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CAM and Design for Manufacturing: A Project-Based Learning Course

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CAM and Design for Manufacturing: Developing a Project-Based Learning Course

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Abstract

To ensure students are capable and ready-to-engineer immediately upon graduation, mechanical engineering programs must teach students how to account for manufacturing considerations in design. Despite this, basic manufacturing knowledge is a hard skill consistently ranked as one of the greatest weaknesses of new mechanical engineering hires in surveys of industrial employers and project managers over the last few decades. Without radically changing curriculum to include more emphasis on design-build projects, one solution university departments could implement to combat this vulnerability is to incubate a lab course in which undergraduates would practice the principles of design for manufacturability (DFM). This paper details a plan for a project-based course conceived to accomplish exactly this while maintaining a realistic scope in terms of safety and available resources. This plan includes curriculum additions such as review of DFM case studies, a hands-on casting lab, and machining observation, although the majority of the course would be self-paced and taught through computer-aided manufacturing (CAM) software tutorials and computer projects. Avoiding the mistakes of past attempts to incorporate manufacturing topics into mechanical engineering education by instead narrowing the vision for the course to the practical context of enhancing students' design skills, the proposed content is targeted to directly benefit the senior design project experience and reconcile mechanical engineering curricula with the hiring need in the industry for engineers who understand common manufacturing processes and how to design for them. Using computer-aided manufacturing and other visual learning methods as a basis in which to root their understanding, students would master the ability to design for specific manufacturing processes representative of universal DFM principles and later apply that knowledge to deeply-involved manufacturing projects further in the course. By the end, students would complete a final project which would assess, qualitatively, their aptitude in designing for manufacture and understanding of the principles of multi-objective design.

Introduction

Though the teaching of engineering science is and should be the dominant basis of modern engineering education, it is a reality that curriculum evolved during the 20th century to marginalize the importance of engineering practice and key skills including design and teamwork. Resulting from a paradigm shift in the culture of American engineering colleges after World War II and the dwindling ranks of faculty members with experience as engineers, this revolution in engineering curriculum sought to prioritize hard science fundamentals in a profession becoming rapidly more diverse. As an unintended consequence, newly minted engineers, while graduating from college technically adept, began to lack many of the basic abilities needed in real-world engineering practice. Leaders in industry and government began to recognize this in the 1980s and 1990s [1] [2], and major employers, spearheaded by Boeing, made concerted efforts during this time to pressure universities into better equipping engineering students with skills codified as most valuable for career-readiness [3].

Tensions between industry needs and higher education came to a head in the mid-1990s when "American industry successfully lobbied the National Science Foundation to fund reform of education" and influenced the Accreditation Board for Engineering and Technology (ABET) to overhaul the basis for accreditation in 1996 with *Engineering Criteria 2000* (EC2000) [4]. Although EC2000 has been mostly successful in improving engineering education, the higher-level goals implemented by ABET, written in part by lobbyists outside academia, have likely not led to the fundamental changes hoped for; while the teamwork skills and ability of graduates to adapt to new realities has improved according to employers, problem-solving skills have reportedly experienced substantial decline [5]. This evidence, which suggests not enough is being done to teach students the practical skills needed to be an effective engineer, has led to the creation of supplementary educational frameworks such as the CDIO Initiative and INCOSE. Praised by some of the most prestigious engineering universities in the world, these frameworks have been sporadically adopted on the basis that, whether students become practicing engineers or not, "their background will be strengthened by setting their undergraduate experience in the context of the conception, design, implementation, and operation of systems and products" [4].

One of the most glaring deficiencies in contemporary mechanical engineering curricula is manufacturing education and, more specifically, design for manufacturability (DFM). DFM is interesting in the context of education because, while arguably the most important manufacturing topic for mechanical engineers to understand, it is also one of the most often neglected. In 2011 in fact, the American Society of Mechanical Engineers (ASME) Vision 2030 project identified manufacturing education as one of the greatest weaknesses of mechanical engineering hires as perceived by employers in the industry sector [6]. Commonly, undergraduates enter their senior project unaware of what a mill is, much less how to make practical, complete computer-aided engineering drawings for a machinist to create a part from. Engineers should know better than to design features in CAD models that do not serve a tangible purpose or specify features with non-standard dimensions, for example, but unfortunately, these are simple skills even many Ph.D.'s lack. Additionally, while 3D printing has grown to become a tremendous educational tool, systemic overreliance on additive manufacturing in student design projects further encourages bad design habits by neglecting to reinforce crucial DFM principles. Many mechanical engineering programs lack even a basic machine shop for students to use to produce their capstone projects, and this knowledge gap severely hinders many mechanical engineers early in their careers.

