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Integrating Small Team Project-Based Learning in Introductory Manufacturing Engineering Technology: Design, Manufacture, and Race Hot Wheels-Type Cars

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Abstract

We propose a compelling session for the ICONEST Conference 2023 that explores the innovative integration of small team project-based learning into introductory manufacturing engineering technology related courses. Our focus is on a hands-on project: designing, manufacturing, and racing Hot Wheels-type cars. This engaging project encompasses various facets of manufacturing engineering technology that includes simple design, manufacturing and assembly planning travelers, scheduling, budgeting, bill of materials, quality inspection, assembly and testing. Educators will gain insights into effective approaches, bridging the gap between theory and practice while equipping students with practical skills. We will explore the use of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) software, fundamental tools in modern engineering, as well as explore simple machining, water jet cutting, and additive manufacturing. By incorporating project-based learning into our course curriculum, we not only foster a deep understanding of manufacturing principles but also cultivate problem-solving, teamwork, and creativity among students. The Hot Wheels-type car project is an ideal vehicle for teaching the entire manufacturing process, from conceptualization to execution and the students enjoy the competition. We believe that our proposal will make a valuable contribution to the conference's mission of advancing engineering technology education, and we look forward to engaging with colleagues and experts to further enhance the quality of manufacturing engineering technology and similar technology programs.

Introduction

Many of our students are nontraditional and are working at least part time in industry. Many work full time and know how production systems operate as a technician at some level. Most are already providing for their own families and raising children. Some already have years of industry experience in manufacturing and production machining, welding, maintenance, and automation, etc. Some already have a technical college certificate in a trade skill supported by local industry. We have to capture their interests and create value for them and the employers that are hungry for their skills and academic credentials, including a future bachelor's degree from Weber State

University in Manufacturing Engineering Technology (MFET) with an emphasis in Welding Engineering Technology, Plastics and Composites Engineering Technology, or Product Design and Development Engineering Technology (PDD), Manufacturing Systems Engineering (MSE) and Mechanical Engineering Technology (MET). Faculty that get to teach fun and engaging hands-on classes in these majors definitely look forward to going to work every day to create value for these students.

Discovery

As a lifelong student I've come to appreciate being born into a family of innovators, most of which meant solving problems in the yard, garage, or home. I was coached by various family members and teachers to solve my own problems and get paid to solve the problems of others. I took every available shop class I could get into in junior high and high school to work out my wiggles and express some overlooked passions. I think fondly of my shop teachers and appreciate their guidance as I explored the S.T.E.M. world. This led me into enrolling into a local trade college to begin and eventually complete my machinist certificate. Doors were opened and I took my first job in industry as a C.N.C. operator for local aerospace companies making tools and components for the military, flight controls for commercial aircraft and jet engine hardware. At the time I didn't know this, but I was preparing to be a STEM teacher and advocate. I got to be a well-versed machinist and learned to utilize tools and documentation that I have now come to love and appreciate. More importantly, I was building an "unseen to me at the time" network of experts and friends in industry. I found myself stuck in the rut of chasing paychecks focusing on what was in it for me. I lacked purpose and fulfillment and felt stuck for lack of progression and shifts in the economy of aerospace manufacturing. After I worked as a machinist for many years, I decided to get my engineering degree. Thankfully, I found a few mentors along the way that helped me discover what I wanted and shifted paradigms to focus on value creation and personal development. I quickly explored my passion by starting my engineering degree at the age of 38. Three years later, working as an engineering intern at a local aluminum extrusion company, I walked away with two associate's degrees and an ABET accredited Bachelors of Science degree in Manufacturing Engineering Technology at Weber State University in Ogden, Utah. I loved every minute of earning that degree, even the calculus, statics and strengths of materials, and the variety of general education courses. The SME Certification exit exam is also a requirement of the program. I made genuine friends and continued to build my network of value creators. A year after graduation, working in industry, I was summoned back to the university to teach. I jumped on board and have never looked back. It is the greatest and most fulfilling thing I have ever done in my career. Having the summers off just happens to be a bonus for those of us who choose to do so. I spend most of my summers developing new coursework, researching and development of new innovations, teaching courses and improving our labs. I am currently finishing up my last semester of my Masters of Science in Systems Engineering (MSSE) degree, a relatively new and emerging field of engineering that I would also highly recommend at my alma mater.

Many students and teachers may have similar stories on how they found their interests in S.T.E.M. and what they went through to get and stay there. Many of my students are literally designing, manufacturing, and programming major theme park rides, military innovations keeping you and I safe, and other world and life changing innovations. Most of my coworkers at Weber State University have worked in industry and have left it in order to enjoy what I call, the teaching gig. Many of us have side hustles, attend conferences, take courses to keep our skills relevant, network or simply play with power tools and stretch our brains to justify and pay for our teaching and tinkering habits. Our students may be in the same situation, wanting to play or dance with S.T.E.M. tools. Unfortunately, many don't know how to yet, or have had experiences that have distracted them from the S.T.E.M. world. When would be a good time to share it with them and how should we do it? Over the last few years I have developed an introductory engineering course with a fun project in the course that I am delivering here as a case study.

Introduction to Engineering

One of my favorite courses to teach at Weber State University, MFET (1000) Fundamentals, is one of the courses I've created by assignment given to me by Rick Orr and George Comber, my department chairperson and coordinator at the time. I was encouraged by Rick to make it a fun, hands on course that utilized project-based learning, degree planning, and to explore a variety of facets of the Manufacturing Engineering Technology degrees into the course. I give them credit for the idea and permission slip to open up the course and utilize my academic freedom to dance with an intro to manufacturing engineering technology.

The original course, MFET 1150 needs to be reviewed in order to discuss the evolution and success of the new course.Rick was my mentor through all of this and I would like to acknowledge his efforts as he has mentored me through the jungle of course development and teaching. He is the one who reached out and asked me to come back and teach engineering technology at my alma matter. Below you will find his comments on the need for change, transformation to hands-on learning, integration of advanced technologies and keeping the technology current is expensive, increased instructor engagement and expertise is needed, and closes with the resulting surge in student interest.

The Need for Change

The introductory course to our Manufacturing Engineering Technology Program, originally MFET 1150, was intended to play a critical role in shaping students' perception and interest in the major. In the initial iteration, which had been active for decades, the course lacked hands-on engagement and failed to captivate technology students. Alumni presentations on potential career paths and course planning exercises were insufficient in conveying the excitement of the manufacturing field. The course was basically a failure and did not help recruit students into the major or assist in student retention within the major.

The initial course structure lacked the hands-on engagement that makes engineering technology students thrive. The absence of practical experiences left students uninterested and dissatisfied, failing to convince them of the appeal and potential of the Manufacturing Engineering Technology major. Recognizing the need for change was crucial to revitalizing the course and improving student retention. The inclusion of alumni talks and course planning exercises in the original course was a step in the right direction. However, it proved insufficient in generating sustained interest. The experience shared by alumni and the course planning exercises did not effectively convey the excitement and potential of a career in manufacturing engineering technology.

Transformation to Hands-On Learning

To address these challenges and enhance student engagement, the course underwent a significant transformation, shifting towards a three-credit format with a focus on hands-on projects. The new course, MFET 1000, utilized traditional and cutting-edge technologies used in the program such as 3D printing, abrasive waterjet cutting, CAD, laser cutting & marking, and welding. This approach led to a remarkable surge in student interest, attracting not only technology majors but also students from other disciplines.The introduction of interesting project experiences such as designing and building “Hot Wheels” race and customized hitch plugs employed a range of technologies used in the curriculum. The projects allowed students to actively engage with the subject matter, showcasing the dynamic and exciting aspects of the field while having fun.

Integration of Advanced Technologies and Keeping the Technology Current is Expensive

The incorporation of advanced technologies like 3D printing, abrasive waterjet cutting, CAD, laser cutting, and welding into the course was a pivotal move. These technologies mirror real-world applications in manufacturing engineering technology, offering students a glimpse into the future of the industry. The direct application of these technologies in the hands-on projects fostered enthusiasm and a deeper understanding of their potential in the field. However, these technologies are much more expensive than simply using a classroom and whiteboard. The hands-on aspect also makes an online class format impractical.

Increased Instructor Engagement and Expertise is Needed

The revised course demanded active and knowledgeable instructors skilled in the technologies involved. The Instructor, Justin Knighton, was pivotal in guiding and mentoring students through the hands-on projects, ensuring a fruitful learning experience. The instructor’s expertise and enthusiasm played a significant role in amplifying student engagement and fostering a positive learning environment. However, finding competent instructors is becoming more and more difficult in the engineering technology area. Currently there are few at WSU capable of teaching the course. Increased focus at Weber State is on ensuring all faculty have a PhD as they build a traditional engineering degree. Finding a PhD that wants to and has actually has the ability to direct hands-on technology projects in manufacturing is extremely difficult. To address this issue Weber State is enabling and incentivizing instructors who are very good at technology to pursue advanced degrees.

Resulting Surge in Student Interest

The transformation of MFET 1150 led to a remarkable increase in student interest. Course enrollment has steadily increased from an average of 10-15 students per semester to filled sections of 20 seats with waitlists.The hands-on approach attracts both technology majors as well as students from other disciplines. The tangible and interactive projects not only showcased the exciting possibilities within manufacturing engineering technology but also encouraged students to pursue their major and envision a fulfilling career in the field. Students are also more enthusiastic and focused on creating a plan to finish their degree.The transformation of MFET 1150 from an uninspiring course to an engaging, hands-on experience underscored the significance of active, technology-driven learning in fostering student interest and retention within the Manufacturing Engineering Technology major. By integrating advanced technologies and providing practical applications, students are empowered to explore, innovate, and ultimately, choose a career path that aligns with their passions and aspirations. This successful transformation serves as a model for designing engaging curricula that can revolutionize the way introductory courses are structured, ensuring a bright future for engineering technology programs.

Starting Over

The course description for MFET 1000 explains it as an introductory course for students exploring or interested in majoring in Manufacturing Engineering Technology, doing so through several individual hands-on laboratory experiences that introduce them to concepts needed for team projects, future coursework, degree requirements and career paths. This course has evolved over the last few years and will continue to do so in order to fulfil its introductory and preparatory place in the value stream of this degree. Continuous improvement is essential to any viable and sustainable training and it requires unique individuals to mentor students through these types of programs. We must utilize the skills and tools we already have, invest in new skills and tools, develop and deliver compelling courses to recruit, empower, and deliver value creators to the world.

I have experimented with a variety of projects in the course that introduce students to Computer Aided Design (C.A.D.), Computer Aided Manufacturing (C.A.M.), 3-D printing and a variety of cutting processes. Students seem eager to do the design and manufacturing phases, so I offer labs that feed that interest. Many of my students are already working in industry as production workers, technicians, and applications specialists. Some of these students already have some applicable skills for the course, but most have never utilized these types of tools before. I make sure my students understand that my course is not a C.A.D. class, it is just a tool we use in each of the applicable course projects to help prepare them for more advanced C.A.D. coursework. This small lie seems to take the edge off as they explore C.A.D., many for the first time.

Many of my students have never touched any type of C.A.D. system so I start with the basics with simple solid models and dimension drawings, which I will dive into that later. On the other hand, I am beginning to get more and more students who have had high school or personal experience with free C.A.D. software such as Tinkercad, Fusion 360 and Inventor. Thank you to those of you who are raising the bar in your high school, or earlier, STEM courses as it plants seeds of interests into the hearts of the next generation. Auto Desk is a great resource for free student licenses for their software suite that includes other programs I use in more advanced courses such as AutoCAD and FeatureCAM. I would and have recommended looking at various Autodesk products, especially if you do not have a huge budget for these types of systems. Reach out to your district and departments, you may already have free access.

- https://www.autodesk.com/education/edu-software/overview?sorting=featured&filters=individual. (Autodesk, n.d.)

Weber State has a student license subscription with Dassault Systems for SolidWorks, a widely used C.A.D. software found throughout industry and my personal favorite.

- https://www.solidworks.com/product/solidworks-education-whats-new#brick--5427--custom-text-condensed--en (SolidWorks, n.d.a)
- https://www.solidworks.com/solution/job-functions/educators (SolidWorks, n.d.b)
-

I recently attended an HTEC 2023 conference to receive a Gene Haas Foundation grant in St. George, Utah where I discovered that Mastercam, a tabled vendor and presenter, has also increased their accessibility to educators with a variety of free C.A.M. tools that are very valuable which I will be reviewing and consider integrating into my more advanced coursework. I would not have easily found that tool if I had not attended that conference. I highly recommend attending these types of engineering and tool conferences, including IConEST, to explore opportunities, technologies and methods.

