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Implementing Mastery-Based CAD Activities into an Introduction-to-Engineering Design Course to Develop Entrepreneurial Mindset

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Introduction

Introduction to engineering courses are often the first touch point a student has with what their future as an engineering student and engineer may look like. The goals of these courses vary but often include teaching basics of engineering principles, engaging students in creative work, and introducing students to the resources available at the school. It has been noticed over the past decade, that more students have been introduced to engineering principles prior to enrolling in an undergraduate engineering program, however, there remain students who do not have previous experience with engineering tools or terminology. Previous studies of our first-year engineering courses by the institution found that while the number of students who had been exposed to ideas such as engineering design increased over a five-year period, the number of students with no exposure to engineering design remained the same, about 10% [1].

The question for first year courses then becomes: How can we equally engage students with diverse backgrounds in engineering knowledge? While this question is very broad, this paper looks at a redevelopment of computer aided design (CAD) activities to help engage students across a breadth of experiences. This redevelopment also had a secondary goal of engaging students in an entrepreneurial mindset, specifically having them consider creating value from the learning experience by pushing through and learning from failure.

Teaching Computer Aided Design

Teaching hands on software tools, such as CAD, has been studied since the widespread availability of such software to students. This decades long debate includes the issue that there is no time to teach students all the available CAD software packages, especially as new tools are moving to the market on a regular basis. Because of this there is need to balance both theory and application of CAD tools so that students not only have practical hands-on skills with the software but also develop the knowledge behind "how" CAD tools work, allowing them to move to different software packages [2].

At our institution the CAD package used is SOLIDWORKS and previous instruction had utilized a textbook with step-by-step tutorials in which the students built a flashlight. While the tutorial appeared effective overall, there were drawbacks to the tool. First, students would become very dependent on the step-by-step directions and were sometimes then unable to build parts outside of these instructions. Additionally, many students were missing the basics behind the CAD theory such as how Boolean operations were used and why things like the origin and plane directions were so important. This meant that when they went to build something on their own, they were often "lost in space" and didn't understand why parts or planes were not aligning properly. Lastly, many students with previous experience, either in SOLIDWORKS or a different CAD package, found following the tutorial tedious as it added many extra steps for the sake of showing different methods to do the same thing. The tutorials did not provide dimensioned engineering drawings of the parts with the option of students building these on their own, and therefore to build the parts the tutorial had to be followed exactly. This not only frustrated experienced users, but even novice users had to go back through pages of instruction to double check something as simple as a dimension. This experience agrees with previous CAD pedagogy research that shows that behaviorist techniques can obstruct the process of learning [3].

Another major concern with the tutorials was that if a student ran into an issue, trouble shooting was very difficult. They could have missed a step two pages before but now had no idea how to connect that mistake with the current issue in the tutorial. This led to frustration by the students, and they would often have to redo an entire part instead of being able to pinpoint what went wrong. This meant that instead of learning from their mistake they felt as if they had to do twice as much work.

These combined concerns led to the decision to change how CAD was taught in the first-year course. It was decided to test a mastery style learning technique. Mastery style learning has been used for many years and was described by Bloom over six decades ago [4]. The technique is based on the theory that almost all students can learn material if given adequate time and appropriate instruction. The benefit of mastery style for learning CAD in this course is that it allowed students with experience to show their skills and then jump into learning something new, while students without experience were able to take their time and learn the material at their own pace with the options of different instructional tools. The mastery technique also allows students to learn from failure, as the assessments of each skill they were mastering could be repeated as many times as the student needed without penalty to their grade.

Course Description

The course in which the mastery learning technique was implemented is called Introduction to Engineering Design. The course is taken by all first-year engineering students regardless of their desired engineering specialty. The class consists of two 1-hour lectures and two 2-hour lab meeting times each week for a ten-week quarter.

The course outcomes are as follows:

1. Students will be able to read and create standard 3-view mechanical drawings and assembly drawings by hand and computer in a timely fashion.
2. Students will be proficient in CAD modeling including building individual parts and assembly.
3. Students will be able to write a formal design report.
4. Students will be able to describe the process of design (client objectives, criteria for success, preliminary design, primary design, manufacturing, testing and modification)
5. Student will be able to effectively work in teams.
6. Students will be able to complete a structured design problem.