From a firm's perspective, these inadequacies in engineers entering the workforce often lead to deep-rooted inefficiencies when prototyping new mechanical devices if years are not spent to entirely train them. Otherwise, the result is frequently a trickle-down effect where many parts in an assembly experience budgetary overruns due to design philosophy ignorant of manufacturing requirements; multiplying the problem by every subcontractor where this occurs grows the problem astronomically to the point where technical deficits become prohibitive in the development of new mechanical engineering ventures. This is not a problem exclusive to any single industry either. The ability to draft while actively considering manufacturing constraints is a universally important engineering skill in all sorts of career paths including research, project management, product design, manufacturing, etc. When put in this context, an engineer's ability to understand manufacturing processes is just as important as their proficiency in CAD software in maximizing end quality and minimizing prototype time and cost. It is the responsibility of higher education to prepare students for the jobs they will face in their careers, and universities cannot claim to adequately prepare mechanical engineers for real-world jobs while neglecting to teach DFM principles.

Other initiatives to incorporate manufacturing topics into engineering curricula have often failed because they attempt to turn students into competent machinists when the support does not exist to facilitate it. Sometimes it is the inverse, and instructors will seek to develop students' expertise in selecting manufacturing processes but neglect to allocate any effort to teaching the skill of how to actually design parts for these processes. Indeed, it is typically not the role of a mechanical engineer to exercise either of these skills in the practice of their degree. It is clear that a new approach, better suited to the skills universally expected of mechanical engineers, is needed to train students whose resumes are marketable to potential employers.

To combat the pain point of manufacturing knowledge in engineering curricula, this paper proposes a plan for a new course focused on teaching DFM principles through CAM software and hands-on manufacturing experiences that, above all, preaches mechanical problem-solving skills key to professional success. This course is anticipated to act as a testing ground for new methods for teaching manufacturing concepts to mechanical engineers, and the focus of this paper is tailored towards illustrating how this idea would be practical to implement as an elective by laying out a plan to maximize existing resources, keeping up-front investment low. This blueprint couples manual machining with CAM, micromachining, and digital data processing [7]–[9] and will offer a potential first-iteration course structure that attempts to avoid the shortcomings of past attempts at curriculum reform with respect to manufacturing education. With a particular emphasis on metal processes, and students will receive proper instruction on how to make appropriate engineering drawings, anticipate work-holding and fabrication constraints early in the design process, and work with a variety of manufacturing methods through both observation and design-build projects.

Course

Many mechanical engineering schools already have some, if not most, of the resources needed to incubate a DFM course: desktop 3-axis CNC mills, sand casting equipment, a laser cutter, a machine shop, and instructors who would jump at the chance to teach a DFM course if it ever became a priority of the department. These are resources common to most well-funded mechanical engineering programs, hence this course would be a reasonable consideration as an elective at a large number of universities. Before beginning to plan the content for the class, the course instructor should conduct a review of resources at their institution to customize the blueprint to what is available. The suggestions given in this proposal should be considered for the value they bring to enhancing students' design skills; it should be left up to the instructor's discretion if they wish to substitute an aspect of the following blueprint in favor of a module that better suits the resources at their disposal while maintaining the same value added by the original.

Machine Shop Training

To complete their manufacturing projects, students will need to be trained on the rules of working in a machine shop, general safety precautions, and how to use tools important to the understanding of machining including band saws, files, taps, drill presses, calipers, and vices. Familiarity with the machine shop should be a prerequisite before lessons on manufacturability can happen because, too frequently, students enter their senior capstone project clueless when it comes to recognizing even many basic fabrication tools. Additionally, expectations for safe behavior, PPE, and supervision should be instilled early to maintain the integrity of working in a room full of hazards that could potentially maim or injure. Small group instruction is preferable to prevent overcrowding in the machine shop, and due to class size restrictions, a portion of the training may be better done via oral presentation in the classroom. The instructor should demonstrate the use of each tool the student will need over the duration of the course and what to be conscious of from a designer's point of view when creating features that require the use of these tools.