- https://ghaasfoundation.org/content/ghf/en/events.html (Gene Haas Foundation, n.d.)
- https://www.mastercam.com/support/education-resources/ (Mastercam, n.d.)
- https://www.2023.iconest.net/ (IConEST, n.d.)

With a quick online search, you can find stacks of videos, tutorials, curriculum and lessons for your choice of CAD/CAM software. Start there. I like to create my own projects now to make life interesting for me but there are a variety of free tailorable tools and tutorials out there to help you get started in your courses. Find a mentor that uses these types of products, take a course, or even better, come and take my MFET 1000 class at Weber State University in Ogden, Utah. Feel free to shoot me an email if you have some interest, hit a road block, or just tired of beating your head against your desk. I would also love to hear about your success stories as you apply these insights into your STEM or other related challenges. I'm giving you a permission slip here to be creative. Engineers solve problems by being resourceful. By all means document the journey, keep it updated and safe so your methods are successful and repeatable.

Let me emphasize, keep your files organized, updated and safe at all costs. Teach your students to do the same. Because my course moves pretty quickly, I hate having students give me the excuse they can't find their files, and as many of you might know, it happens more than you would think. I have a simple and short lecture I give in my class to help my students create files on their personal flash drive and cloud-based storage starting with a file for the current semester. I then have them create sub files for the course, and sub files within the course for specific assignments. It sounds simple but it really does help to show the class how to organize themselves. I love the convenience of flash drives, but they do get lost or misplaced so please back it up on your favorite online drive so it remains accessible. If it is something current or critical, I email a copy of the current file to myself so it remains accessible.

Introduction to Computer Aided Design (C.A.D.) and Solid Modeling

As mentioned before, I introduce my students to solid modeling, many for the first time. I've tried various methods and have found my favorite introductory parts to model are the simplest. I have designed them in a way to require the students to begin by learning where the commonly used software functions are on their screens, how to create simple shapes, extrusions, and holes by manipulating the models using the computer mouse and hot keys. These preparatory assignments help train the students for their final class project, which I will dive into later. I encourage those that catch on quickly to help their classmates.

In a large class, I give a few instructions and then stop to wander around and make sure everyone has the same image completed on their screens before moving on. That way I don't have to stop half way through the design to help someone get logged into their computer, fix an early mistake or to clarify instruction. I thank the students that are helping their peers. I have found that utilizing the students to help teach their peers seems to be very successful and I have less trouble later in the course. These students don't get stuck on relying on me to solve all of their problems. My objective is to create problems solvers so why not start on that journey from the beginning? This method also helps me find the value creators in the class that I can utilize later in team projects as leaders, facilitators and peer mentors.

I make sure the part models are simple enough to complete in about 30 minutes so I have time to give the lab introduction demonstration lecture, where students try to keep up with me on the projection screen. Students follow along and usually complete these types of labs in class. I have also found it useful to offer my office hours one hour before and one hour after this course where I find most of my time being spent with my newest students. The first preparatory part model I have them make in SolidWorks is a simple cube shown below in Figure 1. I start by having them sketch a two-inch square from the origin, and then extrude it two inches to make a two-inch cube. I wander around the class and make sure everyone gets to that point before adding any additional features.

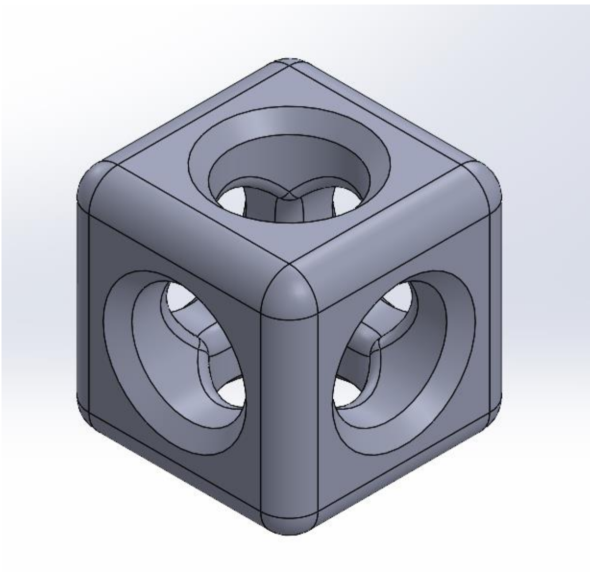


Figure 1. Simple Cube Model

After the cube is complete I have them put half inch diameter holes through the main faces of the cube through the part. At this point I show them how to rotate and orient the part to position the holes in the correct position. The final steps are to put ¼-inch fillets on the outside corners of the part, $^{1}/_{8}$-inch chamfers on the outside of the holes, and $^{1}/_{8}$-inch fillets on all intersecting internal hole edges as shown below. These features begin to introduce some of the skills needed to complete their next project. I am choosing to not give students a practice car to design in order to let the students stretch and struggle a little bit using the skills from these preparatory labs as their training and reference.

The next project I have the students' model in C.A.D. introduces more complex model sketching and extruding or cutting profiles. I have the students choose a logo and design it into a custom hitch plug for a truck or other vehicle with a tow hitch. This same method could be used to create signs, artwork and reverse engineering of parts and projects. I won't go into complete detail of this hitch plug project other than the skills I focus on, as it could distract from the Hot Wheels type car project. Once a student chooses and submits a picture of a logo as a separate assignment, I review and approve or reject the logo, they begin using the C.A.D. software to import their logo picture into a specific drawing file and trace out the profile of their logo on a five-inch circle or five-inch square template I issue to them with a specific fastener hole pattern for future assembly. I give them the size constraints through this same template I've released to them online as a drawing, not a model, and have them follow a tutorial I have created to help them use various sketch tools needed to create a usable sketch. I have found a variety of C.N.C. machine controls that require all splines to be saved as polylines so I choose to not let my students use font, splines or ellipses to trace out their logo profile. This eliminates other issues and saving protocols that I don't dive into in this course. Instead I have them use straight lines, three-point arcs, circles, squares and most of the other sketch tool options that do not create splines. Once the students complete tracing their logo on my plate template as a sketch, I have them select and copy their logo plate profile sketch with my plate template, paste it into the origin of the front plane of a new model file and extrude it the thickness of the material, which is $^{1}/_{8}$-inch thick 5054 Aluminum. This step allows students to see if they have any open or closed boundaries in their sketch because closed boundaries show up a darker shade in SolidWorks model sketches. The other thing that needs to be identified is any overlapping, double lines or gaps in their sketch which are all common mistakes that must be corrected in order to properly load into the C.A.M. software, typically already installed in the machine control. Once the logo sketch is repaired as necessary in the part model file, the logo plate is extruded to the material thickness and a part model is created. If the sketch will not extrude, there are errors with the sketch that still need to be repaired. I make this step a priority to let the students find and fix their own mistakes instead of submitting an incomplete or faulty DXF file to cut out on the machine which is a huge time saver. Recall, I am using this project as a preparatory training tool to turn the students loose later to create the main body of their Hot Wheels type car project.

Keep in mind C.A.D. and C.A.M. software packages are often updated and change over a period of time so please consider the following tutorial as an example of something you could create for your course or project. I usually take screen shots of the process in sequence and add descriptions in Microsoft Power Point, a commonly used presentation tool with easy to use features. I find tutorials a huge time saver. Most teachers and mentors have all been there when you just get done answering a question about a lab and the very next student asks the exact same question. I make my tutorials custom for the project and course for the introductory assignments, made in advanced and updated as needed. Some things get overlooked, left out, or changed in the project so keeping your tutorials up to date will help you solve many of the issues that come with teaching students' new tricks. A word of caution, not all machine controls work well with all drawing tool formats. I have found some of my machine camming software in the controls do not like DXF files with splines in them such as ellipses, fonts and spline curves. Each control is different so keep that in mind as you explore your camming tools. To avoid any conflicts in programming, I require that my students do not use spline type tools in their C.A.D. files. Since this is an introductory course, I personally prefer three-point arcs, circles, straight lines and fillets to complete the projects mentioned in this paper.

Once the logo drawing and model have been completed, I have them save the original file with their name in the file for grading references. I then have them save that same model in data exchange format (DXF) file type to download into a machine's control C.A.M. software used to create a program to cute their logo plate out. The DXF file must be saved from the correct view of the model. As stated previously, I recommend all models are started and sketched on the front plane to make it easier for everyone in the course to follow along. I am currently using a C.N.C. waterjet, CNC plasma table or C.N.C. laser cutter that we have in our labs. I have had semesters where I have had to sub-contract out the cutting to a local shop with a CO2 or fiber optic laser cutter. I have a student that has bought a laser and started a business so they have helped me out when I need the help if I do not have machine capacity for whatever reason. This hitch plug lab project also includes material planning, utilization and optimization through part nesting. I walk students through creating all associated documents and planning to train them. This prepares students to scale and trace out their vehicle of choice to create their Hot Wheels type car model components to fit within given size constraints and optimize material utilization as well as create all the necessary documentation and planning. The hitch plug project also includes some simple milling, drilling, deburring, and polishing processes that could also be utilized in their car project if you or they choose to do so. Additional hitch plug processes include designing a laser cut red acrylic plate to fit in the hitch plug assembly as a light diffuser for their LED lights included in the assembly. The lights require a simple circuit for 9-volt power supply as well as soldering wires in these circuits that get carefully placed inside a 3-D printed spacer plate that they have also modeled per my instructions. When properly assembled their logo lights up when the brake lights come on their vehicle. These features open design options in their car designs with the most important training component being the logo plate. This is how I currently choose to teach these skills. You could come up with similar or completely different projects to teach similar skills. At some point, I might write a specific paper on the hitch plug project in detail. There are several parts in this project that are similar in form so I will not go into detail other than I have the students create all the models, documentation and DXF files for the laser and waterjet cutting processes, machining and 3D printing. Hitch Plug example parts are shown below in Figure 2.

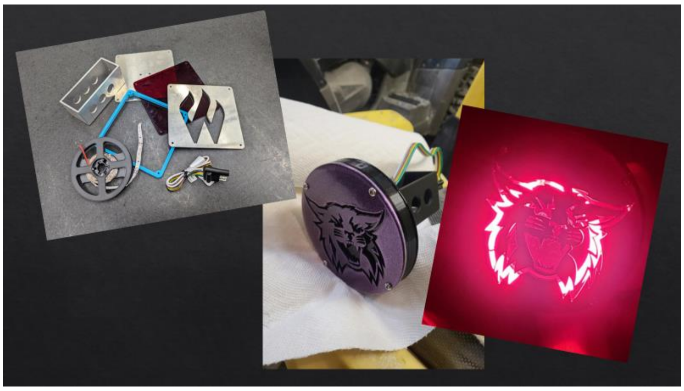


Figure 2. Hitch Plug Project

The next preparatory project I give the students is to model parts referencing issued dimension drawings and a tutorial to model two simple parts that include material sizing, through holes, and a variety of pockets, fillets, and a counter bore. I found it useful to create a tutorial for these parts using a series of screenshots of the process to let the students learn and explore at their own pace. Some complete the models in class while others work on it outside of class and some catch me at my office hours, which I chose to be one hour before and one hour after this course. These models explore a variety of methods that can also be utilized in their car model designs. These models could easily be modified or updated with applicable features of your choice to teach a variety of skills to meet the needs of your program. All of the assigned models and dimension drawings are submitted to me on our Canvas LMS as separate assignments, reviewed and graded. I have included views of some project dimension drawings that I obtained from Professor George Comber in my department shown in Figure 3 and example pages of my tutorial below shown in Figure 4.