Redeveloped CAD Instruction

CAD instruction was initiated in week three of the quarter with an introductory lecture on CAD and SOLIDWORKS. It was during this lecture that the mastery learning technique was presented. After this initial lecture, instruction was primarily done through asynchronous videos that were developed by the instructor. These tutorial videos went through the basics of CAD one technique at a time and included the following topics:

- User Interface
- Introduction to 2D Sketching
- Basic 2D Sketching
- Introduction to Extruded Base
- Introduction to Cut and Revolve
- Basic Extrude and Cut
- Curved Cuts and Fillet
- Patterns
- Thin Feature and Shell
- Basic Assembly
- Drawing Basics

Each tutorial had an accompanying handout that described the goals of the video and gave basic instructions for what would be built. An example handout is shown in Figure 1.

Introduction to Engineering Design
SOLIDWORKS Tutorials

Video 6 – Basic Extrude and Cut

This video will go over how to make a basic widget using extrude and cut tools.

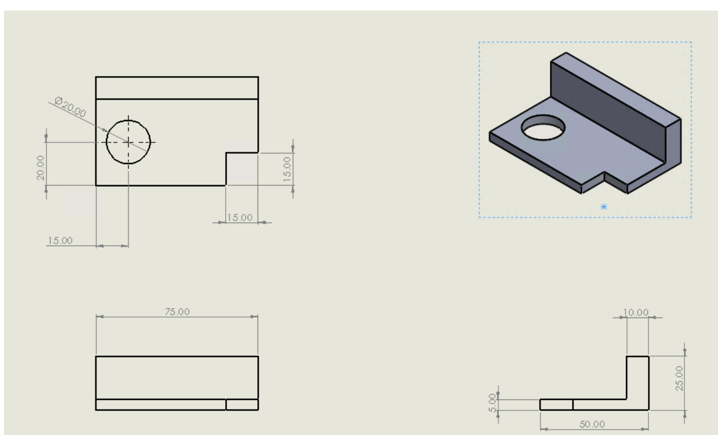


Figure 1: Drawing of the widget. Note, dimensions are in mm.

Steps
1. Open a new part in SOLIDWORKS
2. Change the units to MMGS.
3. Sketch the L-shaped profile shown in the right-view above on the right plane. Make sure the origin is located at the bottom left-hand corner of the sketch. Match the dimensions shown in the sketch.
4. Use the Extrude Boss/Base feature to extrude the sketch in the negative x-direction 75 mm.
5. Cut a 15 mm x 15 mm square from the front – right corner. Use the top of the flat surface as your sketch plane.
6. Cut a 20 mm diameter circle into the flat surface as shown. Note that the circle center is 20 mm from the front edge and 15 mm from the left edge.

Figure 1: Example handout from an asynchronous tutorial video.

Along with the video tutorials, students were given additional resources to help with their learning of the software. A resource page was developed in the course management system that included links to additional video tutorials, written step-by-step guides, and information on access tutorials in the SOLIDWORKS software itself. Students also had access to their GTA and instructors during lab times and office hours.

Because this course has multiple outcomes, the CAD portion of the course was set up to be 40% of the student's overall grade. This meant that if a student did not pass the minimum requirements of the CAD assignments, they would receive at most a 60% in the course, which would be a failing grade. While this may sound drastic, the goal of mastery learning is to set up a minimum set of skills meant to indicate that a student met the course outcomes, in this case outcome two listed above: Students will be proficient in CAD modeling including building individual parts and assembly.

To pass the minimum requirements of the CAD assignments students had to pass four quizzes. The quizzes each assessed a specific CAD skill:

1. Build a simple part
2. Build a complex part
3. Part assembly
4. Part drawing

While each quiz assessed a certain skill, some skills from the previous quiz may be required during a latter quiz. For example, when being assessed on part assembly (Quiz 3), students had to build simple parts to be assembled, similar to what was assessed in Quiz 1. Because of this, quizzes had to be taken in sequential order and a student could not move on until the previous quiz had been passed. Once a student passed all four of the quizzes their grade for the CAD portion of the class become a 70%. If a student did not pass all four quizzes their CAD grade was a zero, regardless of if they had passed any of the quizzes.

An example quiz is shown in Figure 2. Each quiz required the student to complete a build in SOLIDWORKS that was then checked by either a GTA or instructor. If upon first inspection the GTA found an error, they would let the student know and give them a chance to fix the build. If the second inspection still showed an error the quiz was noted as "not passed." If a student did not pass the quiz they could retake the quiz with a new part at any time, although it was recommended that students work through the quiz they did not pass first and consider what errors were made. Students were not penalized for taking a quiz more than once, and while roughly ten versions of each quiz were prepared, no student required more than three attempts to pass a single quiz. To help students prepare for the quizzes there were several versions of practice quizzes posted for them to go through prior to taking their official assessment.