Manual Mill and Lathe Observation

Before instructing on how to use CAM software to teach DFM concepts, students must understand the functionality and limitations of the two cornerstones of subtractive manufacturing: the mill and the lathe. The best way to illustrate how these machines work is to manually demonstrate their usage, and for viewing purposes it is easier to show this on a manual machine rather than a CNC. Additionally, this gives the opportunity for students to grasp the differences between what can be accomplished on a manual machine versus a CNC. Degrees of freedom, travel limitations, cutter selection, work holding, multi-face operations, and machinist workflow includes some of the most important concepts an engineer must understand before beginning to optimize parts for machining, and there is no substitute for teaching these concepts other than showing them in action. Using only a piece of stock and an engineering drawing of a part requiring most if not all of the basic milling/turning operations, students can observe as the instructor explains each cut they make and the subtractive manufacturing process for making the desired part.

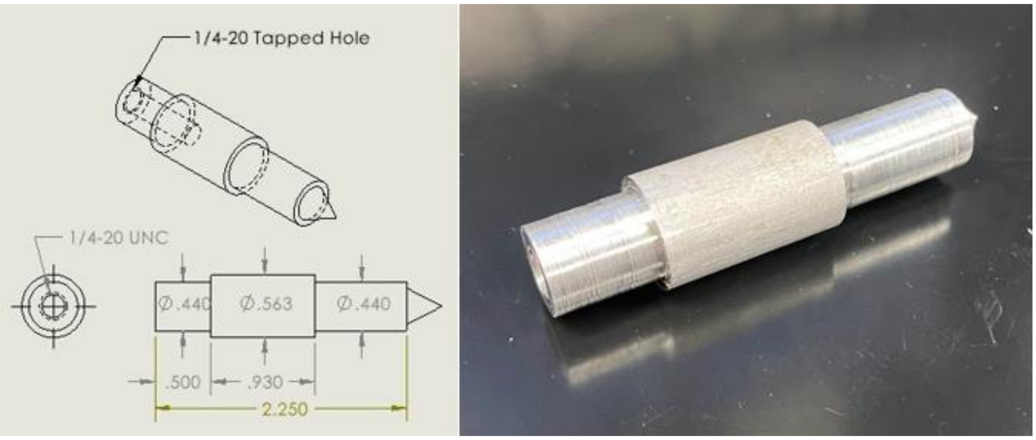

Figure 1. Example of a demo project which allows the instructor to demonstrate the basic operations of manual rotary machining including axial cuts, angle cuts, boring, and tapping.

It would be time-consuming to train each student on how to individually operate both a manual mill and lathe; proper certification would require closely supervised practice, a thorough understanding of machine components, and passing a “machining project” test to prove capable of manually performing the essential machining operations of each machine. Training students to be machinists is not the goal of this course, and in many cases, there is already an outside-of-class opportunity for students to become certified in using manual mills and lathes in the machine shop if they are motivated enough. Instead, the machining concepts for this class will be taught primarily through CAM software because the seamless integration with CAD and ability to interact with machining simulation make it a far better means for teaching the principles of DFM which is the focus of this course.

In-Class CAM Tutorials and Instructional Resources

While most mechanical engineering students will already be accustomed to using SolidWorks Student Edition, NX CAM, Autodesk Inventor, etc., and these software packages come with their own capable suite of CAM features, Fusion 360 is just as capable on a technical level but with certain advantageous features that make it the best choice for an educational setting. For one, Fusion 360 has far more developed tutorials and external learning resources. This is essential because a significant portion of the class should be self-paced as students are beginning to learn CAM. Fusion 360 is also favorable in that it is cloud-based software, meaning teams of students can work within the same file simultaneously for team projects and all users use the same version of the program, avoiding backward-compatibility issues prevalent in other CAM packages. Additionally, students should be able to acclimate to the Fusion 360 software quickly through in-class exercises since the vast majority of CAD features and workflow carry over from other 3D modeling software packages. The manufacturing interface is seamlessly integrated with the design interface as well such that all that is needed to switch between the two is to toggle.

It will be important for students to learn the workflow of taking a part from CAD model to completed manufacturing setup before endeavoring into more nuanced DFM concerns related to machining. Therefore, the first CAM exercise students should partake in is following along to an in-class exercise of creating a basic milling program. In this exercise, students will:

a) Apply CAD skills to create a 3D model for a part-stock-vise setup
b) Create a “machining setup” by defining cuttable areas and sequencing a series of simple machining operations to rough out and subsequently finish the part with a finer tool.
c) Run a successful simulation from start to finish in Fusion 360 and the post-processor provided by the CNC mill manufacturer to demonstrate the process they design is complete and error-free.

