Engineering Design Applications in the Introduction to Mechanical Engineering Curriculum

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Introduction

At the New Mexico Institute of Mining and Technology (NMT), mechanical engineering majors are required to take an Introduction to Mechanical Engineering course. In essence, this course is their first impression of the topics Mechanical Engineering encompasses, and their first taste of what pursuing this degree entails for their future. It is well established that a key aspect of engineering is the application of fundamental engineering principles through design. Engineers must be capable of applying principles into a design, making the exposure to design imperative to their success in the field of Mechanical Engineering. Design provides hands-on understanding of the materials learned and properly models behavior for later projects. As technology has become a larger aspect in engineering, the two main critical skills required for most projects and applications are modeling and coding. As such, the first-year students are provided instruction in Solidworks and Arduino to provide them the necessary skills for success. Additionally, the projects model workforce behavior, as group projects help develop teamwork skills, and healthy problem solving. The introductory course at NMT includes three different semester-long design projects, referred to as: Modal, Transfer Case, and Rocket are utilized to reinforce design: Solidworks, Arduino, and the application of engineering principles Students are broken up into groups of 3 to 5, and each student is assigned a role for accountability and communication purposes. This paper analyzes the beneficial effects of a design-focused Introduction to Mechanical Engineering course.

While students at many other universities do not begin design until their later years, our unique structure recognizes that early career design is beneficial for students. All ABET-accredited universities maintain a design requirement per ABET learning outcomes B and C for the 2018-2019 requirements [1]. However, our emphasis on design is focused to obtain early engineering principles such as hands-on understanding of force, energy and motion. We believe that these three principles are one of the most significant topics to cover at an early stage, as instruction in these areas can lay the foreground to higher levels of Mechanical Engineering concepts such as stress, strain, tension, torsion, and more - all of which are implemented in the upper-level design courses at NMT.
Course Structure Redesign

The introduction to Mechanical Engineering course was previously structured such that there were 16 weeks of modeling using Solidworks. The associated lab followed a Solidworks modeling textbook [2], while the lecture quickly introduced the multiple fields of Mechanical Engineering, such as fluid thermal systems and solid mechanics. The course was considered an “easy A” and sometimes viewed by students as a waste of 3 credit hours of needed instruction, similar to that of an Introduction to Aerospace Engineering course offered at Georgia Institute of Technology [3]. Arguably, the class did not properly prepare the students for their upcoming classes. The course was, therefore, determined to need a revamp when a new professor began teaching the course. To improve the course, a series of four ideas, seen below, were used. The ideas are similar to that of the course offered at Georgia Institute of Technology, but were modified to further emphasize the hands-on applications without focusing on intense mathematical explanations [3].

i. Provide a general overview and visual introduction to the discipline, supplemented with talks from experts in the industry and freshman seminars from faculty experts.

ii. Provide basic equations and concepts from the various disciplines, and let students solve problems related to each discipline, while minimizing the mathematical intensity.

iii. Use hands-on construction projects to emphasize the required techniques in the application of engineering principles.

iv. Use competitions to motivate creativity and logical decision-making.

To include all of the aforementioned aspects into the course, it was decided that the course would be based around the importance of design and the application of principles while also preparing students with skills required for a successful career in academia, industry, and engineering in general. Both the lecture and lab were restructured, each given a purpose. The lecture covers topics related to both general Mechanical Engineering and covers the concepts needed for lab. The lab, however, focuses on the application of concepts needed for small weekly assignments, building each week to cover everything needed to complete the semester project. The restructuring resulted in the lecture increasing the number of topics covered, guest lecturers, and related more heavily on the lab to reinforce the concepts covered in lecture. The lab maintains to cover Solidworks but also now covers Arduino, coding, and focuses on preparing the students with the hands-on skills needed to work on the semester long projects.

The three engineering principles defined by the American Society of Mechanical Engineering (ASME) are “force, energy, and motion” [4]. Arguably, these are the main foci that encompass the realm of engineering, and thus what the goal for the redesigned course is. These ideas are primarily instilled through the students’ semester-long projects, each of which require a conceptual and practical understanding of the fundamental principles. Additionally, the
aforementioned engineering principles are implemented through Solidworks and Arduino, as this is a main aspect in the realm of the workforce.