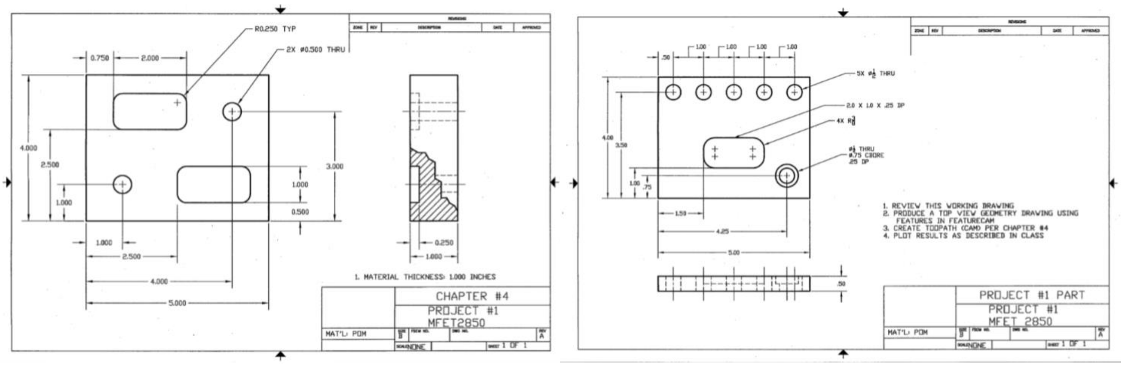


Figure 3. Practice Solid Model Prints

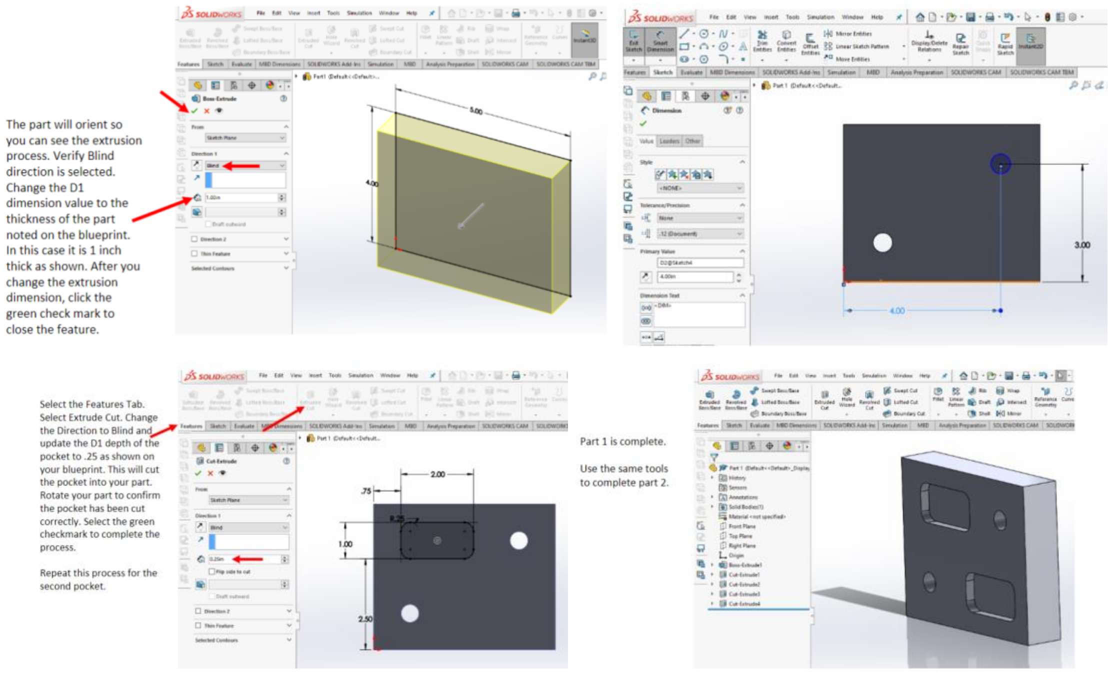


Figure 4. Practice Solid Model Tutorial Example

These models can also be saved as stereolithography (.stl) files to demonstrate preparation for 3D printing these and other model files. There is one part in the hitch plug project that I have students create by modifying and extruding their logo plate as a template. Here is an example of that part saved as an STL file shown in Figure 5.

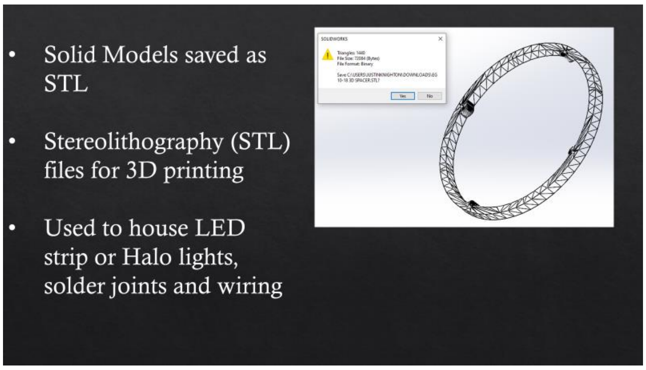


Figure 5. Practice STL File

I will make 3D printer recommendations later in this paper. Once the students complete the models, I introduce them to dimension drawings.

Dimension Drawings

Once the students are familiar with the basic solid modeling of the previous cube project and the other two simple part models I introduce them to the creation of dimension drawings using two of those part models. I demonstrate how to set up some basic A.N.S.I. standards on their document and import their part model files into separate drawings to recreate the same dimension drawings I issued to them as a .pdf used to create their original model files. This gives students a standard template to reference which I have found makes it easier to introduce them to dimension drawings. I demonstrate to the students how to create the first part drawing in class and assign them to create the second part drawing on their own time outside of class. This process also includes updating the title block found at the bottom of their document. As the students create these dimension drawings from their models, many of them discover that some of their dimensions are incorrect, which requires them to go back and edit their part model file and the associated dimension drawing should update automatically if done correctly. Once the dimension drawings are completed, I have the students save their files as a .pdf document and submit them online to my Canvas course. Although I request for very specific files to be submitted for grading, I find students submit their model files again, or the wrong file type of the document. If they have submitted the assignment on time and this occurs, I cut them a short temporary break by giving them a zero and request they submit the correct file immediately for credit. If they fail to update the drawing file within the due date extension, they get to keep the zero. I do not do this for every assignment, but I have found this helps get past a common mistake and prepares them for other courses. I have my students recreate the original dimension drawings I have issued to them to model the part as a template to follow.

After completion of the part models and dimension drawing assignments, we move forward with a more challenging part of the hitch plug project, which I call the hitch plug box. I have my students model the part using a copy of a blueprint shown below that I created and have them recreate the same dimension drawing. I get mixed results in dimensioning, but I have found that this part is also useful in preparing students to design their car body in the next project. Here is the print that I issue for this assignment shown in Figure 6.

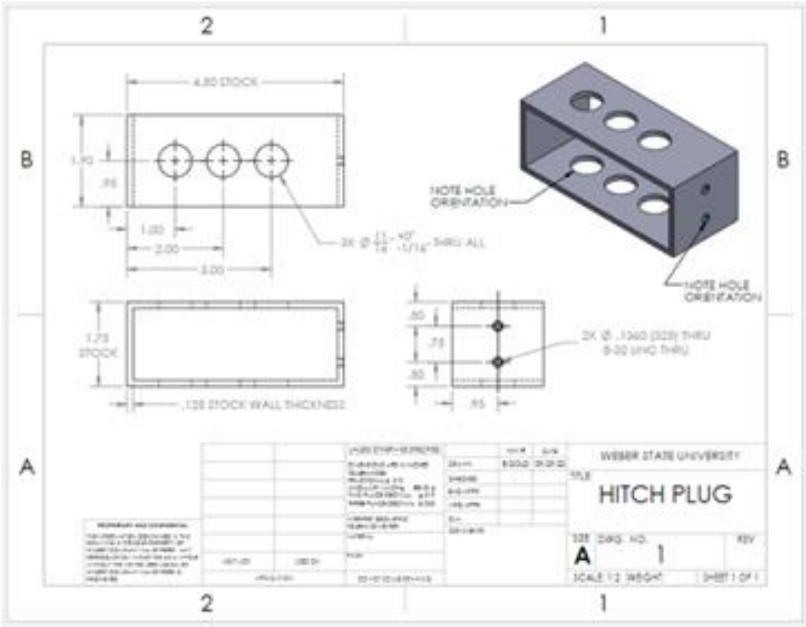


Figure 6. Hitch Plug Box Print

Data Exchange Files (DXF) Tips and Tricks)

I find some confusion when students create their two-dimensional (2D) drawings of their project parts when first being introduced to save and submit their drawing as data exchange files (DXF). They are getting comfortable at this point in creating simple part models. A very specific view needs to be saved of the part file to create the two-dimensional drawing of the file to be cut out on the available or preferred machine(s) you have access to. Most of the time I choose the waterjet or laser to cut these projects as they make a cleaner cut. Plasma table cutting is also a good option. If students save their dimension drawings directly as the .dxf file, it is saved with all of the associated details of those types of files, including title blocks, dimension lines, center lines, and other annotations found in a traditional drawing file. These additional annotations and details would create an obvious problem when imported into the specific machine control and associated CAM software when creating the part program. I make it a point to talk about this error, show students examples of this error and I still get students that go ahead and submit the error anyway. Since this is an introductory course, I give them a zero with a note to allow them to immediately fix and resubmit the file. I am tempted to go ahead and cut parts out with the error but I do not want to waste material so I just point it out, have them fix it and move on. Here is a student example of a traced logo saved as a DXF file shown in Figure 7.

At this level, I show the students how to setup and run the cutting machines, but I typically do all of the production work unless they set up an appointment with me to program it themselves. In reality, as an engineer, they will likely have an operator, technician or vendor cutting their parts out anyway so my primary focus is creating the correct documentation and files to have someone else do it. I do give them a demonstration of the equipment and how to set it up in class but I do not give them free reign to run the machines yet. I save that for future CNC courses.

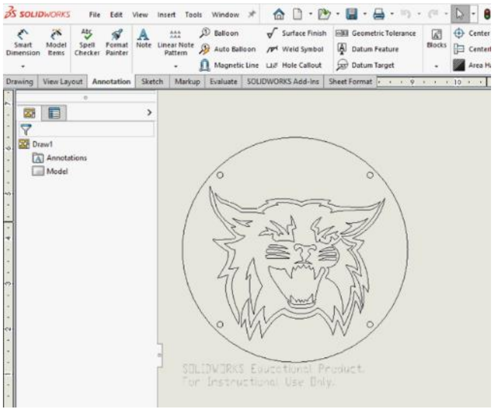


Figure 7. Example Hitch Plug Logo DXF

Standard Operating Procedures

I have found it is difficult to capture every detail of a procedure in manufacturing planning/travelers. As an engineer in industry I had to create standard operating procedures for a variety of technical processes, which is quite challenging because describing procedures can leave out details and some details can be open to interpretation. In my course I give my students 15-20 minutes to create a set of instructions to assemble their favorite sandwich or taco. They are to only give me assembly instructions only with the assumption that all ingredients are prepared and available for use. The results vary from a few bullet points or sentences to several paragraphs. After the assignment has been completed, I have them submit the assignment, along with all other digital work on Canvas. Once their instructions are submitted, I have them watch a subtitled video in class with a dad following instruction on how to make a peanut butter and jelly sandwich that his two children have written. I would highly recommend searching online for this "Exact Instructions Challenge" video and use it as a discovery tool. https://www.youtube.com/watch?v=Ct-lOOUqmyY (Now I've Seen Everything, 2018)