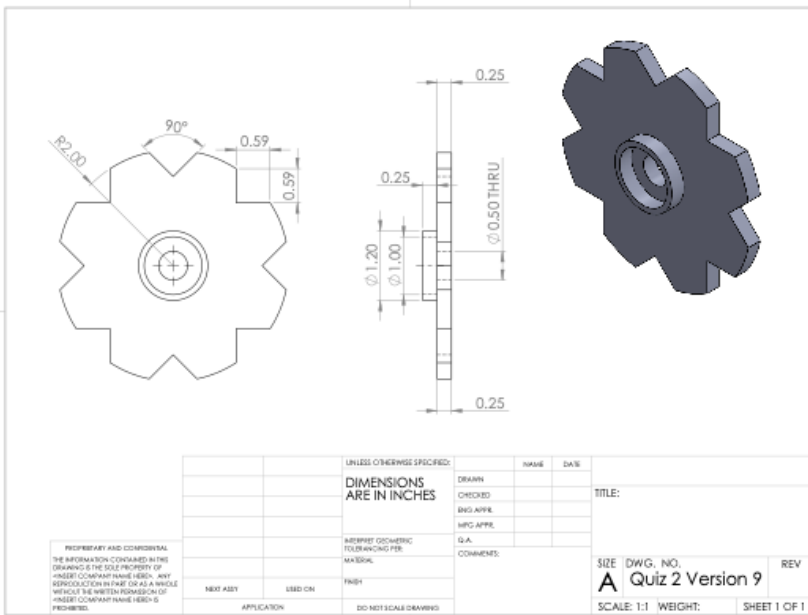
VERSION 9 **NAME** ________________________________

Introduction to Engineering Design
Quiz 2 – Complex Parts

Closed Book and Notes. You may only use your laptop for SOLIDWORKS. You may use the SOLIDWORKS Help Menu.

1. Build the model below in SOLIDWORKS. Once you build the model raise your hand and have your TA/Instructor check off your part

   *Note: You have two chances to build the part. If upon first inspection your TA/Instructor finds your part to be incorrect, you will have another chance to fix it. If your part is incorrect during the 2nd inspection you will receive a zero.



1st Inspection: Correct Incorrect initial ______

2nd Inspection: Correct Incorrect initial ______

Figure 2: Example of a quiz used to assess CAD.

Once a student has passed all four quizzes, the had the option to bring their CAD grade from a 70% to up to 105% by completing additional assignments. The goal of these assignments was that students could either learn a new skill or improve upon what they had previously learned. The additional assignments included the following options:

- SOLIDWORKS Tutorials – 3% each (up to 15%)
- Build your own item – 5% each (up to 10%)
- Build your own assembly – 15 %
- Make your own tutorial – 10%
- Learn to use a different CAD tool – 5%

Each assignment required deliverables such as proof of completion, for example an engineering drawing of the item they built, and a written reflection on what they learned from completing the assignment. Students could earn up to 35% towards their CAD grade from any combination of the assignments they chose.

Starting in week three of the quarter, one 2-hour lab period of the week was devoted to CAD working time. During this time students could work on CAD tutorials, take any of the quizzes, or work on their additional assignments. The labs consisted of roughly 20 students and were run by a graduate teaching assistant (GTA) with instructor support as needed.

Entrepreneurial Mindset

As mentioned above, the secondary goal of using the mastery method was to engage students in an entrepreneurial mindset (EM). While EM can be defined a variety of ways, this course uses the definition from the Kern Entrepreneurial Engineering Network (KEEN) which broadly states EM as "a set of attitudes, dispositions, habits, and behaviors that shape a unique approach to problem-solving, innovation, and value creation." [5] KEEN has specifically developed a framework for adding EM skills to engineering skills with the goal of developing engineers to not only be knowledgeable on technical topics but also foster a mindset of curiosity, building connections, and creating value.

For this first-year course, it was decided to highlight the importance of creating value, an important spoke of EM, through learning from failure. The mastery method of learning is particularly beneficial for this because students can fail without penalty. However, they must also learn from their mistakes to move forward. Additionally, students were encouraged to create value through their selection of the additional CAD assignments. While some most likely selected these additional activities based on time or what they thought may be easiest, students were encouraged to select activities that allowed them to grow their CAD skillset. This is also why they were asked to reflect on what they learned, not just present a final product.

To help students reflect on their EM experience there were in class activities that discussed the overall idea of EM, growth mindset, and the importance of character spread throughout the quarter. The goal of focusing on EM, specifically on persisting through failure, was to encourage students who are still very early in their engineering career to push past failures and understand that no everything may come easily during their engineering education.

