a Hostess Twinkie at a target. The students worked in their design project groups of four. After a half-hour review of the physics of projectile motion, students enthusiastically began developing design concepts. On the second day the students were given the parameters of the launch (height and distance to the target, mass of the Twinkie, number of trials allowed). They performed the necessary analysis and finalized their design geometry. This included spring stiffness, angle of launch, and energy required to reach the target. On the third day, students were introduced to Working Model, a dynamic simulation program. While they were provided with starting templates with which to model their designs, most groups chose to build their own simulations from scratch. Within 1-1/2 hours, all groups had working simulations that nearly matched their hand calculations. Slight modifications were made as necessary, but most designs changed very little. On the fourth day, students had 1 hour to construct their launchers from basic supplies such as 1"x2" pine, springs, elastic bands, string, duct tape, and simple fasteners. During the second hour of class, the launch competition began, with three of the four groups hitting the target on either their first or second try (Figure 1). Not only were the designs successful, but the students were able to see their engineering analysis put into action in working designs. The project was a valuable lesson in learning how to relate equations learned in class to real-life devices, and the students were able to eat the surviving projectiles after the competition.



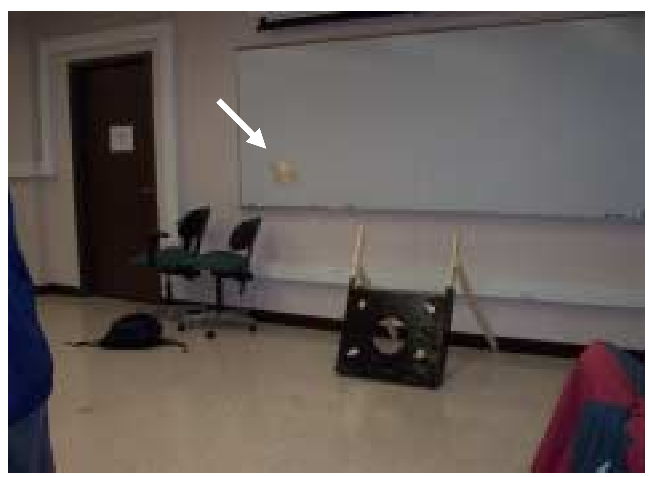


Figure1: Students designed, analyzed, and built devices to launch Twinkies at a target – most flights, like the one shown here, were successful.

Working in teams

In contrast to the other non-engineering courses the IMD students took, most work in this class was done in teams. The instructor met with each team periodically every two to three weeks outside of class to ensure that members were communicating adequately and that they were staying on track with their work. While there were some incidents of one team member failing to contribute when needed, most teams were able to learn to work around their differences.

In addition to working within teams, students were required to work between teams in developing the Rube Goldberg project concepts. While this got off to a very disorganized start, with all 16 students trying to talk at once to give their opinions, the situation improved rapidly. Within one class period, each group had designated a representative to speak for them. With these leaders doing most of the talking, the groups were able to divide up the space allotted for the design between the groups, divide up the sequence of steps that would have to be performed, and come up with an overarching theme for the whole contraption.

Technical writing and presentations

Students were required to submit a formal report for the first design project and a formal presentation for the second design project. Leading up to this, one lecture was spent rewriting a pre-prepared lab report as a group effort. Students were then asked to submit a 1-2 page formal experiment report of their own; each was critiqued by the instructor, and the students also swapped papers for peer comments on clarity, organization of technical detail, grammar, and spelling. The following week, the first formal project reports were due. Students were expected to write well-organized, detailed reports, making appropriate use of figures, tables, appendices, and references, as discussed for the lab reports. During the final exam period, students were required to make formal group presentations on their Rube Goldberg projects. Students were expected to make presentations that clearly conveyed their design concepts, with an introduction and final summary, using PowerPoint. Most groups made additional use of computer animations to illustrate their group's Rube Goldberg steps.

Student feedback

Students were given two opportunities to give feedback on the course: One mid-quarter survey and the formal end-of-quarter course evaluation. Aside from typical student responses (classroom is too cold, class should include nap time, etc.), there were several notable observations:

- "I'll never look at a wheelchair the same way again," and "I never thought there was so much to learn about wheelchairs"
- It has helped a lot to get used to [working in groups]. I prefer working alone, but it will not always be that way, so this is good practice."
- "I find myself learning better in a relaxed environment" [a comment on project-based evaluations, rather than formal exams]
- "The integration between the two types of classes [project work and traditional lecture] helped a lot."

The students were fairly evenly divided on several topics:

- Being given step-by-step instructions for learning new computer software (I-DEAS, Working Model) vs. being given an overview and then time to experiment on their own.

- The balance between traditional lecture and hands-on activities.
- Their views of course material that is not purely quantitative and analytical.

Other student comments were overwhelming requests for more time spent with I-DEAS and in the Machine Shop. As the first quarter was intended to be an overview of the steps used in mechanical engineering design, this was understandable. The second quarter is intended to go into more detail about I-DEAS, give the students opportunities to make components of their project as well as the traditional RIT Hammer in the machine shop, and learn more about manufacturing and assembly issues in design.

Summary

In the process of completing IMD I over a 10 week period, the students were taught:
- Basic technical sketching concepts.
- Working knowledge of I-DEAS, a multi-function CAD/FEA/simulation program.
- Basic dimensioning and tolerancing conventions.
- How to use machine shop equipment to manufacture components for their own designs.
- Techniques for creatively solving open-ended design problems.
- Technical communications, including written documents and oral presentations.

By working effectively in teams on unfamiliar problems, the students were able to gain additional knowledge with minimal guidance from the instructor:
- How to learn enough about the function of a new system to be able to modify its design.
- How to apply their basic knowledge of physics to design, analyze, and build simple mechanical systems.
- How to use a simulation program to model performance before building a design.

The next step in the evolution of IMD will be to incorporate it with Measurements, Instrumentation, and Control (MIC), another freshman pilot course in Mechanical Engineering at RIT. The two courses compliment one another in two ways: first, students will be able to design and build the components they need for the MIC experiments; second, students will be capable of testing the designs they create in IMD to determine whether they function as predicted. Ultimately, the two courses will create a first year experience that gives students a hands-on introduction to a wide range of Mechanical Engineering activities.

Acknowledgements

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