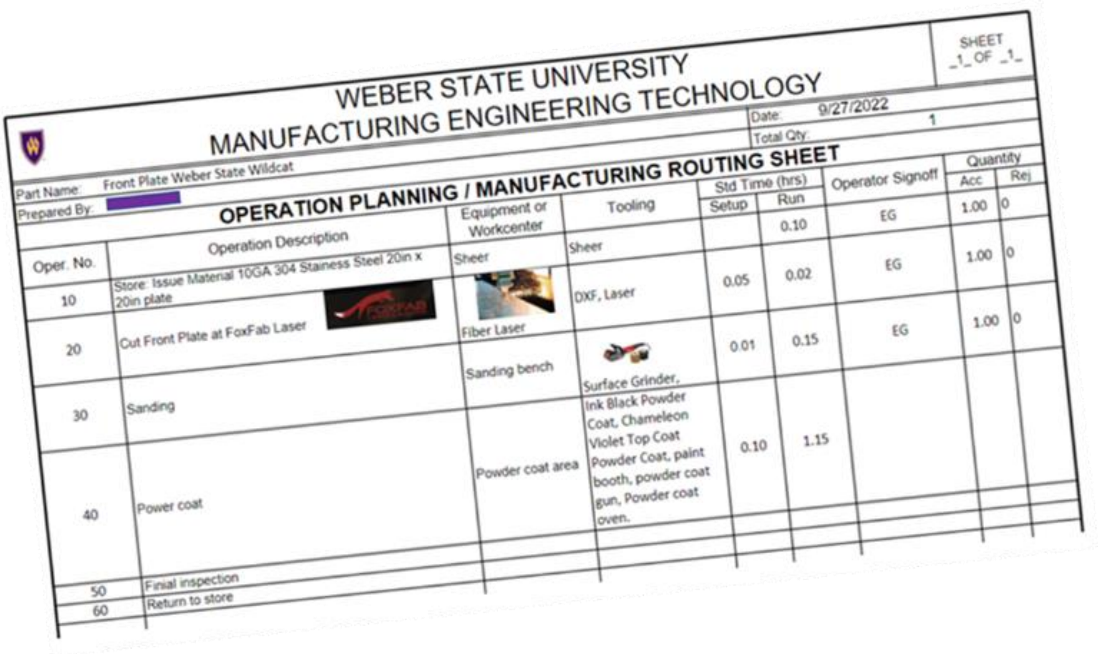
After the students watch the video, I ask the class if anyone needs to rewrite their personal instructions and most of them raise their hand. I do not have them rewrite them for sake of time, but I have proven my point that technical instructions are challenging. At this point I introduce them to Standard Operating Procedures (S.O.P) and have them start thinking about how they could better communicate technical instructions. Through open discussion, the class usually figures out that detailed drawings and pictures are valuable tools. I use the term "Lego instructions' as a reference to get them thinking about step by step communication solutions so that steps are not miscommunicated as process details are captured and delivered. Blueprints, dimension drawings, sequencing and literal pictures of the processes are discussed for future documentation assignments.I recommend using Microsoft PowerPoint (PPT) to create S.O.P.s as pictures can be added to the slides and arrows and other notes can be added to the pictures to share information and add clarity to a process or procedure. I will give an example of an S.O.P. with the hitch plug assembly planning section

.

Manufacturing Planning

I take some time during these projects to make sure the students understand that not only are we designing a product, we need to design it for manufacturing and for assembly. Do not overlook these parts of the process. Keep in mind, I do not have them document how to design the part(s) in the manufacturing planning. Manufacturing/production planning is for manufacturing and production purposes only. The design phase has already happened in the model and dimension drawing phase. Although I encourage them to document program and machine settings, I encourage them to leave out standard machine operating procedures (S.O.Ps) out of the manufacturing planning.

Creating a machine (S.O.P. would definitely be another excellent assignment option. In this case, I am only interested in documenting the process sequence(s) to create their parts that have already been designed. I have them assume the operator or technician already knows how to run the machines that will be processing their parts. I take time in class to help the students to identify and record the very specific sequence of manufacturing their hitch plug parts, including releasing material, processes and equipment operations, required tooling, setup and expected cycle times, quaintly of parts to be made, inspection and final storage of the completed parts. This assignment helps prepare the students to create manufacturing/production planning for their unique parts and processes in their Hot Wheels type car project and prepares them for similar adventures in industry. I have included example planning below shown in Figure 8.



WEBER STATE UNIVERSITY
MANUFACTURING ENGINEERING TECHNOLOGY

SHEET _1_ OF _1_

Date: 9/27/2022
Total Qty: 1

Part Name: Front Plate Weber State Wildcat
Prepared By: [redacted]

OPERATION PLANNING / MANUFACTURING ROUTING SHEET

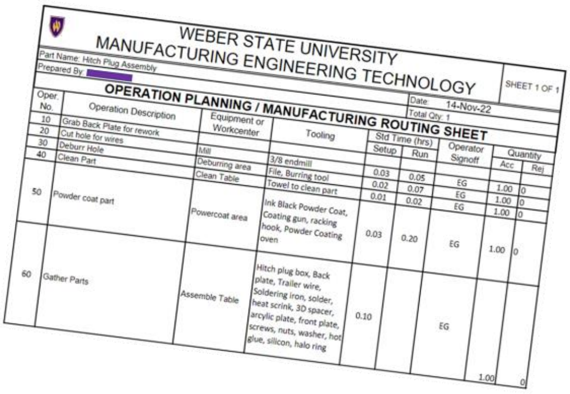
Oper. No.	Operation Description	Equipment or Workcenter	Tooling	Std Time (hrs) Setup	Run	Operator Signoff	Quantity Acc	Rej
10	Store: Issue Material 10GA 304 Stainess Steel 20in x 20in plate	Sheer	Sheer		0.10	EG	1.00	0
20	Cut Front Plate at FoxFab Laser	Fiber Laser	DXF, Laser	0.05	0.02	EG	1.00	0
30	Sanding	Sanding bench	Surface Grinder,	0.01	0.15	EG	1.00	0
40	Power coat	Powder coat area	Ink Black Powder Coat, Chameleon Violet Top Coat Powder Coat, paint booth, powder coat gun, Powder coat oven.	0.10	1.15			
50	Finial inspection							
60	Return to store							

Figure 8. Example Planning/Traveler

Assembly Planning

Assembly planning, like manufacturing/production planning, provides crucial instructions on how to complete tasks and operations in a sequential and orderly way. Documenting these processes help solidify the system so it is measureable, traceable and repeatable. I walk my students through the process of creating assembly instructions for their hitch plug project and have them use the same planning (traveler) documents in the assembly planning. My favorite tool is to have them use their cell phone cameras to take pictures of each method and activity of the assembly process and collect them in order with sequential operation descriptions, tools needed, and any necessary information to assemble their project.

They must use proper names of their components, tools, machines, consumables and other information necessary to identify and create their assembly planning map. This could include part numbers and names, machines and tools used, component orientation and position, fasteners and adhesives, custom sizing and fitting instructions, mechanical and electrical instructions, etc. In some cases, a student or two may have some C.A.D. skills and I allow them to create an exploded assembly view to include in their planning and bill of materials. This is a great place to include an assembly S.O.P. with picture details captured in an organized sequential format and referenced in the assembly planning. I include surface coatings in the assembly planning process. Example student planning and portions of an assembly S.O.P are shown below in Figure 9.


WEBER STATE UNIVERSITY
MANUFACTURING ENGINEERING TECHNOLOGY
SHEET 1 OF 1
Part Name: Hitch Plug Assembly
Prepared By: [redacted]
Date: 14-Nov-22
Total Qty: 1
OPERATION PLANNING / MANUFACTURING ROUTING SHEET

Oper. No.	Operation Description	Equipment or Workcenter	Tooling	Std Time (hrs) Setup	Std Time (hrs) Run	Operator Signoff	Quantity Acc	Quantity Rej
10	Grab Back Plate for rework							
20	Cut hole for wires	Mill	3/8 endmill	0.03	0.05	EG	1.00	0
30	Deburr Hole	Deburring area	File, Burring tool	0.02	0.07	EG	1.00	0
40	Clean Part	Clean Table	Towel to clean part	0.01	0.02	EG	1.00	0
50	Powder coat part	Powercoat area	Ink Black Powder Coat, Coating gun, racking hook, Powder Coating oven	0.03	0.20	EG	1.00	0
60	Gather Parts	Assemble Table	Hitch plug box, Back plate, Trailer wire, Soldering iron, solder, heat scrink, 3D spacer, arcylic plate, front plate, screws, nuts, washer, hot glue, silicon, halo ring	0.10		EG	1.00	0

Figure 9. Example Assembly Traveler and S.O.P.

Bill of Materials

The Bill of Materials is a separate document I have students create as a shopping list for every component, part and consumable necessary to assemble their projects. I provide the following link to a free document template for them to use. I prefer this Lego template and use it in my introductory course shown in Figure 10.
https://www.vertex42.com/ExcelTemplates/bill-of-materials.html (Vertex42 n.d)

On the Bill of Materials assignment, students must include associated costs per unit, quantity, a picture of the item, and an applicable product web link to where the specific item can be acquired. This is why I like using the LEGO B.O.M. template, I have changed the Color column title to Web Site Link, as shown above, where they share the link to their products. I typically have them use the following websites to standardize the assignment.

- https://www.mcmaster.com/
- https://www.fastenal.com/
- https://www.grainger.com/
- https://www.amazon.com/

Hitch Plug Assembly

Assembly Name :	Hitch Plug
Assembly Number :	1
Assembly Revision :	0
Approval Date :	12-Nov-22
Part Count :	1
Total Cost :	$186.62

Part #	Part Name	Description	Qty	Units	Picture	Unit Cost	Labor	Cost
1	Hitch Plug	6061 Aluminum, Powder coated with holes for back plate and pins, 1.70 in x 4.5 in x .125 in	1	Each		$ 8.00		$ 8.00
2	Back Plate	6061 Aluminum, Powder coated, counter sink holes	1	Each		$ 7.00		$ 7.00
3	Front Plate	304 Stainless, Powdercoated	1	Each		$ 27.00		$ 27.00
4	Halo Ring	Red Halo ring	1	Each		$ 7.12		$ 7.12
5	3D Ring	Spacer	1	Each		$ 2.00		$ 2.00
6	Red Arcylic Plate	Red Arcylic Plate	1	Each		$ 4.25		$ 4.25
7	Trailer wire kit	Trailer Wire Kit	1	Each		$ 1.96		$ 1.96
91099A266	18-8 Stainless Steel Philips Flate Head Screw	82° Countersink, 8-32 Thread, 5/8" Long	2	Each		$ 0.12		$ 0.24
91821A009	18-8 Stainless Steel Nylon-insert Locknut	8-32 Thread Size	2	Each		$ 0.07		$ 0.14
92141A009	18-8 Stainless Steel Washer	for Number 8 Screw Size	2	Each		$ 0.02		$ 0.04

Figure 10. Example Bill of Materials

Not every specific product will be available on these websites, so if we run into an instance where the exact product isn't available here, they can link to other websites as necessary. McMaster Carr is an excellent website that also has C.A.D. models of most of their products that can be used in project documentation. Maybe you prefer other applicable websites. Local hardware and materials vendors are a good source for educator discounts, project sponsors, and remnants.

I also snoop around a local recycling company that sells materials that are still usable at a fraction of the cost. I would encourage you to explore your options. In cases where the student made the item in our lab, I have them estimate the costs of the item and treat it as though it was purchased in house to capture overhead and associated costs of their project. That would include associated material costs, shop rates and labor. I help them recognize machines do not work for free as they take up valuable real-estate (floor space), electricity, maintenance and other costs such as fluids and tooling. I have different costs associated with different pieces of equipment which you could develop or just standardize for assignment purposes. Later in the course, using my template again, I have the students create their own assembly instructions and bill of materials with much less help from me for their Hot Wheels type car project.

Hot Wheels Type Car Project

History and Revision Changes

My original project in the course was something I had to come up with the weekend before the course started. As mentioned earlier, it is hard to find people to teach hands-on technology related courses and it is a very real struggle. I was hired on a Friday and had to start teaching on the following Monday, tasked with creating the course from scratch. I decided to have the student teams design, build and test tooth pick bridges at the time and had the students create all the applicable documents as discussed, more like a rough draft, along the way. It ended up being quite messy. The testing sequence was fun as the students would compete to see which team's bridge could hold the most weight spanning a six-inch gap. We designed a fixture to hold various sizes of weight lifting plates onto the bridge and kept stacking the weights until it would break. Some would break with a touch, while others could hold hundreds of pounds. The issue with this project was it was not feasible to create an exact digital model of the bridge, although they would do a decent job at making a dimension drawing showing the basic design size and dimensions. It was also quite messy and there were some hazards in the testing process that I am going to leave to your imagination.

The hitch plug project was also used but was a much simpler version without the LED lights. Just two plates, a logo plate and mounting back plate, along with hitch plug hardware to fit and mount into a receiver hitch. This project was successful so I improved it and continue to use it as a preparatory training tool.