Student Experience

Students were given a brief survey at the end of the quarter which included asking them about their CAD experiences, their confidence in their current CAD skills, and allowed for open comments about the mastery style learning experience. The survey found that 45% of the students reported having no previous CAD experience, while 4% self-reported as being very experienced at CAD, leaving about half the class with some or a fair amount of experience. After completing the CAD mastery activities, 83% students reported that they were confident or very confident building simple parts in CAD and 50% were confident or very confident in building complex parts in CAD. Only 1% and 3% of students claimed they had no confidence in building simple or complex parts respectively. These percentages indicate a positive outlook of the students' feelings towards their CAD skills as they finished the course.

The survey allowed for students to give feedback on their experience and the responses consistently highlighted positive aspects of the CAD course, emphasizing the effectiveness of its self-paced and mastery-based approach. Overall students mostly stressed an appreciation for the flexibility and autonomy of the method, the multiple available resources, and the ability to learn from their mistakes.

When it came to flexibility and autonomy, students found the self-paced structure, the ability to choose when to take quizzes, and the option to retake them reduced stress and allowed for independence in the learning process. The self-paced nature allowed individuals to progress at their own speed, especially beneficial for those with prior CAD knowledge. Responses also showed the students valued the tutorial videos, practice quizzes, and in class work time with GTAs and instructor, which gave them multiple resources for learning. Students indicated that completing quizzes and feeling a sense of significant progress contributed to increased confidence in CAD skills.

While the overall reaction to the mastery method was positive, there were some suggestions for improvement. There were concerns about the level of interactivity, clarity of tutorials, and challenges with time management. The feedback suggested a need for balancing self-pacing with occasional lectures, addressing concerns about GTA support, and providing more opportunities for engagement and personal feedback. Future plans are being developed based on this feedback to include additional teaching resources and more "check points" along with way for students who struggle with time management to avoid having students rushing at the end.

In the survey students were asked "Did the phrase 'learning from your mistakes' resonate with you while working on SOLIDWORKS this quarter? Why or why not?". Responses showed that overall, the students strongly resonated with the phrase "learning from your mistakes" while learning SOLIDWORKS this quarter. Many highlighted the importance of trial and error in the CAD learning process, emphasizing that mistakes led to a deeper understanding of the software. Some expressed gratitude for the opportunity to retake quizzes, which allowed them to correct errors and reinforce their knowledge. The self-guided nature of the learning process contributed to a sense of continual improvement through identifying and rectifying mistakes. Overall, the sentiment was positive, with respondents acknowledging the value of overcoming challenges and errors in the learning journey.

This lesson on learning from their mistakes was reiterated to the students through the idea of EM during the quarter. On their final exam students were asked to reflect on three things they learned while working with SOLIDWORKS this year. While many mentioned the skills they learned, such as building parts or developing engineering drawings, several students noted lessons outside of these skills. For example, one student stated, "I learned that failing at something one time makes me want to achieve it even more the next time. After failing quizzes, I made sure I polished my skills and passed the next. It was a good learning method."

For an overall perspective, the three years previous to the new CAD implementation had course fail rates of 6.2%, 9.8%, and 5.3%. This past year the fail rate was 1%, which was one student out of a total of 98. This one student only attempted to take one quiz, which they passed on the first try, but failed to attempt the other three, even with consistent reminders. While there are many factors that could have led to a difference in these rates, it is of interest to see this drop in the number of failing students.

Overall, the initial experience using a mastery-based method to teach CAD was successful and will continue to be used in the future. A few changes will be made to help augment the tutorials and add extra teaching resources. Also, threads between EM and the mastery-method will continue to be developed with the goal of encouraging students to develop a growth mindset earlier in their engineering education.

References:

[1] Roszelle, Breigh N. “Full Paper: The development of a first-year design project: focusing on creativity, independence, and design understanding”. *2019 First Year Engineering Experience Conference*, University Park, PA, Jul 28th-30th, 2019.

[2] Yue, Jianping. "Teaching techniques in computer aided design." *1999 ASEE Annual Conference*, Charlotte, NC, Jun 20th-23rd, 1999.

[3] Chester, Ivan. "Teaching for CAD expertise." *International journal of technology and design education* 17: 23-35, 2007.

[4] Bloom, Benjamin S. "Learning for Mastery. Instruction and Curriculum. Regional Education Laboratory for the Carolinas and Virginia, Topical Papers and Reprints, Number 1." *Evaluation comment* 1.2 (1968): n2.

[5] “Entrepreneurial Mindset” engineeringunleashed.com. https://engineeringunleashed.com/mindset (accessed January 2nd 2024).