In addition, the revamp was needed to accommodate the lack of preparation for later classes. One of these classes was the required four-semester design sequence beginning junior year. Faculty noticed that students entering junior design lacked the ability to operate microcontrollers, which were needed in many of the projects. The lack of preparation was received as feedback from one of the instructors of the senior design course. According to Jim Ruff, PE a lecturer in the Mechanical Engineering Department “Solid modeling and digital controls are essential skills for today’s Mechanical Engineers. Exposing students to these fields early in their education will help them in school and in the workplace after graduation.” Aspects of 3D modeling proficiency were also lacking, but this inadequacy mostly related to the lack of practice in these applications. In addition, the Mechanical Engineering department’s Industrial Advisory Board emphasized the need for more coding throughout the department curriculum. All three of these concerns were considered and factored into the redesign of this course.

The changes to the course encompass multiple recommendations from both internal and external sources. Though these changes were extensive, they only improved the prior version of the course. For example, in the “easy A” version of the class there were 14 lab assignments dedicated to SolidWorks, each taking about 1 hour to complete. However, in the restructured version there are 8 lab assignments that take about 3 hours to complete as the result of covering more chapters and problems from the SolidWorks textbook, while also requiring students to apply the skills to their semester long design project. Arguably, the 8 assignments were more relevant and practical to introduce, compared to the 14 lab assignments from the first course. This is because the assignments from the first course pertained to car parts and assembly, having little application towards projects. The change in assignments allowed for the students to have a better understanding of the engineering principles. The addition of Arduino and coding also improves the students’ abilities to gain skills while also preparing them for other classes in the department’s curriculum.

With the restructuring of the course, there was not a substantial change in the number of students who took the course (an average 90 students). The lecturer is an associate professor of the Mechanical Engineering department. The course previously relied on one teaching assistant (TA) per lab section, while the new course has at least 2 TAs per section, a graduate and undergraduate student. Of the 5-6 total TAs for the course there are 2 graduate students, with 3-4 undergraduates. Three of the TAs had machining experience, in addition to the 2 available machinists. This course is offered once per academic year meaning 6 lab sections in both the prior course and new version of the course. There are about 15 students per lab section. The course is divided into 1 credit for the lab which lasts 3 hours once a week, with a 2 credit lecture meeting 2 times a week for 1 hour. Both the TAs and professor have office hours, about 4 hours
per week for the first half of the semester and 10 hours a week for the second half. In addition to the availability of the TAs, they hold their office hours in the on-campus workspace. Along with the workspace the students have one 3D printer available which is dedicated to this lab. However, the students can also gain access to the department 3D printer or the 3D printers and laser cutter in the campus machine shop.

**Importance of Design**

Design was chosen as an avenue to improve the course because the application of fundamental engineering concepts in a design is an imperative skill for an engineer. Engineers are required to design parts and systems throughout their career, making this an extremely important skill to possess [5]. The revamped curriculum allows for a deeper understanding to be implemented, as it provides a basis for what is expected of a Mechanical Engineer according to the Bureau of Labor statistics [5]. Additionally, this hands-on experience is arguably a more effective way to learn the material, by promoting students’ learning and builds on their intrinsic motivation [6]. In addition, it helps to mold the problem-solving skills needed in the actual application of previously learned concepts.

**Course overview**

The outcomes that students of the Introduction to Mechanical Engineering course are expected to achieve are outlined in Table 1 and follow The Accreditation Board for Engineering and Technology (ABET) standards [1]. It is worth noting that most of these outcomes are achieved through hands on experience.