This follow-along exercise is a crash-course introduction to CAM software and will enable students to progress to more advanced topics easily. Beginners to computer-aided manufacturing are often surprised by how natural the integration is between CAD and CAM, and most start to become comfortable with the combined workflow after just a few hours in the software. Students can move on at their own pace to tutorials that teach how to use the more advanced machining operations available in Fusion 360 CAM and key milling concepts that must be accounted for in design like work holding, “3+2”-axis machining, end mill selection, etc. that will be applied in subsequent computer projects. The course instructor or TA should be available to answer questions during class while students are tasked with these tutorials.

There are a great number of Fusion 360 learning resources to assign to students which will bring them up-to-speed on how to use CAM:

- Fusion 360 offers short, free, online courses through the Autodesk website in milling and turning basics, including how to use the multi-axis capabilities available which are also free to education. This should be the first tool beginners turn to when learning the basic functions of Fusion 360. Since this resource is self-paced, it can serve as a quick, easy-to-access reference for students when they have a question about a particular machining operation they want to use.
- The Autodesk Knowledge Network offers six Fusion 360 learning pathways useful for the purposes of this course. Modules from these courses can be assigned via the back-end of the website at the instructor’s discretion through custom learning playlists. These include:
  - CAM for 2.5-axis milling
  - CAM for turning
  - CAM for 3-axis milling
  - CAM for multi-axis milling
  - CAD for mechanical design
  - Design for manufacturing
  - These pathways come with helpful instructor resources, self-paced courses with industry-aligned projects, and interactive course lessons which explicitly teach best practices for DFM. The CAM for 2.5-axis Milling and CAM for 3-axis Milling pathways in particular include projects inspired by real-world designs that challenge the student to come up with their own machining strategies that meet a final inspection report; these can be used as the template for future CAM computer projects in the course.
- NYC CNC is the leading free 3rd party website to learn CAM and how to operate CNC machines. Their YouTube channel offers some of the best learning tutorials and CNC project examples out there on the internet, and heavy inspiration for Fusion 360 computer projects can be taken by the instructor from the videos they have published.
- The Fusion 360 YouTube channel has a wide range of video tutorials ranging in expertise from intermediate to advanced. While not as organized as the resources mentioned above, it is a comprehensive place to look for answers to more advanced questions.
- The Fusion 360 community is a great resource to turn to as well for troubleshooting and demonstrating the use of Fusion 360’s capabilities. The quality of YouTube content varies greatly but can be quite excellent if properly vetted.

As they become more adept in using the CAM interface, the visual feedback from the software will force students to understand the limitations manufacturing techniques, specifically machining, impose on their designs. Toggling between CAD and CAM to develop processes that accomplish the production of the desired part effectively through trial and error establishes a firm basis for the concept of concurrent engineering. It is this interactive experience with machining, in a virtual environment where the student has the control to manufacture the part as if they were the machinist, that propels understanding of DFM principles.

CAM Computer Projects

The goal of CAM computer projects should be to push students to apply DFM principles early and often in the design process, forcing them to cope with the consequences if they do not properly analyze manufacturing considerations. If they design a part the “correct way” from a DFM perspective, students are rewarded with an easier model to create a machining plan for. Conversely, students will be forced to put in extra effort if DFM principles are ignored in their design, and they may have to revise their original drawing altogether. This project structure illustrates the implicit costs of poor design habits and encourages students to actively think about manufacturing constraints in CAD which is one of the key learning objectives of this course. Projects should take a few hours for each CAD drawing and respective CAM machining plan, and they should involve a fair degree of complexity for the stage in the course they are assigned (e.g., a part requiring multi-axis toolpaths to meet tolerances should only be assigned after those skills are taught through the tutorial resources in the class schedule).

