Strategies for Contemporary CNC Machining Curriculum

Introduction

A Community College serves two customers when it comes to industrial trades development. One is the student who must graduate from a program demonstrating skills deemed useful to industry. The second is the industrial community needing a gateway to introduce newer capabilities. In that manner graduates find their skills employable, and their employers deploy newer capabilities with these hires.

The one constant in manufacturing is that the cost to produce a product continually goes up as supply and utility costs rise. Since customers never like a price increase, manufacturers are pressured to improve or cut their margins. The latter is a last measure leading to collapse; it cuts profit and capital needed to improve. New techniques and tools in design and manufacture are more sustainable at keeping cost increases in check.

When the manufacturer hires a student, they should be hiring a person with the capability to implement a needed upgrade. That in turns helps support the decision to investment to make changes. Buying a new machine alone does not achieve the performance. Knowledge of how to use it with to reasonable performance goals is also needed. A local college whose students can demonstrate capabilities through "newer" equipment and techniques are a community's industry and business development expectation. "Newer" may not be the newest in global industry, newer is more advanced than the average local industry. When colleges demonstrate capability, the manufacturers may exercise it to greater capacity.

Students in CNC machining must have guided practice time on machines. Some of those machines need to be newer, and meet or exceed the capability of local manufacturers, employers. The key machining elements to learn are Safety, Quality, Precision, and Speed (time to make parts). Those are always cost reducing. These should be practiced with newer technology, as competition elsewhere can reset the bar. Colleges need to stay current.

"Production" vs "Job-Shop" Machining:

Business communities like those in Lane County are in a transition period. This is always true. "Production" businesses, those that produce hundreds or thousands of the identical item, have been switching from manual machines, or older numerical control machines (NC), to production using more current computer-controlled machines. Newer machines with their newer computers and software can produce more complex parts, parts that can improve the products by design or reduce the manufacturing costs. Older machines either do not have computers, or have computers with less capability to run large programs.

A "Job Shop" activity is typically when only one or a few exact copies of an item are needed, a short run. These shops are typically custom houses in various industries from mechanical repair, welding, to art. If a machinist is only making one simple item, it is less beneficial to program tool paths and then run a machine. Manual machining with a skilled machinist can produce high quality parts. That will continue to be a useful trade skill. But quality, precision, and speed are dependent on the machinist. Making thousands of an identical item changes the scope, and manual machining becomes cost-prohibitive.

A computer numeric control (CNC) machine is program controlled, which increases the speed, safety, quality and precision of producing the same part. Computers, software, and machines advance technically, and the result is machines can reliably and repeatedly run longer and more complex programs. CNC provides opportunities to cut cost in production of a given part. CNC also provides opportunities to improve a product by design. Parts that are more complex to machine provide designers options for product performance and achieve industrial design goals. Program control in the production environment was and continues to be a huge evolutionary step.

Since CNC machines are operated by a program turning the screws, not a machinist turning the control wheels, they are friendlier to safety. The machinist can keep more distance. The CNC Industry has been moving to closed door operations, that is a machine enclosed in a cabinet with doors closed while cutting. Machines will not cut unless doors are closed. This is a huge industry cost savings. Liability, safety, is determined by the severity of the hazard. It is mitigated by the frequently an operator is exposed to that hazard. For a "shop" operation, the liability is lowered by the infrequency of machine use. Production operations are continuous, closed-door operations mitigate the exposure.

Safety is further mitigated with training for machinists, operator/programmers. A closed-door operation reduces liability, it does not eliminate it. An industrial CNC machine can be described as a machine whose "spindle assembly weights more than the operator, and moves with cat-like reflexes". There is a clear preference for students/employees with certifications that cover safe operation.

A true "Production" machining operation is pressured to update technically. Perhaps not every day for a given company, but once in a decade could prove useful. If they do not update, they are giving an advantage to their competition who will.

> *With the current advent of Industry 4.0, a suite of machines can be programmed to function "cooperatively" for "lights-out" operations or normal operations with operators as a part of the system. Stock, for example, can be moved between machines by robot; parts measured for quality; and, production may be re-routed or halted if a particular machine in the suite is operating out of spec. What makes Industry 4.0 better than Industry 3.0? It is evaluation by the same criteria as Industry 3.0 over 2.0; improved Quality, Safety, Precision, and Speed.*

The criteria for improvement in Industry sets a performance bar for trade skills education. CNC Graduates should know the keys to performance improvement, and have practiced machining to newer technology capabilities. The better the students the better the industrial community.