<table>
<thead>
<tr>
<th>ABET Learning Outcome</th>
<th>Specification</th>
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<tr>
<td>B</td>
<td>Students will be required to design and run tests and process the data as part of their design project.</td>
</tr>
<tr>
<td>C</td>
<td>Work as a team to successfully design a system as part of semester project.</td>
</tr>
<tr>
<td>E</td>
<td>Students will formulate a problem statement for the semester project and develop a plan to solve it.</td>
</tr>
<tr>
<td>G</td>
<td>The students will present their design mid semester and then present an assessment of its performance at the end of the semester.</td>
</tr>
<tr>
<td>K</td>
<td>The students will learn to use modern engineering tools like Solidworks and additive manufacturing.</td>
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The technical portion of the class is structured around the implementation of three semester long projects with a series of assignments that focuses on two major categories: design and prototyping. Both of which are interrelated and complement each other. The design process, shown in the figure below, is the primary education objective of this class but the construction of a working prototype is the courses’ objective. Traditionally, exposure to the design process and design project was not seen by students until their third year. As such, one of the primary changes made to the course after the instructor change was the addition and emphasis of the design process. It is for that reason a semester-long design project was added to the course.

![Figure 1: The Engineering Design Process](image-url)

Additional education objectives are for the students to develop proficiency in Arduino and Solidworks. As a result, the students are required to perform a number of assignments in the two programs, both of which are directly used for their project. Instruction in Arduino and SolidWorks is delivered through the lab with detailed lab manuals, structured such that the skills learned in the manuals can be directly related to the objectives of the course. The labs are broad enough that they cover the scope of all three of the projects, while still remaining relevant to the actual course. A brief overview of the topics covered in the lab are outlined in Table 2.

<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
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<tr>
<td>1-3</td>
<td>Introduction to Solidworks 3D modeling.</td>
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</tbody>
</table>
Advanced models involving the basics of creating drawings and assemblies. Incorporate SolidWorks models and drawings into semester project.

Introduction to Arduino, how to wire, and basics of programing.

Interface and manipulate sensors and other peripherals. Incorporation of Arduino coding into projects.

Open lab time to focus on the building of the team projects

Competition and presentations.

From the ABET learning outcomes above, there were a few skills that were imperative that the students learn. These skills were introduced to understand the basics of producing a digital 3D model of a prototype, be capable of producing technical drawings ready for manufacture, proficiency in the setup of electrical circuits and peripherals such as sensors and lights, and be proficient in computer logic. These desired skills can be summarized as technical drafting and coding. The two primary software packages used to develop these skills were SolidWorks and Arduino, both of which are well developed and have an extensive repertoire of support documentation, providing the students with a useful resource and simplicity in learning. The extensive support documentation allows students working outside of class to receive help and provides them with similar examples, furthering their knowledge of the subject matter. Both of these software programs also have benefits for future classes and resume building. SolidWorks is a very commonly used software in the workforce. Arduino is also a very common platform to perform rapid prototyping, and is considered by makers as "open-source electronics prototyping platform based on flexible, easy-to-use hardware and software" [8]. Arduino’s capabilities are also an adequate platform to perform the required tasks. Arduino also allows for coding to be introduced early, providing the skills of logic processing needed for other coding programs like MATLAB. The availability and industry acceptance of these platforms made them a good choice as a medium to teach the desired skills. These software packages are only a medium as the skills can be easily transferred to other similar programs with a minimal learning curve, having the primary difference be syntax.

Project Objective

To perform an effective introduction to engineering design, the projects were broken into a series of phases, listed in table 3 below. These phases align with our learning outcomes and the engineering design process on a fundamental level. The phases are applied to all of the projects, including industry projects, which effectively outline the milestones needed to produce a working prototype. The phases and their steps further break down and are described in detail, with respect to their relation to the overall project objective.
Table 3: Project Phases [9]

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
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<tbody>
<tr>
<td>Project Research</td>
<td>Teams chose one of the three projects available and begin conducting research. The research includes topics related to their project, including results from previous groups.</td>
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<tr>
<td>Project Proposal</td>
<td>Teams submit a formal proposal, detailing out a proposed design, schedule, budget, and a statement of what they plan on building.</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Teams create design sketches in Solidworks of all parts needed for their design, along with any wiring diagrams needed for the Arduino.</td>
</tr>
<tr>
<td>Prototyping Phase</td>
<td>Teams begin building their design and testing components built in Solidworks.</td>
</tr>
<tr>
<td>Build Final Design</td>
<td>Teams assemble their projects with emphasis on the manufacturing of parts.</td>
</tr>
<tr>
<td>Competition and Presentations</td>
<td>Teams compete against one another to see who had the best design and present their results and findings to the class.</td>
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</table>