On campus we have a Society of Manufacturing Engineers (SME) Club. A member of that club, who later became the president of the club, approached me several years ago about supporting a project designing and building a Hot Wheels league car track which would be similar to a national racing league. https://www.racehotwheels.com/ (Cox, n.d.). The concept was fun and several students from the SME club joined in the club event. The track was an open oval helix track design, designed in C.A.D. and 3D printed in house by this student. As the track slowly came together, interest began building and students started designing cars to compete in the upcoming contest. The cars had to fit within league open modified rules (constraints) which I used to begin the constraints for my course project. Because I had to modify those rules slightly to include a 3D printed body and machined or cut bottom plate chassis it would fit better in the Builders Challenge Race rules. https://www.racehotwheels.com/p/rules-and-race-classes.html (Cox, n.d.). The entertaining race event was held and inexpensive awards were given to the winner(s). We had awards for the fastest car, coolest design along with other awards for the heaviest, the slowest, etc. The only downside of this particular open track design was that there was not a specific lane for each car. Most cars would tip over as they were top heavy and some of the 3D printed features would get broken off or disfigured as other cars would crash into them, creating road blocks and discontent. The track was retired at the end of that semester and I searched online for a more practical track that was easier to set up and manage, similar to a Pine Wood Derby style track if you are familiar. This club activity inspired me to make a major change to my introductory course and drop the tooth pick bridges. It has been a huge success as I have incorporated this project into the course.

After careful consideration, I found a premade track online that fit the objectives of my project scope, league rules, and the time constraints of the course. The current track is made by Mattel, called the Hot Wheels® Super 6-Lane Raceway. I like this track because it has multiple lanes, a sensor at the finish line to identify the winner only, and breaks down into a compact mobile rolling assembly that I can easily hide in my office for storage. https://shop.mattel.com/products/hot-wheels-super-6-lane-raceway-v1983. (Mattel, n.d.) Shop around, I bought mine on amazon.com.

Figure 11. Mattel Hot Wheels® Super 6-Lane Raceway

The Wheels and axel assemblies were a challenge as I wanted to try and cut costs on the project. At first it was cheaper for me to buy sets similar cars at the store for $1 each. Each team got a different design with different wheels & axles which inserted some undesirable variation into the project. The teams would disassemble the purchased Hot Wheels cars to get the wheels and axels off of them. That process required carefully drilling out the rivets on the bottom of each car assembly, disassembling the car, salvaging the wheels and axels along with any accessories the teams wanted to utilize in their design such as plastic engines, exhaust pipes, etc. Much like a modern-day chop shop. The unused parts were thrown away or recycled. This process created some unusual results as some students have never operated a hand drill with a drill bit, or disassembled something in general. I had some close calls and safety violations as students would drill out the rivets full throttle on the drill motor, drill right through the car and into the vise. In some cases they would drill right through their axles and scrap everything. I even had a student not follow directions and pull the wheels off the peened axels (similar to rivet heads) with pliers to disassemble the car and wondering why they were having so much trouble with the destroyed wheels they were trying to salvage.

I began offering extra credit to students who could find me a vendor online where I could buy bulk wheels and axels cheaper than the way I was collecting them through destructive methods. The trick was I needed to be able to buy them tax exempt since I am making purchases on my university "P-Card". Eventually a student found a great source on https://www.aliexpress.us/w/wholesale-car-wheels.html (AliExpress, n.d.) and I ordered a bulk supply that should last me several semesters. This change has removed the design variations using sets of random car designs. The only noticeable thing different in this set is the color options which likely doesn't make a statistical difference but is open for experimentation (see Figure 12).

Moving forward with the project description, I have already reviewed most of the planning and other instructions given in the hitch plug project. The students have already been trained on how to create the documentation for their cars and have their own homework examples and my tutorials as reference to complete the project. At this point in the course, I do not provide tutorials for the students. It is time for them to use the tools they already have picked and reviewed during the course. Below I will give more information, and offer some tips and tricks to timely complete this project along the way.

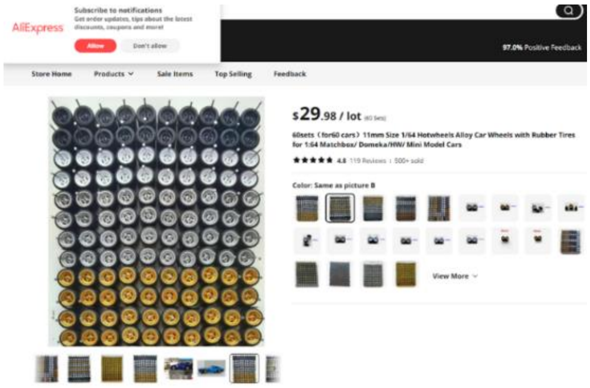


Figure 12. AlieExpress Wheels and Axle Supplies

Assigning Teams and Roles

My classroom has a few rows of desks with an isle down the center so it makes it easy for me to break the class up into four to six groups, depending on enrollment. The students tend to separate into peer groups that prefer to sit together anyway throughout the course so I leave them in their preferred groups. By this point in the course I have a pretty good idea of who is doing well and who is struggling. If a group of struggling students gets organized together, I find they actually improve faster as they have that performance pressure put on them with the assignment and they usually end up delivering some nice work. You could randomize or organize the teams however you choose, or just divide the room up into groups like I do.

Once the teams are separated, I give them a task to create a team name, often associated with their projects secondary function that will be discussed later. I also task the teams to nominate or designate team roles amongst themselves. I require a team leader, documentation manager, design manager, and manufacturing manager. I do not want anyone to feel like their role is most or least important. If I find that roles are conflicting on a team, I make the assignment or create a new role such as team coordinator, team facilitator, action item coordinator, etc. These management roles do not necessarily mean they are the only member of the team to complete the associated tasks under their management. I prefer that everyone has input in each of these areas and action items get delegated accordingly. Occasionally I get a student that has trouble getting along with their team or team member(s) so I make changes as needed.

Team member accountability needs to be measureable to make sure everyone contributes on each team. I have to make sure that all the work is not completed by one or two team members and that the workload is evenly distributed. To accomplish this, I have each team create a work breakdown structure which will help them define who is going to do what. A team project schedule and action item tracker will be discussed later.

Rules and Constraints

In addition to the following rules, I only give my students three weeks to complete the project of designing, building and racing their cars. That only gives them five class periods before race day. Since we only meet twice a week for about two hours per class period, they have to work on this outside of class as well as schedule time on the 3D printer and other processing equipment such as the CNC laser cutter and water jet. Once the project has been assigned and released, I leave the class time open to them to work on their project and I stay out of their way with the condition that they can only use the processes that they have been trained on in the course. That way I do not have to personally program a CNC mill or some other piece of equipment for them. I want them to use the skills they already have.

The rules and constraints, as previously mentioned, are taken from the www.racehotwheels.com website with a few minor changes, specifically for the D64 Builders Challenge Race Class. Most of the rules I use come from the Open Modified Race Class.
https://www.racehotwheels.com/p/rules-and-race-classes.html (Cox, n.d.).

- Cars must be 4 oz. or less.
- Cars may be modified for speed, looks, or both.
- Length: must be 3.75 inches or less
- Height: must be 2 inches or less
- Car must have 2 axels and 4 wheels
- Width: must fit on Hot Wheels orange track
- Dry lubes only
- 1 car per team
- Car must have a 3D printed body
- Car must have a bottom plate chassis cut on a CNC machine and held in place with at least one fastener into the assembly.
- Car must have a pocket chamber for weight and at least one separate window or opening in the design
- Car must have a pre-approved secondary function
- Teams must provide all project documentation as requested.

Secondary Function

The secondary function of the vehicle adds a fun twist to the project and that function must be defined before starting the project. I require the students to design some other function into their car design. I give some simple examples to get them thinking about this secondary function. This function could be completely hidden in the 3D printed car body or an obvious attachment to their design. Common features that are chosen are flash drives, bottle openers, pencil sharpeners, secret compartments, tools and laser pointers. I require an approval process so I can confirm the secondary design before they make it because I do get some sketchy proposals. I have had glass water pipes, fireworks, solid rocket “A” size thrusters, and a variety of other proposals try and get through the approval process. I reject anything that has to do with drugs or weapons. If the design is sound, I have approved rocket engines and fireworks as long as they do not light them off in the school or on my racetrack. I have set up a metal track (C channel) and launch pads with applicable safety precautions for those wishing to display their rocket motors after the race.

This really is one of the most creative portions of the project as students try to come up with something unique. Some of my favorites have been spring loaded drives, or magnetic assemblies to hide or release their secondary function. L.E.D. lights, music box and other electronics have also been incorporated with batteries. My favorite was a Santa sled with L.E.D. lights and it played Christmas music. It takes a lot of effort to squeeze some of these ideas into such a small package.

Once the secondary function has been approved, I have the teams create their project schedule.

Schedule

Ideas and proposals without a schedule never get completed. Once the teams have been created and their secondary function has been approved (verbal) I have them create a list of all their action items needed to complete every part of their project, including all planning, processes, manufacturing, assembly, etc. Each item must be assigned to a team member and tracked by creating a team project schedule and action item tracking report. I usually only give the teams about a half hour to come up with their secondary function and create their project schedule in class before submitting it online to a specific assignment issued on Canvas. I do not require a Gantt chart, only a bullet point milestone type schedule shown in Figure 13.

Team GOLP

Hot Wheels Project

Schedule 11/4-11/22

- Body – Emilee
  - Model (Emilee 11/14/22)
  - Dimension of drawing (11/15/22)
  - Prototype (11/14/22)
  - Inspection report (11/16/22)
  - Final Model (11/17/22)
  - Production run
- Chassis– Tanner
  - Body Model (input) (Tanner 11/14/22)
  - Design (11/14/22)
  - Material (Aluminum donated by Fox Fab laser)
  - DXF file (laser, water jet)
  - Prototype 11/15/22
  - Inspection report 11/17/22
  - Final Model 11/17/22
  - Dimensions of drawing 11/15/22
  - Production run
- Secondary Function – Josh
  - Research
  - Model (Josh Call 11/14/22)
  - Drawing 11/15/22
  - Prototype
  - Testing/function 11/17/22
- Assembly
  - Final assembly planning/traveler (11/16/22)
  - Prototype (11/17/22)
  - Final production assembles 11/22/22
- Testing
  -
- Race Day 11-29

Figure 13. Example Milestone Schedule

Models

Weber State University has a SolidWorks network license and is the C.A.D. software of choice for faculty and our employer advisory board. I have trained my students to use specific methods in SolidWorks that will aid them in creating their design model of their project cars. Occasionally I have students that prefer Fusion 360, another free C.A.D. software from Autodesk that you could use in your courses. Since this MFET 1000 course is an introduction to our Manufacturing Engineering Technology degree, I prefer to use the software that is used in the other engineering courses in our department, so I try to limit anything but SolidWorks for project C.A.D. design in my courses.

I only require models of the parts that the students are going to make for their project. This eliminates requirements for the buy items, specifically the wheels and axel assemblies, fasteners, added weights and add on hardware such as the secondary function if it is a purchase item. Since this project is more of a rapid prototype that we will race, I loosen the perfection requirements giving students wiggle room around the project’s function.

Students have been given enough training up to this point to complete the following:

Car Body

This model is the most challenging as it must accommodate the design rules including the wheels and axels, room for added weight, the bottom plate chassis, and the secondary function, etc. I do not expect something perfect in form, but I do expect it to function properly. The previous practice assignments have prepared them to make a simple model and this pushes students to find ways to model their creative ideas. I recommend the students find a side profile picture of a specific vehicle that they want to design their car after, save and trace that picture (.jpeg) in the C.A.D. software. This process is taught in the hitch plug process as they create their logo plate. This process requires scaling the picture to a specific size. I have them make a quick rectangle dimensioned to their size constraint rule, 3.75’ long by 2” high, and then scale the picture to fit within that constraint. Quite often I find student in my class with some C.A.D. design skills picked up in school or other interests along the way. Some students even have their own 3D printers at this level that I encourage them to use to free up machines on campus. Below is an example of a dimension drawing of a model based on a Tesla type truck shown in Figure 14. This drawing was not completed using ANSI standards so I docked this team a few points for using ISO standards in dimensioning.

Bottom Plate Chassis:

The primary function of this component of the design is to hold the wheels and axles into the 3D printed car body as well as to secure optional weights into the underside of the 3D printed car body if that is where the teams design that feature. The bottom plate chassis could also be the secondary function such as a metal plate with a tool shape incorporated into it or a rigid way to mount the car body and secondary function together. To make this plate designed for assembly, I have the teams use the bottom view of their car body model as a template to create this plate by saving that view as a .dxf file, taught earlier in the hitch plug project. The bottom view .dxf can be cleaned up to remove unnecessary lines leaving the outside profile and applicable fastener holes. An example of a chassis is shown in Figure 15.