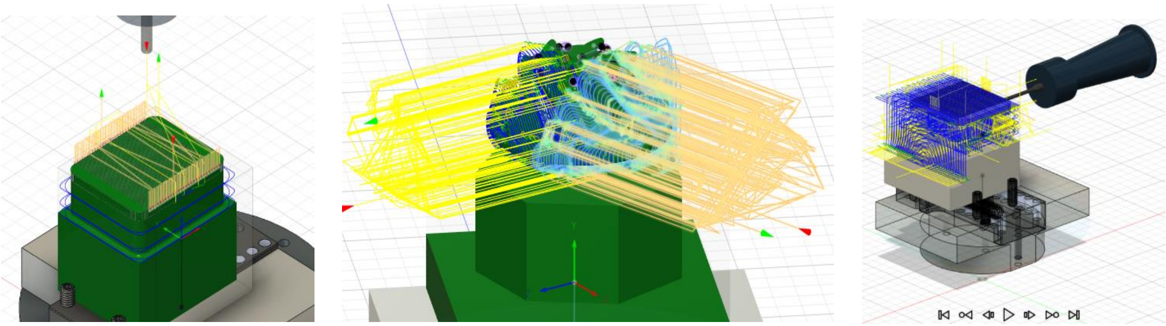

Figure 2. Fusion 360 CAM software simulating machining toolpaths for some example “3+2”-axis computer projects.

Some sample *design-manufacture* computer project ideas appropriate for this class are given below, categorized by the CAM skills applied:

- 2.5-Axis Milling Projects
    - Cylinder head
    - Gear
    - Sign-making
    - Gear Box Housing
- 3-Axis Milling Projects
    - Mudguard Mold
    - Simple Injection Mold
- “3+2”-Axis Milling & Work Holding Solution Project
    - Wheel Rim
    - Motorcycle Suspension Linkage
- CNC Lathe/Turning Project

    - Shafts
    - Fasteners
- Continuous 5-axis Milling Project (note most of the machining should be “3+2”-axis with some 5-axis finishing operations)
    - Intake Valve (5-axis pocketing, swarf, flow operations)
    - Impeller

<u>3D Printing and Sand-Casting Project</u>

While the proposed course primarily emphasizes machining, it would be keen to educate on other manufacturing methods mechanical engineers frequently have to design for. The most popular and, quite arguably, a most important manufacturing method in a large number of industries is casting. Many of the DFM principles for casting are similar to a host of other processes as well including injection molding, forging, extrusion, and powder metallurgy; hence, it would be sensible to include a casting project in this course. Although there are perhaps more than a dozen different casting techniques commonly used in industry and fabrication shops, the principles of designing parts for casting remain mostly the same across each. Sand casting is the most obvious candidate for educational purposes by virtue of it being highly accessible to learn and use. The resources for performing sand casting are inexpensive too, so in most situations, it would simply be a matter of dedicating the facility time, and space needed for a class project this ambitious. Limitations on facility space could be approached by splitting a class into smaller sections.

Figure 3. Physical teaching aid demonstrating the concept of a draft angle (left) and no-bake casting method after an aluminum casting is completed (right) [10].

Using 3D printers to rapidly produce the patterns for the molds, student teams would design a part in CAD to meet a given purpose and set of specifications (e.g., a wall hook meant to hold two 20-pound weights), consider the parameters of the sand-casting technique, and carefully plan and document the positioning of the sprue, runner, and risers as well as the parting line separating the two halves of the mold. The no-bake method of casting is recommended for the purposes of this lab since it incorporates many of the same design principles as a permanent mold. Students will have to design the part they cast so that it will eject well from the mold, forcing them to carefully consider the part geometry and incorporate a draft angle on affected contours. Wax or specialized casting polymers could be used in place of molten metal to improve student safety and reduce initial costs if the price of furnaces is prohibitive. Implementing a casting lab would also allow students to personally examine what causes defects in casted parts and afford the perfect opportunity for a lesson in understanding surface finish with post-processing methods such as filing, sandblasting, secondary machining, and sanding.

DFM/DFA Case Studies

A course like this is the perfect place to contrast case studies of how to and how not to “correctly” approach designing a part or assembly. For students to distinguish their skillset as a designer to employers, they must be able to prove they can effectively minimize the cost and production time of their designs. The ultimate objective of this course is to motivate students to adopt habits for designing parts for manufacturability, and to do that it is necessary to highlight why DFM skills are important through cost analysis and examples of real projects.

Drawings of poor DFM scenarios with notes for how to improve are readily available in many texts dedicated to the subject of design for manufacturing, but while these may be useful as complementary materials to illustrate technical concepts taught throughout the course, dedicating a portion of lecture time to real-world examples would be beneficial in its own right. Because their real-world relevance would drive home the importance of DFM skills and extend to design for assembly (DFA), there would be plenty of benefit to introducing case studies that examine these topics. Generally speaking, products that have been successfully mass-produced for a long time or are commonly used as components in mass production are shining examples in DFM. Some excellent examples include flat-packed furniture, injection molds, and engine blocks, of which schematics are readily available to teach with and call out design choices that have helped to reduce manufacturing costs. The best real-world examples often have interdependencies with other components because effective solutions must usually embody the design philosophy of concurrent engineering which is critical in an engineer’s repertoire.