The design portion of this class is emphasized through the use of semester-long projects, complimented with instruction about the design process through expert guest lectures from industry. The teams are allowed to experiment with their designs through SolidWorks and are required to build their entire prototype in SolidWorks using assemblies. Documentation is also an important aspect of the design process, as it requires students to have a series of status reports containing a portion of their project for each report. These reports help ensure that students are making progression throughout the semester and help them with skills to write an effective status report for future classes and industry work.

The prototyping portion of the student projects emphasizes the transition between the virtual world to the real world. Producing a prototype makes the projects go full circle and complies with the design process chart (in figure 1 above). The key aspects that are involved in the prototyping phase include: installation of the instrumentation systems, rapid prototyping with digital manufacturing tools, redesigning SolidWorks models, and sourcing/ordering parts.

The instrumentation systems primary focus is to teach the students how to effectively apply basic coding to a project. The coding is taught through the use of an Arduino mega and a series of sensors such as altimeter, pressure sensor, and a tachometer but varies depending on the project selected. All projects are required to utilize Arduino to help provide students exposure to coding early on. Additionally, errors are very common in coding, especially for inexperienced coders. Errors help develop skills with trial and error, and problem solving, as coding errors can come from a multitude of things. By introducing the students to Arduino, it is in the hopes of
preventing possible future difficulty with similar programs. Programming has become increasingly more important and is a general skill that engineers should possess in today’s current industries [10]. Arduino and other coding programs require the use of circuitry and electronics, which is an integral part of implementing the instrumentation systems. The overall goal of providing exposure to instrumentation systems is to give them a basic understanding of their operation and integration with systems. This basic understanding does not require a math background, and yet it conveys the concepts and techniques so that they can be implemented into their projects. These concepts are further reinforced from a math perspective in later courses.

![Figure 2: Example of a Wiring Diagram Created by a Team](image)

Producing their design in SolidWorks gets students into the habit of modeling their designs first before building them, often an expectation in industry. Computer Modeling allows for the visualization of the design without producing a physical model. The visualization allows the students to determine how their design is assembled, and thus its interaction with the other parts. In addition, this provides the students the ability to experiment with multiple designs, and make revisions for optimal performance, before the design is produced [11]. This ability to experiment with designs is advantageous for many students, as this is their first time ever designing something for a specific application. Producing a model in SolidWorks or similar package allows for seamless production of engineering drawings, preparing students for industry, manufacturing tolerances, and drawing techniques for proper production. Drawings are also extremely important with the overall documentation, and can be the most useful piece of documentation in a project.
The final step of the prototyping phase is to manufacture the prototype. There are two main ways to produce a prototype: digital fabrication tools and commercially available parts. The goal is to primarily use digital fabrication tools such as 3D printers and laser cutters, both of which have gained popularity in industry and require special design considerations. While there is a preference in digital manufacturing, it is not always efficient. A number of parts have to be ordered, some of which are modified in the machine shop. Students are not able to directly use the digital manufacturing tools or the machine shop because they have not received the required safety training. This forces the students to produce better drawings so that trained fabricators and machinists can understand their drawings and thus produce their parts properly. In industry, it is very common for the engineer to have fabrication personnel produce their designs. It’s important to develop these skills, as communication with the machinists allows for a seamless design of the product. However, having machinists perform the manufacturing limits hands-on manufacturing experience, but it does not affect the hands-on building. Hands-on building is arguably more important, since the interaction and mechanical relationship between parts is our focus with the hands-on projects. Experience with both the building and manufacturing are advantageous so that the students know how manufacturers produce parts and thus how engineers should produce technical drawings to minimize fabrication failure.