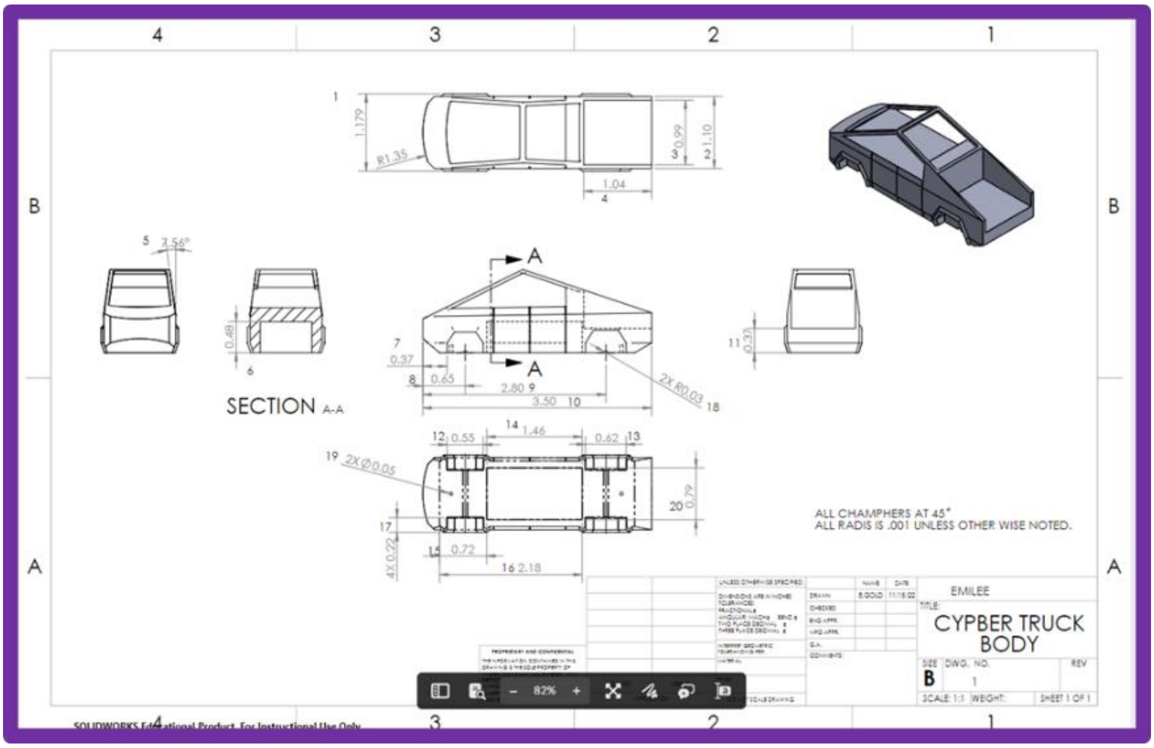


Figure 14. Example Car Model Dimension Drawing

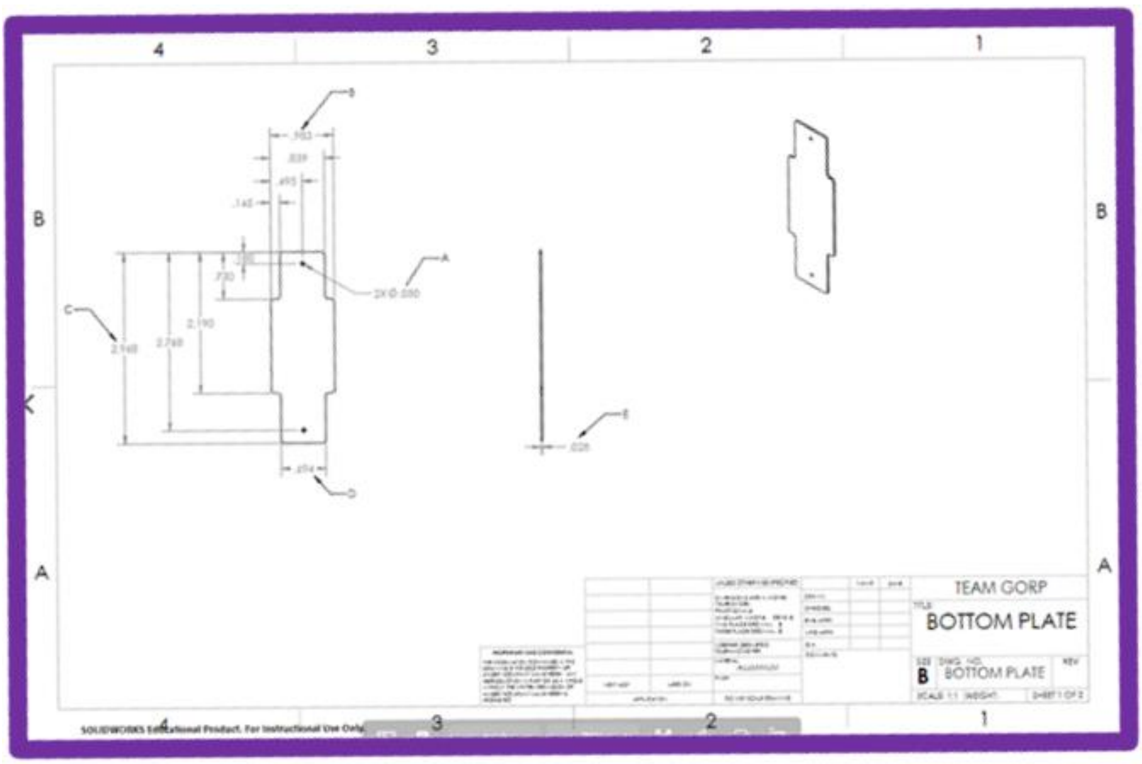


Figure 15. Example Bottom Plate Chassis Model Dimension Drawing

I prefer that these plate designs be cut out of metal or acrylic sheet instead of 3D printed but if one does not have that option, they could easily be printed. The DXF files will be uploaded into a CNC laser, plasma or waterjet cutter to cut out the plate for assembly. My first choice would be a CO2 or fiber laser cutter. Our department just bought a 2kw CO2 Boss laser and we are in the process of setting it up now. These lasers come highly recommended. I also mentioned we have a CNC waterjet and Plasma table that would also be a good choice to cut various metals for this and other projects. If you want to laser cut plastic for this part of the project, I would recommend the Epilog Fusion Pro.

There are some printing software options you can use to upload your DXF files into to create programs to cut out or engrave on the laser. I have been using Adobe Illustrator and CorelDraw. Training for these cutting processes is performed during my hitch plug project. At this level, I let the students program their parts and cut them out with my assistance on the machine. I always let them video and take pictures of their setups and processes for reference material. All parts must be properly deburred, remove all sharp edges and cleaned after manufacturing.

Assembly

I do not require C.A.D. model assemblies or assembly C.A.D. drawings at this level in this course. I will discuss assembly planning later. If students have previous skills and want to create an assembly model and drawings, I encourage them to do so but it is not a requirement. Here is an example in Figure 16 below. As previously discussed, I prefer the students take photographs of their processes and procedures using their cellphones or digital camera and include them in their planning and S.O.P.s.

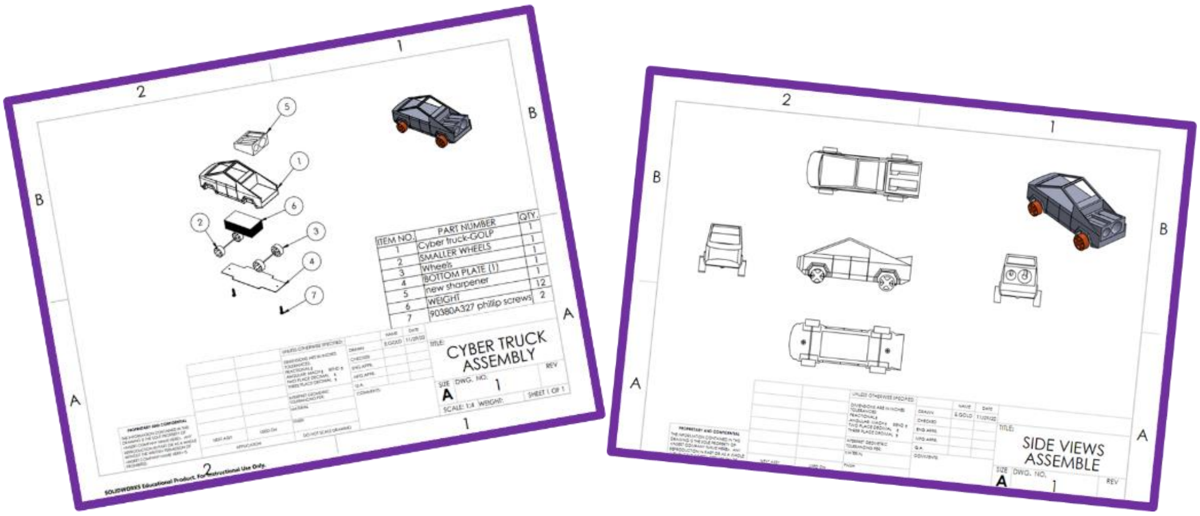


Figure 16. Example Model Assembly Drawings

Prototypes and 3D Printing

Since this project is really an experiment in prototyping, I have the teams create one complete assembly before creating a copy of that assembly for each member of their team. This saves time on tying up the 3D printer with a long print queue of parts that may or may not even work as intended. I often find wheel clearances and assembly constraints are often overlooked and several revisions need to be created before their production run. Again, I do not let my students 3D print a bunch of unusable models, just one at a time until the design has been proven. Once the prototype design has been proven and approved by the team, then they can nest a group of models on the 3D printer for production purposes and an overnight print job.

3D printing is not a fast process so I carefully control print queues. Students download .stl files into the print queue on the printer and delete other team's queued files. I set up a queue in class for one prototype from each team and nest as many of those parts in one print program. I usually have one or more nested group of parts in the queue and start printing them right away. I try to have them printed by the next day, or at the very least, before the next class period. Prototyping should be completed by the end of the second week and production needs to be running in order to be able to have the project completed by race day at the end of week three. I will discuss 3D printer recommendations towards the end of this paper.

Dimension Drawings

Dimension drawings are a requirement for this project and used to manufacture, inspect, and assemble the project. I do not require models or dimension drawings for purchased parts in order to reduce the workload. In most cases, dimension drawings are created only for the 3D printed car body, the bottom plate chassis, and the secondary function if it is not a purchased item. If any purchased item requires modification or cutting, I require a dimension drawing. For example, cutting the handle off of a bottle opener so part of it can be attached to the back of a 3D printed car design as an air spoiler or some other secondary function with aesthetic appeal.

I limit dimensions on the drawings created so they can be measured with digital or dial calipers only, such as overall length, height, width and thickness. There is not time enough in the course to teach other metrology methods such as height gages, micrometers, laser scanning and coordinate measuring machines (C.M.M.). These methods can be taught in other courses. Student just make simple blueprints to confirm parts are within the project constraints (rules) and that their designs are within their design specification (manufacturing inspection reports). If you have other inspection tools that you would want to incorporate into the project, set some constraints that require the use of that equipment or tool. I have given a previous example of a car body dimension drawing in the car body section of the Hot Wheels project.

Manufacturing Planning

Traveler/Route Sheet

I use the same traveler template used in the hitch plug project for both manufacturing and assembly planning. Students must document all processes and procedures in the sequence required to complete them as previously taught in the hitch plug project. I do not require every specific detail such as machine setup instructions or how to deburr a part, etc. If specific details are required to do a process, then I have the students create an S.O.P. for that specific operation sequence and reference it in the planning. To simplify this project, I usually have them omit all machine setup instructions and S.O.P.s for this project. Since they have made several travelers up to this point, I will be more critical in grading these documents.

A gentle reminder here that manufacturing planning instructions does not include design instructions. No matter how many times I saw this in class, I still get students documenting C.A.D. model design instructions or some other design process which is not a part of manufacturing planning. I remind them about their sandwich instructions and video while reinforcing that the design engineering has already been completed and that manufacturing planning instructions are to document the manufacturing processes in a very specific step by step sequence that they determine.

Tooling

All tools used for each process must be listed for use at that sequence. There is a column in the traveler to capture them. Examples include hand tools such as screw drivers, sandpaper, files, etc. Equipment can also be listed such as laser cutter, waterjet, mill, specific 3D printer, etc. The students must also list the program files and applicable .dxf and .stl files used to create the parts.