Industrial Community Needs of Local Colleges

In many cases local manufacturers are using manual and older numerical machines for production. That is no surprise, and any real community will lag the latest available technology. The costs to change should be evaluated. Manual machines, if used frequently or continuously, need to be upgraded.

Upgrades are not always the answer. For example, if an older numerical machine is reliable and paid for; and, the product is an unchanging standard (like a nut or bolt), then cost might favor no change. A new machine may be needed if capacities exceed the older machine. If new parts are often in the mix, or if part designs change each production year, then cost favors the upgrade.

It should be obvious that production businesses are less interested in backing education of skills that have been in practice for a half-century or more. The unfortunate “switch to service industry” focus of the latter 20th century did lose a lot of domestic manufacturing skills, businesses closed and past generations retired with their skills. There remains a need to re-learn in that skills vacuum. The big “re-learn” to manufacture needs to be to a currently competitive level. Production businesses are aware of that. If not, clients of those businesses are, because the evidence is the bottom line. It follows then that local industry wants local institutions to help them stay competitive. To serve that need is a college that builds the combination programming and machining skills, or “NERD” machinists (Numeric Electronic, Robotic and still Dangerous). There is a lot of interest in employing to Industry 3.0 and Industry 4.0 capability, students in CNC.

Upgrading a business requires three things. One is INVESTMENT, to cover the cost of capital expenditures. The second is SKILL BASE, possessing the skills to operate and program the new equipment. The third, more of a dilemma, is EXPECTATION. Does a given business know what gains can be expected by an upgrade? The latter two need to be quantified and supported by a business plan in order to secure investment, answering risks versus benefits for expenditures. A business cannot demonstrate a capability it does not have, and a college can do so as an independent interest (not the sales team marketing the machine). College graduates should provide the Skill Base pollination, and College labs should demonstrate the newer Expectations.

Improving any production process benefits from improving Speed, Quality, Safety and Precision. The SPEED lowers time to make a part, machine and operator time is cost. Quality reduces the number of Out-of-spec parts, waste, which costs both time to produce and the raw stock used. Safety counters costs in insurance and post-accident down time. Precision may be considered a form of Quality; however, it separated here as machine and operator capability rather than a part-outcome. Precision eases Quality concerns, it the ability to cut within a given tolerance range as insurance against being out-of-spec. Precision and speed can improve simultaneously with improved skill, machinery, and tooling. Speed, Quality, Safety and Precision are control features of total production cost.

Curriculum

Speed, Quality, Safety, and Precision are the key goals for students in a machining trade skill. In a current CNC curriculum, they do this in practice, practice, and more practice. They start operating and then programming 2 and 3 axis machines to 5 axis Mills and Lathes with complex tool turrets and tailstocks. While they advance, they also learn to verify parts by measurement, and then use measurement to reverse engineer and recreate a part. Precision is important, as the level of precision they can execute tends to be inversely proportional to the money they can earn.

Lane Community College offers a CNC 101 course as a stand-alone, single term course for CNC Operators. They learn the safety, use, maintenance of CNC Lathes and Mills. During the course they can get industry certified as machine operators. This one course can help businesses upgrade, but it is also an introduction or gateway to the College’s two-year program. Once students and their employers are exposed to the CNC in operation, it develops their expectation of what can be.

Current CNC Machining and Inspection Program

Course List

CNC 111	Introduction to CNC Operator	3
CNC 111L	Lab for Introduction to CNC Operator	2
CNC 112	Introduction to 3D Modeling for Machinists	3
CNC 112L	Lab for Introduction to 3D Modeling for Machinists	1
CNC 113	Introduction to Production Inspection	3
CNC 113L	Lab for Introduction to production inspection	1
CNC 121	Basic CNC Lathe/Mill Operation and production	3
CNC 121L	Lab for Basic CNC Lathe/Mill Operation and Production	2
CNC 122	Introduction to CAM Toolpaths	3
CNC 122L	Lab for Introduction to CAM Toolpaths	1
CNC 123	Inspection 2	3
CNC 123L	Lab for Inspection 2	1
CNC 131	Basic CNC lathe/Mill Projects	3
CNC 131L	Lab for Basic CNC lathe/Mill Projects	2
CNC 132	CAD/CAM CNC Lathe/Mill Projects	3
CNC 132L	Lab for CAD/CAM CNC Lathe/Mill Projects	1
CNC 133	Inspection 3	3
CNC 133L	Lab for Inspection 3	1

A Short Description of LCCs Two-Year Program

From the first course and labs, students are spending hours operating machines, producing parts they can include in their resume. There is no substitute for hands-on experience. A good CNC resume includes a variety of parts that the student has machined. That resume will include articles machined in different materials, and students will learn the differences.