Teams are required to determine what parts they will need to accomplish the project objectives. Teams are only given select parts that are required by all projects, such as an Arduino, sensors, and wires. For any additional parts, the teams are required to source commercially or source raw material to build their own. For example, rocket teams’ source premade body tubes and motor mounts but source wood and acrylic to make their fins. Teams may also use 3D printing as a tool to create parts, and are required to have at least one 3D printed component on their projects. All teams are prevented from using commercially available kits or premade plans, which forces them to build a majority of their project and source the required parts/materials. Part sourcing typically
comes from Amazon, McMaster Carr, and local stores as these provide the most consistent availability. Sourcing parts and materials are imperative to any design because without it, the design will only live in the virtual world. Additionally, this approach requires the teams to further consider what they need to make their designs, and thus how to interface with industry vendors and procurement (both of which will be beneficial in the workforce).

**Description of projects**

The three projects that were chosen were Rocket, Modal, and Transfer Case. Each project requires teams of 3-5 students to accomplish a similar set of fundamental objectives. The application of them, however, is approached in a different way to accomplish their overall project objective. While the students are limited by the number of projects, their creativity is not limited. With a narrower scope of choices, students still have ample room to develop ideas, as there are many open-ended options within each project. “Freshmen are unaware of what they do not know, and there is time before others convince them that engineering is difficult, and lock their creativity in straitjackets. The confidence of solving problems can be used iteratively to build rigorous understanding in later courses” [3]. In reality, it increases their creativity by forcing teams to come up with a new way to solve the same problem. For example, with the Rocket project, teams are all given the same sensors to use but no two identical rockets have ever been launched. The rockets have always differed by fin design, size of rocket tube, nose cone design, and payload mounting. Similarly, with the Modal project teams have approached the task by utilizing, motors, speakers, impact hammers, and air compressor jets. Even when two teams have used the same starting approach their final designs have always been different based upon their design, approach, and testing of the system. Finally, for the Transfer Case project the elements required were the same but how teams designed the outer housing and what gear ratios they decided to use all varied. By the end of the semester, teams with similar projects compete against one another. This provides a healthy competition scene, not only encouraging the students to do the best they can on their projects, but also preparing them for the workforce where they will deal with interpersonal competition on a regular basis.

The Rocket teams were tasked with building a model rocket capable of collecting data during the launch. This data included the acceleration, pressure, and max altitude. Each group was given the opportunity to record additional data, such as a GPS tracking of their rockets. Some groups were more creative, and went as far as video recording the flight through their coding. All teams were provided the rocket motor size class of 29mm and a brief list of the components needed for their design. This motor size was selected due to its availability and average launch altitude. These motor sizes also had a large repertoire of data, allowing them to be simulated using Open Rocket, which is an open source rocket design and simulation program. Teams were not given their motors until launch, so their design and simulations were based around expected size and weight. This provided limitations to work around, as realistically there will be many unknowns in any
design. Teams were then expected to model their rockets’ components, in SolidWorks, around the given rocket motor size. This included the fins, motor mount, and nose cone such that they all worked with their selected body tube. The nose cones had to be designed such that they were able to be 3D printed. Parts could also be laser cut from wood or acrylic. For the competition, the rocket that went the highest was the winner. For this, students had to consider size and weight of the rocket and the payload. Weight and shape, of course, provide limitations in how high the rocket can go, which is an additional component the students had to consider in their design.

The Modal project teams were tasked with building a device to excite a Lego plane such that modal analysis could be performed. The data that the teams were looking for was the harmonic frequency of the plane, and to collect the acceleration of the wing tips. Teams had to research different types of excitation techniques and choose which one would best interface with the Lego plane and produce adequate data. The design was to be modeled in Solidworks and produced from laser cut material, 3D printed and purchased parts. Teams were encouraged to use speakers, DC motors, and stepper motors as these would produce more consistent results and were simpler to implement, in comparison with suspending the Lego plane and manually exciting it with the use of a hammer or similar. Students however, did choose a wide variety of options to excite the plane. Modal analysis is arguably one of the most important aspects for engineers to conceptually understand and be able to take into consideration for structural integrity. Failure is very common, and the design of the structure can provide stronger resistance against any problems that may ensue (weather conditions, temperature changes, etc.). The natural frequency of an object causes the most vibration, making it weaker altogether. The students took this knowledge to understand how the strongest reverberation could affect the structural integrity of an airplane. Through analysis of their code and accelerometers, the students were able to find the natural frequency of the plane, and see why this is an important factor to consider in plane design.
The third project is the transfer case. Teams were tasked with building a gearbox that could work with a specified motor, had 2 speeds, and could lift a minimum of 50 lbs two feet off the ground in less than 2 minutes. The Arduino was used to determine the torque and speed of the motor and output shaft during the lift. The designs were required to fit within a specific size constraint. Teams were able to use laser cutting and 3D printing to produce the housing and gears. Laser cutting was the most common because this was more efficient with regards to time and cost for the production of the required parts. Each group had to do additional research on the design of gear ratios and basic motor engineering to make the gearbox operate via computer control.