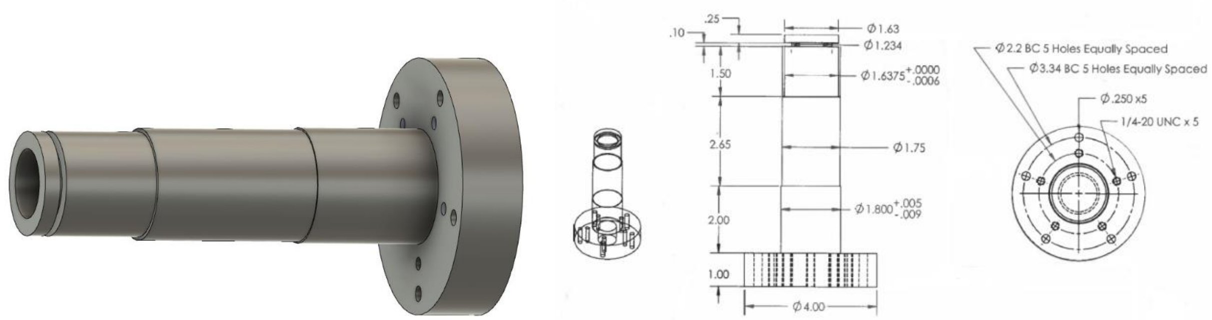

Figure 4. Example of a shaft housing designed by a mechanical engineering senior design team for a linear actuator. This would be much more practical to machine if it were machined as two parts instead and then either welded or press-fit together.

History is full of infamous, expensive engineering projects that flopped due to engineers failing to account for manufacturing as a result of gross design complexity. Cases such as NASA’s failed X-33, in which the fuel tank required an extraordinary amount of support structure due to its multi-lobed shape [11], and the Space Shuttle, which required each of the 35,000 thermal protection tiles to be individually inspected and manufactured specifically for a unique spot on the shuttle [12], are great examples of design decisions in aerospace that caused excessive cost overruns which eventually contributed to project termination. Failed NASA projects are easy to point to because of the complexity that easily takes hold when developing a new space vehicle, but there are plenty of other infamous cases (consumer goods, toys, medical devices, etc.) in which a product failed because of high manufacturing complexity.

Tapping into past capstone design projects is another thoughtful approach and perhaps the best way to get students invested in DFM concepts since senior design is something they will also have to take on during college. These types of case studies are ripe with examples of DFM mistakes both glaring and subtle and make perfect examples to share in class because the capstone project course instructor will already have the part and assembly files available to share. Senior design projects will also help ground the discussion in real-world anecdotes and cost analysis while at the same time being easy to understand since none of the engineering was designed to be proprietary. Taking Figure 4, a housing for a lead screw, as an example, a part of this size would typically need to be machined from a rectangular block of aluminum at least 7.5”x4”x4” in size on a conventional CNC machine. As such, this would result in a tremendous amount of material to going to waste as chips, extremely lengthy man-hours, high cost per part, and possible surface defects on the central hole on account of chatter. It is still possible to machine the part, but especially if these were to be produced in a high quantity, it would be far faster and cheaper to design it as two parts (the base and the stepped shaft) and then join them with either a weld or temperature press-fit depending on the forces present in the application. Many machinists who specialize in supporting senior capstone would likely be willing to volunteer some of their time as guest speakers to talk about examples like this they regularly come across. It makes their job exponentially harder than it needs to be when a student team comes to them with a part that could be made much more practical with just a few simple, non-invasive changes to the design.

CNC Milling Project

As an extension of one of the computer projects assigned during the course, students will form teams to physically machine a given two-sided aluminum milling project on 3-axis desktop CNC routers. These desktop machines are ideal from a safety perspective because, using no bigger than a 1/8” end mill, little more damage could be done if something were to go wrong other than breaking a tool or ruining the part. Nonetheless, because for most students this will likely be their first time operating a CNC, this lab in particular will need to be taught under close supervision. Toolpaths and milling simulations will need to be manually inspected by the instructor or TA before proceeding with any cutting.