Material Optimization, Nesting

Nothing gets me more frustrated about life than to find a beautiful piece of material in the lab with a small part cut out of the middle of it laying against the side of a machine. I make sure to point this out long before students start cutting. Material optimization is a critical piece of process planning and wasted material is expensive. Most camming tools on machine controls have multiple part nesting options that should be utilized. Some are better than others. Part files can be nested close together in one C.A.D. file prior to uploading them into the machine control. A single nested file works great for most machine controls but I would use caution in doing so as some controls can get confused with interior and exterior features getting mixed up by the controller.

Assembly Planning

Traveler/Route Sheets

Students are required to create an assembly traveler with specific sequential operations listed, as well as all other tools and equipment required to assemble their car project. Students can use their previous hitch plug project assembly planning as reference. Typically, students struggle with capturing every tool and step here. Since this is a final project for the course I am a little more critical of the assembly documentation.

Lego Type Instructions

Standard operating procedures (S.O.P.s) are required for their assembly planning. I remind students again of their previous sandwich/taco assembly instructions and video as well as reference their Hitch Plug Project assembly instructions. A picture is still worth a thousand words and I require pictures of every process in this assembly. Cell phones have made this easier as I ask students use their cameras to intentionally document everything along the way.Here are some more examples of S.O.P.s for the car project assembly shown below in Figure 17.

Figure 17. Example Assembly Standard Operating Procedures (S.O.P.s)

Bill of Materials

This assignment is very much the same as the B.O.M. for the hitch plug assignment. Here is an example of an Assembly Bill of Materials shown in Figure 18.

[Team Golp Cyber Truck]

Assembly Name :
Assembly Number :
Assembly Revision :
Approval Date :
Part Count : 26.47
Total Cost : $39.87

Picture of Assembly

Part #	Part Name	Description	Qty	Units	Picture	Unit Cost	Labor	Cost
1	Model Material		1	each		$ 1.59		$ 1.59
2	Support Material		1	each		$ 0.76		$ 0.76
3	Hot Wheels Car		1	each		$ 1.40		$ 1.40
4	pencil sharpener		1	each		$ 0.69		$ 0.69
5	Screws		2	each		$ 0.01		$ 0.02
6	Hot Glue		1	each		$ 0.09		$ 0.09
7	Hot Glue Gun		1	each		$ 11.99		$ 11.99
8	3/16 Drill bit		1	each		$ 2.79		$ 2.79
9	Flat Head Screw driver		1	each		$ 5.99		$ 5.99
	Small Phillips Screwdriver		1	each		6.99		$ 6.99
10	5052 .018 Aluminum	.98 x 2.98in x.018	1	each		$ 0.58		$ 0.58
11	20 GA Galvainzed A36 Steel	.77in x 1.5in x .036	12	each		$ 0.02		$ 0.24
12	labor for laser cutter	40 seconds weights, 7 seconds for bottom plate	0.47	each		$ 5.83		$ 2.74
13	labor for design	10 hrs		each				$ -
14	labor for assembly	5 min		each				$ -
15 s	Laser Set-up Fee	Set-up Fee	2	each		$ 2.00		$ 4.00
								$ -

Figure 18. Example Assembly Bill of Materials

I often encourage students to find cheaper ways for me to buy the wheels and axel components for the car project and offer extra credit to students that can save me money on them. This could apply to any specific items in a bill of materials such as recommend cost savings for 3D printer filament, metals, fasteners, etc.

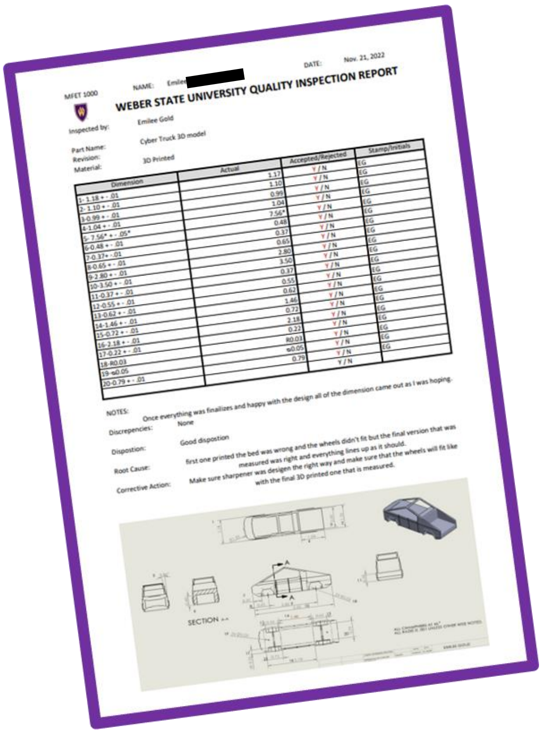
Open Labs

As mentioned before. I train the students on C.A.D. and the equipment needed for this project early on in the semester, issue this car project and get out of their way. I still hold class, I just don't have any planned lectures or other assignments for these three weeks other than this project. I have an open lab during class for this project and I help teams setup and run their parts on each piece of equipment on a first come first serve basis and by appointment depending on the need. Equipment utilization is definitely a constraint and must be carefully planned as other courses and faculty might need to use the same equipment. I do carefully control the 3D printer queue to optimize printing of the prototypes and production runs, preferably by nesting a series of files in one print file letting them print overnight while I am away from campus. Although I encourage students to do so, if student files are queued, I make every effort to check in on the 3D printers so I can unload finished parts and hit play on the next program in queue. I do find students butting in the print queue line, deleting other student's files so they can expedite their work. I discourage students from doing this, and have found if I see the 3D printers not printing, I try to take care of it as soon as possible and get the next file up and running. I am currently considering buying several more 3D printers to free up queue times. I do make extra effort to help students with this project outside of class. I have also trained lab aids and other staff members on how to use the equipment and 3D printers to give the students more resources.

Inspection and Testing

Students create inspection reports for each part of the project using their own dimension drawings and planning as reference. They already have the template file from the previous projects. It is important for students to learn to document the requirement and the result. I sometimes find students manipulating their measurements in order to create a good part which nullifies the reason for inspection in the first place and discredits their engineering and manufacturing documentation and planning. The last thing you would want is for them to play those type of games in industry. At this level, I am more concerned about them defining and documenting design measurements and constraints and then measure and document the results. As for testing, I simply have the students set up the track long before race day and confirm their prototype car will function as intended on the track. Sometimes students discover during the testing process that they overlooked something. A variety of design errors can be discovered during testing such as the car will not fit in the track lane, the chassis bottoms out and drags at the bottom of the track where the ramped track levels off along the floor, or their wheels rub the car body, etc. These errors can quickly be identified through inspection and testing and design changes can be made and implemented quickly so another prototype can be 3D printed and assembled. Repeat.

A great example of an inspection sheet with an attached dimension drawing for reference is shown in Figure 19. On the inspection sheet I have the students list the required dimensions, what the dimension actually measure, is each item accepted or rejected, and room to initial each feature by the inspector. I encourage students to think about the operator or inspector when creating documentation. Once the prototype has been tested and approved, a production run for the remainder of the team cars are manufactured.



MFET 1000 NAME: Emilee [redacted] DATE: Nov. 21, 2022

WEBER STATE UNIVERSITY QUALITY INSPECTION REPORT

Inspected by: Emilee Gold

Part Name: Cyber Truck 3D model

Revision:

Material: 3D Printed

Dimension	Actual	Accepted/Rejected	Stamp/Initials
1- 1.18 + - .01	1.17	Y / N	EG
2- 1.10 + - .01	1.10	Y / N	EG
3-0.99 + - .01	0.99	Y / N	EG
4-1.04 + - .01	1.04	Y / N	EG
5- 7.56* + - .05*	7.56*	Y / N	EG
6-0.48 + - .01	0.48	Y / N	EG
7-0.37+ -.01	0.37	Y / N	EG
8-0.65 + - .01	0.65	Y / N	EG
9-2.80 + - .01	2.80	Y / N	EG
10-3.50 + - .01	3.50	Y / N	EG
11-0.37 + - .01	0.37	Y / N	EG
12-0.55 + - .01	0.55	Y / N	EG
13-0.62 + - .01	0.62	Y / N	EG
14-1.46 + - .01	1.46	Y / N	EG
15-0.72 + - .01	0.72	Y / N	EG
16-2.18 + - .01	2.18	Y / N	EG
17-0.22 + - .01	0.22	Y / N	EG
18-R0.03	R0.03	Y / N	EG
19-ø0.05	ø0.05	Y / N	EG
20-0.79 + - .01	0.79	Y / N	

NOTES: Once everything was finalizes and happy with the design all of the dimension came out as I was hoping.

Discrepencies: None

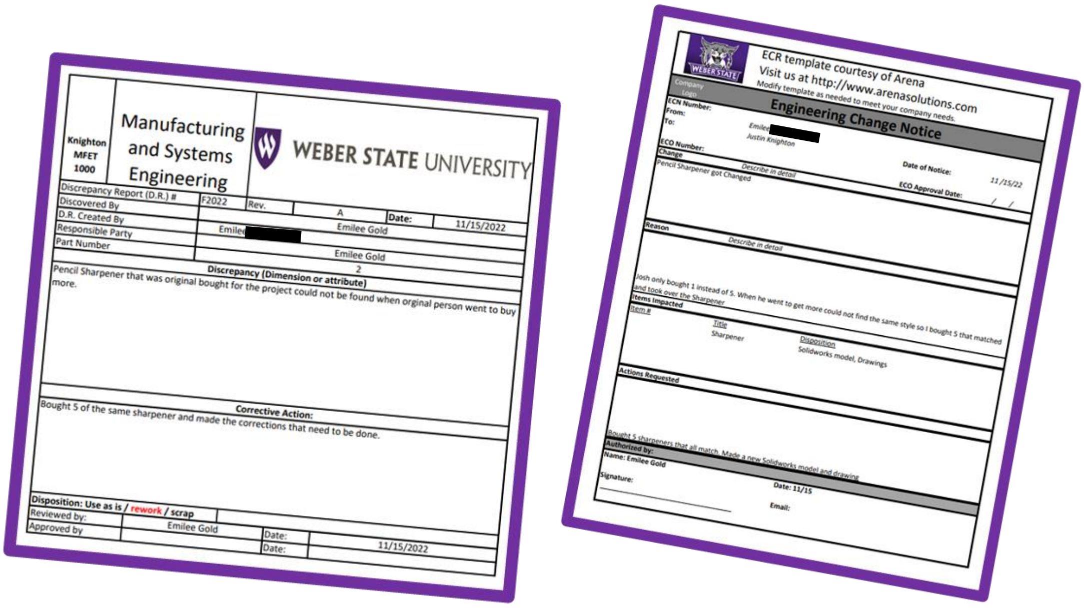
Dispostion: Good dispostion

Root Cause: first one printed the bed was wrong and the wheels didn't fit but the final version that was measured was right and everything lines up as it should.

Corrective Action: Make sure sharpener was desigen the right way and make sure that the wheels will fit like with the final 3D printed one that is measured.

Figure 19. Example Inspection Report

Mistakes are made: Typically, in industry, if an engineering change has to be made, there are protocols to follow in order to do it in an orderly process to ensure all documentation and design changes are recorded and justified. Since this project is in the prototype phase, using a Discrepancy Report (D.R.) and Engineering Change Order or Request (ECO or ECR) is not necessary, but I choose to incorporate them into this project so students are exposed to these types of protocols. I have students fill these forms out if they want to deviate from original hitch plug design constraints or significant revision changes to their hot wheels car project and assignments are made to complete them. Below are some examples of a Discrepancy Report (D.R.) and an Engineering Change Notice (ECN) shown in Figure 20.



Knighton MFET 1000 — Manufacturing and Systems Engineering — WEBER STATE UNIVERSITY

Discrepancy Report (D.R.) #	F2022	Rev.	A	Date:	11/15/2022
Discovered By	Emilee Gold				
D.R. Created By	Emilee [redacted]				
Responsible Party	Emilee Gold				
Part Number	2				

Discrepancy (Dimension or attribute)

Pencil Sharpener that was original bought for the project could not be found when orginal person went to buy more.

Corrective Action:

Bought 5 of the same sharpener and made the corrections that need to be done.

Disposition: Use as is / rework / scrap			
Reviewed by:	Emilee Gold	Date:	
Approved by		Date:	11/15/2022

ECR template courtesy of Arena

Visit us at http://www.arenasolutions.com

Modify template as needed to meet your company needs.