How these projects relate or meet the course objectives

The three projects were selected because they encompassed three of the main fields of Mechanical Engineering: aerospace, structural analysis, and energy transfer. The chosen projects are also similar enough such that they could be graded on the same fundamentals regardless of which project the team selected. All the projects required Solidworks, Arduino coding, and were
all of reasonable size such that they could be completed in the course of a semester. These projects were also based on what is likely to be seen in industry, while also maintaining forward thinking in its ability to be used in possible future projects. According to the American Society of Mechanical Engineers (ASME), Mechanical Engineers are “concerned with the principles of force, energy and motion and use their knowledge in these fields to design, manufacture, and operational processes to advance the world around them” [4]. The Rocket and Modal projects relate to motion and force, with the Transfer Case project relating to force, energy, and motion. All three projects also require knowledge in the fields of design, manufacture, and understanding of operational procedures. While all these projects encompass similar ideas, there are many different directions that each one can take- and each group has proven to follow suit. The groups were all unique in their choices of gears, or cameras, and general design, and they took the projects where they wanted to go with it. Their passion for the design was seen through their creativity of the choices made in each one.

The projects chosen and overall course had a few main objectives. From the class perspective these were to prepare students for future Mechanical Engineering courses, prepare them for early internships, and give them a broad overview on what Mechanical Engineering is. To further refine the objective of preparing students for future classes, we have focused on SolidWorks and coding. The projects work to meet these objectives based on the project requirements. The objective of teaching the students SolidWorks meets both the industry requests and the future class needs. The students’ final SolidWorks assignment (a complete assembly of their design) demonstrates their proficiency in the basic skills needed to produce a design, a common requirement in industry. The teams also had to produce drawings that could be provided to a machinist to make their laser cut parts and then machine their parts. Both of these were essential requirements of the project and the course objective. The application of coding in their designs showed proficiency upon the accumulation of data from the teams’ sensors. All of the teams were able to interface with an Arduino and necessary sensors used in their project. The prior experience to Arduino cannot be assessed yet because the students have not entered Junior or Senior design or our Mechatronics course. Some of the students, however, have been exposed to one of our coding classes, sophomore design, where there was not a concern with the lack of preparation in coding. The preparation for this class includes the basic understanding of coding fundamentals such as logic and conditional statements. From the current standing of the students in the first subsequent class, we believe that the students are prepared for the other ensuing classes. The course also addresses the objective of preparing them for industry, since the department’s Industrial Advisory Board suggestions were considered in the selection of the team projects. The last objective that we were trying to address was early preparation for internships which relates to the preparation for industry.
Conclusion

Starting with design at the beginning of the Mechanical Engineering curriculum is the most beneficial to the preparation of students. New Mexico Institute of Mining and Technology has six semesters of design courses, and arguably, initiating with the Introduction to Mechanical Engineering curriculum sets up students for a path of success in future coursework and their engineering career. The course focuses on the introduction of concepts and the development of skills, both of which can be applied to different projects and software packages. This is done through the implementation of three different design projects, all ranging in the scope of mechanical systems. The course and respective projects focus on the overall fundamental concepts, meaning content is first-year appropriate and not hinged on higher-level mathematics or sciences. This allows us to refine our focus to engineering principles and the hands-on application of them, which allows us to best prepare the future engineering workforce.

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The students of the Introduction to Mechanical Engineering course at New Mexico Institute of Mining and Technology for the pictures taken throughout their projects.

References