To reiterate, it is not the goal of this course to teach students to be machinists, but a predominantly virtual manufacturing class would be missing a key component if it did not try to educate on how a CNC milling machine works. While utilizing CAM software to facilitate a visually interactive learning environment is an effective means of illustrating to students how to design a part that is feasible for particular manufacturing processes, the reality is that CAM software alone is not representative of a number of practical considerations that must be accounted for in the design of a machined part. This project will give students the chance to actually interact with a CNC mill rather than working exclusively with simulations, providing hands-on experience with many of the topics discussed in class but not put into practice outside of this lab. It will be an opportunity to work within real-world constraints like machine travel limits, work holding, standard stock sizes, chatter, and surface finish which serve as valuable experience to refer back to when considering how future design projects will be affected by the factors a machinist must inevitably cope with. Many of these topics can be covered through lecture, but implementing these ideas in a lab is the preferred method because students may learn through mistakes that cause their part not to turn out perfect. Whether the future projects students go to develop are intended for mass production or not, this lab will act as an excellent basis for judgment calls on making a part cost-effective to manufacture. Students should also be able to demonstrate they can tap a hole, deburr a part, file sharp edges, and put dimensioning and tolerances into practice; in this regard, a CNC machining lab would be a great opportunity for abbreviated machine shop experience through post-processing.

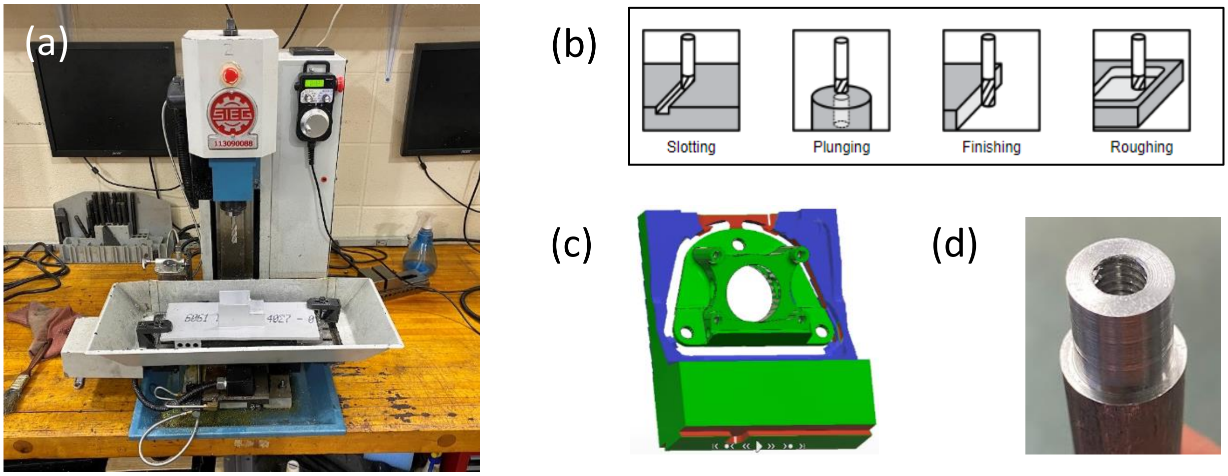

Figure 5. (a) Example of a 3-axis CNC desktop router in the $3,000-$5,000 range which would be suitable for a supplementary machining lab, (b) examples of operations that could be required to be incorporated into the machined part, (c) an example of 3-axis work holding that might be developed by a student, and (d) manual drill and tap operation done manually and post-process.

“Design and Set up for Manufacture” Final Project

A multi-week, outside-of-class project intended to assess cumulative DFM skills at the end of the course should be considered in place of a pencil-and-paper final exam. For this final project, there are several options that could be adopted, but students should be able to draw a CAD part to meet a given set of design requirements, plan a work holding arrangement, and create an appropriate machining strategy that completely and effectively machines the part in a reasonable amount of time. An example of how a project such as this might be structured is given below:

> The instructor assigns a CAD part, such as a wall hook or a shaft, that is supposed to accomplish a particular engineering objective under a load but has DFM issues associated with it. Students must redesign the part while preserving functionality to be suitable for both mass-production CNC machining and another manufacturing method dictated by the instructor (such as casting). It must be tested for failure at a specified load via finite

element analysis and then simulated for safe, error-free production in Fusion 360 with a limit on maximum total machining time. Afterward, the student will write a short report including a cost analysis of before and after the redesign.