Company Logo

Engineering Change Notice

ECN Number:

From: Emilee [redacted]

To: Justin Knighton

ECO Number:

Date of Notice: 11/15/22

ECO Approval Date: / /

Change — Describe in detail

Pencil Sharpener got Changed

Reason — Describe in detail

Josh only bought 1 instead of 5. When he went to get more could not find the same style so I bought 5 that matched and took over the Sharpener

Items Impacted

Item # — Title: Sharpener — Disposition: Solidworks model, Drawings

Actions Requested

Bought 5 sharpeners that all match. Made a new Solidworks model and drawing

Authorized by:

Name: Emilee Gold

Signature:

Date: 11/15

Email:

Figure 20. Example Discrepancy Report and Engineering Change Notice

Race Day

Here are some examples of student work showing various views of their designs and secondary functions shown in Figure 21.

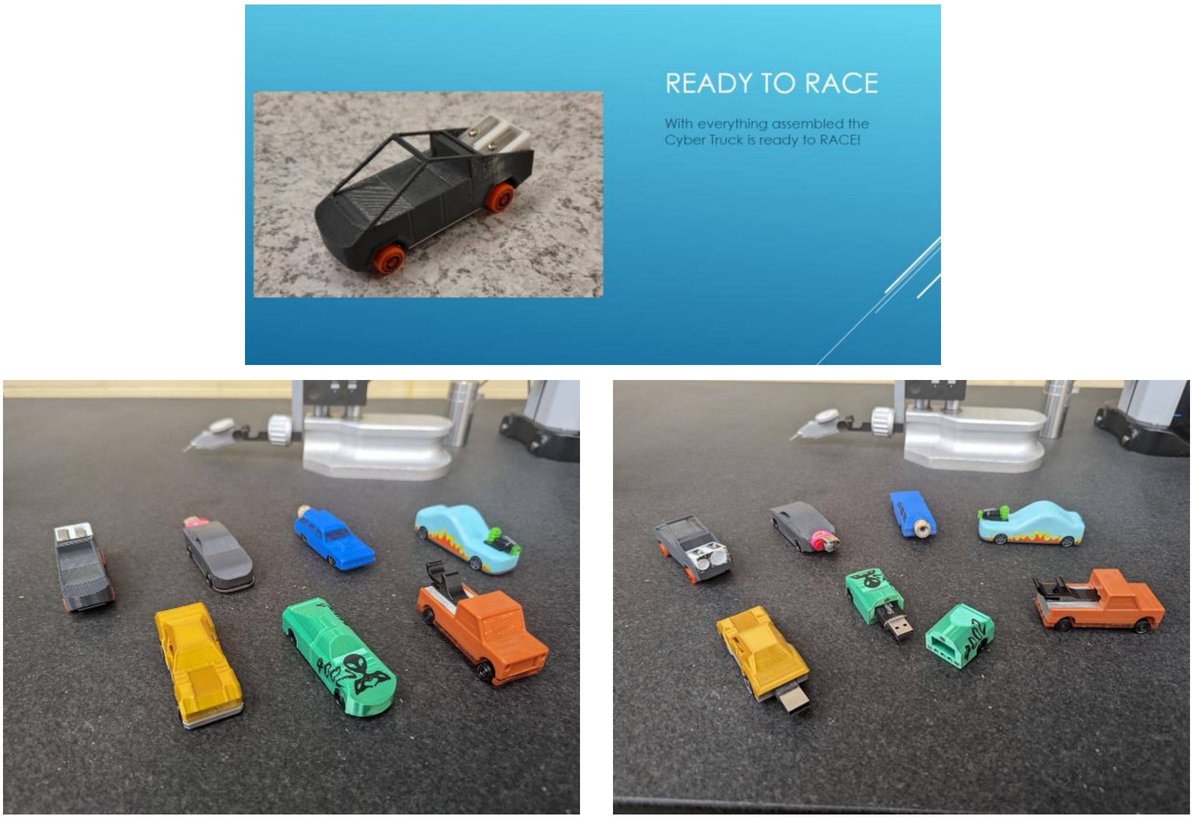


Figure 21. Example Car Designs with Secondary Functions

Race day is the due date for the project and all work must be submitted online including pictures of their final assemblies. I have the students meet in the classroom first where I release the entry inspection form I have created to confirm each entry meets all of the constraint requirements. I give them an hour to tie up loose ends with their project and complete the entry form. I bring the weight scale that I have made available throughout the project to confirm the weight of their car as well. During this time, I also utilize my students to help set up the racetrack that I have previously recommended in one of our labs where we have more room to set up and observe. The track itself does not take up a lot of space, but having everyone stand around makes for a crowded classroom.

Some teams really get into this project and go above and beyond the requirements. I have had a couple of teams design t-shirt logos with their team's name and a graphic that would represent them. One of those teams used a copy of their car model in their graphics, and gave me a shirt to wear during the race. How fun is that?The race track I recommended is easy to set up and use. Since this is really a final test application of their design, I let them race as many times as they want to define the fastest team's car. Each team is to only race their fastest car to reduce the time spent at the competition. Cars are placed at the top of the track and a release lever is pulled to release up to six cars down the track at the same time. The racetrack has an electronic device at the finish line that captures the first car across the finish line and which lane the car was in. I rarely have more than six teams so the race does not take very much time. I have them rotate through each lane of the track to make sure the track is not affecting the race results. I do not keep track of any other placement level than first place in the race but that could definitely be an option if you are interested in adding different levels. (Mattel, n.d.).

Figure 22. Mattel Hot Wheels® Super 6-Lane Raceway Set Up

Once a winner car is determined through racing, the awards for the winning team might be very familiar to a college student. I thought this out carefully as I wanted them to get some sort of gold cup for winning the race. I decided on a chicken ramen cup of noodles as it is gold in color and adds some element of surprise and humor to the event. These cups are inexpensive and can be found at a local grocery store. I give each member of the winning team a prized cup of noodles.

Student Work Submissions

In order to keep documents controlled and up to date, I mentioned that I have my students set up a folder online in Google Drive, or some other cloud-based storage file. Our institution also has a box type account set up for faculty and students to use so I prefer that they either use their Google Drive account attached to their student email account, or their Box account on their online student portal. I make sure the students share that file path with me and their team as well as give me permission to view files so I can grade them. I also have one member of each team print a paper copy of their documentation and submit that to me on race day. Personally, I like the paper copy so I can write on it during my grading.

I have been making the project one big assignment and expecting the students to follow the rubric and submit all required documentation, files and one final assembled car. I don't always get what I ask for so moving forward I am breaking up the one large assignment into sub assignments in order to keep each item on the student's radar so that they do not get overlooked. I use the Canvas Learning Management System (LMS), which is provided by the university. It is a fantastic tool to share and deliver information and grades to my students. I creating the main assignment section worth a certain percentage of their grade and add all the sub-assignments in that section which include separate assignments for all of the documentation, models, and other requested files. I highly recommend breaking this up as students will have notifications of separate assignments due to help them plan their submissions and personal homework schedules.

3D Printer Recommendations

I have tried a variety of 3D printers and I have my favorites that I will share with you. There are a variety of ways to pay for them. I have used department budgets, Perkins Grants, and National Science Foundation Grants to help support equipment budgets. Reach out to your local experts in grant funding for ideas on where and how to apply.

As an instructor, if I needed some equipment, I would just go work with other professors and my department chairperson to apply for funding and help me learn the valuable tricks to navigating these types of programs. I am not a grant expert yet, but have learned that once funding is available, you have to list very specific details on your purchase request in order to get the equipment you want or need to acquire. If not, your purchasing agent will buy the cheapest thing they can find. Trust me, bottom of the barrel, cheap 3D printers are more than just a disappointment. Do some research online, watch some videos and learn the tips and tricks for your printer or you can you my recommendations. With any 3D printer, designing parts to be 3D printed needs to be a consideration as part features and printing orientation can affect your results and part strength. Here are the 3D printers I currently recommend.

Stratasys F370 ($$$$$$).

My personal favorite 3D printer. I do not have to mess with the print settings other than choosing material, infill, and support options. Most of the time I can just download the .STL file to the printer using the Grab CAD Print slicer that is also owned by Stratasys and press print. I do adjust the support material settings to reduce material consumption, usually by adjusting the raft settings to just print under the model only. This is a huge trick to saving material on this printer. Infill settings are available and simple to change. My favorite material to print with on this printer is PC-ABS which is a blended filament that I have found to meet most of the needs of my students for functional prototypes, tooling and fixtures.

ABS is my next favorite material on this printer but there are some others available that I also use. The most unique material I have printed with on this FDM printer is a flexible elastomer for unique applications. There is a huge assortment of FDM materials for this printer so make sure you get the printer and print heads that can use these materials. I have found not all materials are available for every printer so you will need to decide what applications you need before purchase. I absolutely love the solvent soluble support material which makes digging out the support material a breeze but does require a separate solvent tank made for the job.

The down side of this printer is that they are the most expensive FDM printer that I have used. I have upgraded to two Stratasys printers recently and try to only use them on prints that require soluble support structures because of filament costs. They are solid machines that I can expect the same consistent results on all year long. They have recently released a composite ready series that I will upgrade two when my F370 and F170 wear out. The filament is proprietary and has a chip in the spool case, so you do have to use their filament, which is on the pricey side. The upside of having a chip in the spool is the printer keeps track and updates the chip of how much material has been used on the spool and lets you know if you will run out during a print. I love the fast and easy auto material loading and calibration features. If you do not have a large budget to support this printer, I would consider the Bambu below.

Bambu Lab X1-Carbon Combo 3D Printer ($)

One of my students recently acquired one of these and was bragging to me about how fast and nice it was. He showed me some of the things he printed and I was intrigued. I had him email me some information and product links so I could check it out. There was some funding available in the department account and I had my department chair go ahead and order one for me that I could play with. This is now my affordable printer of choice and I highly recommend it. I will be writing a grant to get eight to ten of these printers soon to help support my courses as well as to support all of our Product Design and Development C.A.D. courses. Look them up online and check out the specifications and speed of these printers so you can add these details to your purchase request.

The only competition they have is the Voron 3D printers that are open source like Prusa. I didn't want to put my printer together so I opted for the Bambu. With the multi-filament automatic material system, LIDAR and AI integrated sensors this printer is fantastic. Check them out. There are tricks to getting the prints to stick to the bed, but just follow the instructions for the printer and you should be good to go. If you can print without support material, this printer is one of the fasted FDM printers on the market. If this printer had dual extruders so it could cut the support material changing cycle time, it would be that much better. The price is worth it. If I had to pick an affordable 3D printer, this would be my first choice. Two thumbs up from me.

Prusa i3 MK3S ($)

I have three of these printers and really like them. Prusa has been around a long time and has a great reputation. I ordered the MK3s with an upgraded enclosure so I could print with ABS. Since then Prusa has released the MK4 and preorders are available for the XL. Either of these printers would also be a good choice and I would pick them before the MK3.

If the printer only comes with one print head, like the MK3, you can only print with one material so in my case, I have to print any supports with the same model material and that can be difficult to remove in hard to reach areas. The MK4 is faster and the XL does have an option to add additional print heads so support material would be an option at that level. Keep in mind, the XL is still in the preorder stages so they are still working out the wiggles in the system. If you need large print volume, the XL might be a good choice for you. Once they are fully released, I will buy one or two XL printers for my lab.

Ultimaker S3 ($$$)

This printer gives me similar results as the others. I like this printer because it has a dual extruder so it can print with water soluble or breakaway support material. This printer comes with an enclosure. It is a higher priced printer but dual extruders are a huge time save. I have two of these and would recommend them.

Conclusion

I'll admit, this has been a challenging course correction but it has been worth it. Students are eager and come to class on time. Project based learning projects like this show the world that students are having fun using advanced tools and methods, and getting internship jobs in engineering as freshmen in my course which is another paper in and of itself. I have found that being authentic with your students breaks down barriers and gives them a permission slip to be creative. Give them the tools and permission to be creative and get out of their way. Let them explore but give them some time constraints. Objectives and deadlines get things done. A completed prototype is better than a perfect prototype as lessons are learned and revision improvements are made, just like in industry.

Using simple projects like this make a huge impact on inspiring students to play bigger games with bigger projects being value creators. I love to see my students who have graduated working on projects that they can't tell me anything about because of security and proprietary protocols. All I say to them is good work. Congratulations. Thank you for keeping me and my family safe, entertained, and traveling the world one way or another.

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