This example would integrate CAD, CAE, and CAM into a single project. As a result, the student would need to consider multiple objectives during design: purpose, external loading, and manufacturing considerations. This exercise in concurrent engineering would serve to check overall computer-aided engineering competency in addition to allowing the instructor to assess DFM skills in the context of a practical application. Additionally, having the student perform a cost analysis will ensure they understand the implicit benefits of incorporating DFM principles early in the design process.

Placing the design and grading of this final project in the context of the larger course, the desired outcome should be qualitative and quantitative indicators of the ability of students to design practically and with the aptitude to consider multiple objectives early in the design process. If the final project is designed correctly and the course well-realized, these attributes should reveal discernable improvement when examining the grades and overall quality of the work turned in. In this regard, a pre-test at the beginning of the course might be considered to help the instructor gather feedback. The success of this course module will also likely be evident by judging the students' senior design project experience and whether students who take the course show substantial improvement in the outcomes of that course of the likes of their peers in prior years.

Overcoming Obstacles to Curriculum Reform

"While some believe a real revolution in engineering education is necessary, it is our opinion that it can be a peaceful one." – John McMasters

The driving force that motivated ABET to make sweeping changes to the accreditation standards that over 890 institutions now abide by is just as valid today as it was 25 years ago: industry and government alike value engineers who understand the complete problem before jumping to a solution. Engineering curriculum is largely dissociated from that skill, however, and it is ultimately students who suffer for it. Truer now than it was then, students and employers alike are the customers of colleges, and amid climbing tuition rates and public scrutiny of the value of a degree, project-based learning and other strategies structured towards more practical side of engineering offer a solution that statistically prevents students from dropping out [13]. Additionally, to boost quantifiable alumni success, differentiate curriculum quality, and foster stronger hiring relationships within industry, engineering programs must adopt initiatives that prioritize aspects of concurrent engineering such as DFM, strengthening the value proposition of the degrees they offer and talent pool available to them.

It is frequently an uphill battle to gain faculty support where it does not already exist for teaching topics tied to practical design. Most of the motivated experience to teach manufacturing-related classes is in industry, and the prevailing attitude amongst university faculty seems to be that design is a niche branch of mechanical engineering that is not justified in being a point of teaching emphasis despite decades of statistical and anecdotal evidence to the contrary. This is why, if a shift towards concurrent engineering education is to be implemented, it is necessary to influence these perceptions with what curriculum reform can contribute to the program's goals.

To generate genuine faculty interest in adopting a DFM course or offering a manufacturing degree concentration on the department/college level, a proposal must offer incentives for the college and require a low initial investment. Funding has to be of concern to educational decision-makers when considering the implementation of a new program, and, historically, the cost has been the main factor prohibiting curriculum changes that have to potential to benefit students from being realized. A proposal for a supplemental course will need to maximize existing resources to have the best chance of success. Additionally, securing faculty support is paramount; contextualizing a manufacturing course to teach skills that are universally useful to engineers, such as DFM, will go a long way towards meeting this end. A faculty member with the will and expertise to implement a DFM course on their own accord is another factor that will make or break an attempt to launch the blueprint contained in this paper.

If a technical elective can be successfully incubated and demonstrate substantial improvements in students' engineering competency after taking the class, then a solid case could be made to expand that course to be part of the curriculum. Additionally, there is potential that a successful DFM course would be modeled after by other universities, and in the end, there might be a substantial, outsized impact by early adopters on the broader engineering education scene.

Conclusion

Likely only a small percentage of students will go on to spend their careers as CAD designers, and indeed most will go on to achieve much bigger aspirations. Despite this, the ability to quickly understand and predict pain points of manufacturing and assembly is a fundamental expectation of mechanical engineers critical in ensuring the smooth development of engineering ventures. DFM skills cannot be neglected if higher education is to adequately prepare engineers for the real world. Allowing students to learn interactively with CAM and gain hands-on manufacturing experience would reinforce key skills for designing for manufacturability and promote a design mindset conscientious of manufacturing costs and time which managers and employers value. The goal of any proposed engineering curriculum addition should be, in some way, to better prepare students to be ready to engineer immediately upon graduation. This proposal outlines a plan to accomplish exactly that by reconciling with the need in the industry for engineers who understand common manufacturing processes and how to design for them. Whether a student goes on to become a researcher, practicing engineer, project manager, independent consultant, or engineering entrepreneur, their background will be strengthened by an understanding of manufacturability considerations and systems engineering. For this reason, a course with a vision to teach a fundamental understanding of how to adapt design philosophy to manufacturing processes, both common and unknown, would universally enhance mechanical engineering education.

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