They advance in machining from basic CNC 3 axis mills to more complex (5 axis) mills and lathes. Learning to CNC machine, involves programming and machining combined in advancing steps. Gradually the machining, programming and fixturing get more complex. For example, the first mill they use will be a 3-axis machine, and they will advance to 5 axis machining centers.

Students are also introduced to CAD and 3D printing in CNC 111. To 3D print a student's designs, using Computer Aided Design (CAD) software, and converts the CAD model to G-code using a slicer program. A "G-code" is a machine program that contains tool paths; it is utilized by 3D printers, and CNC Machining centers (mills and lathes). It is unlikely a student will ever write more than a simple G-code program, but knowing the syntax will help to navigate and modify. The G-code programs will be primarily written by Computer Aided Manufacturing (CAM) software, and those programs can be thousands of lines long.

A student's ability to evaluate their own work is tied to their ability to measure and inspect. Those skills advance too, from calipers and micrometers to gages and eventually a Coordinate Measuring Machine (CMM). The later typically measures with accuracies less than 1/10,000 of an inch. That level of performance is consistent with machining to support cutting edge research programs.

Strategy and Skills Commons.

A CNC Machinist needs to be familiar with the CNC Machines, tools and fixturing. The knowledge helps them to program the machines, to generate the G-code. Then they need to know how programs can be tailored for performance's sake. Programming approaches vary the tool-life, precision, speed, and quality of the resulting articles. Programming is the heart of CNC Machining. Unfortunately, the machines, tooling and fixtures are pricy items for colleges. The programs are much easier to acquire and a program's produce CAD and CAM files are easy to share and modify to support varied curriculums and industries.

CAD and CAM (or CAD/CAM) files are the intellectual output for the Oregon SCC Grant Consortium Project that can be shared via the Skills Commons website. Ideally that would result in a library of exercises, or examples, available to instructors. The CAD/CAM files are "native" files, created with the tools built into their host program. A host program could be Dassault Systemes' SolidWorks, AutoDesk's Inventor, PTC's OnShape, or AutoDesk's Fusion360. Each of these programs somewhat differing tools that may be applied differently for a given design outcome. It takes a couple of steps to produce a helical curve in Fusion 360, but there is one tool for that purpose in either Inventor or SolidWorks.

In the CNC Lab at LCC the primary program used is AutoDesk's Fusion 360. This program is generally free to educators, a smart plan by AutoDesk. The program can be used for a fair amount of engineering work on a few parts, a small assembly. Engineers, more than machinists, may be designing larger assemblies, a task which is better suited for AutoDesk's Inventor. A CNC Machinist needs to focus on the one ""principal"" part they are machining, and may consider and make parts that mate to that principal. At times an assembly, or could get the assembly or project delivered to them from a teacher, or client.

The Fusion 360 program allows the user to change language and functionality preferences. It has pop-up balloons to explain each tool in its menus; and, it tabs over quickly between CAD and CAM. It is a particularly useful program in a CNC Machining lab. The files created contain the CAD and CAM information which can be shared between institutions.

CAD skills do transfer from one program to another, the learning curve from Fusion 360 to SolidWorks or Inventor or OnShape is smaller than learning any one CAD program from scratch. 2D sketches are drawn and used to create solid objects in 3D space, those objects are modified by various tools, cuts, chamfers, fillets, and so on. Opening the door to CAD in one program, opens the door to CAD.

Sharing a "native" CAD file with a user using the same host program, also provides the history of how the model was created step by step. In transferring a finished part in a STEP or IGES or STL format sends the finished 3D model without the design steps used to build it. Access to those design steps is of particular value to educators, to see what was done and modify it for class purposes.

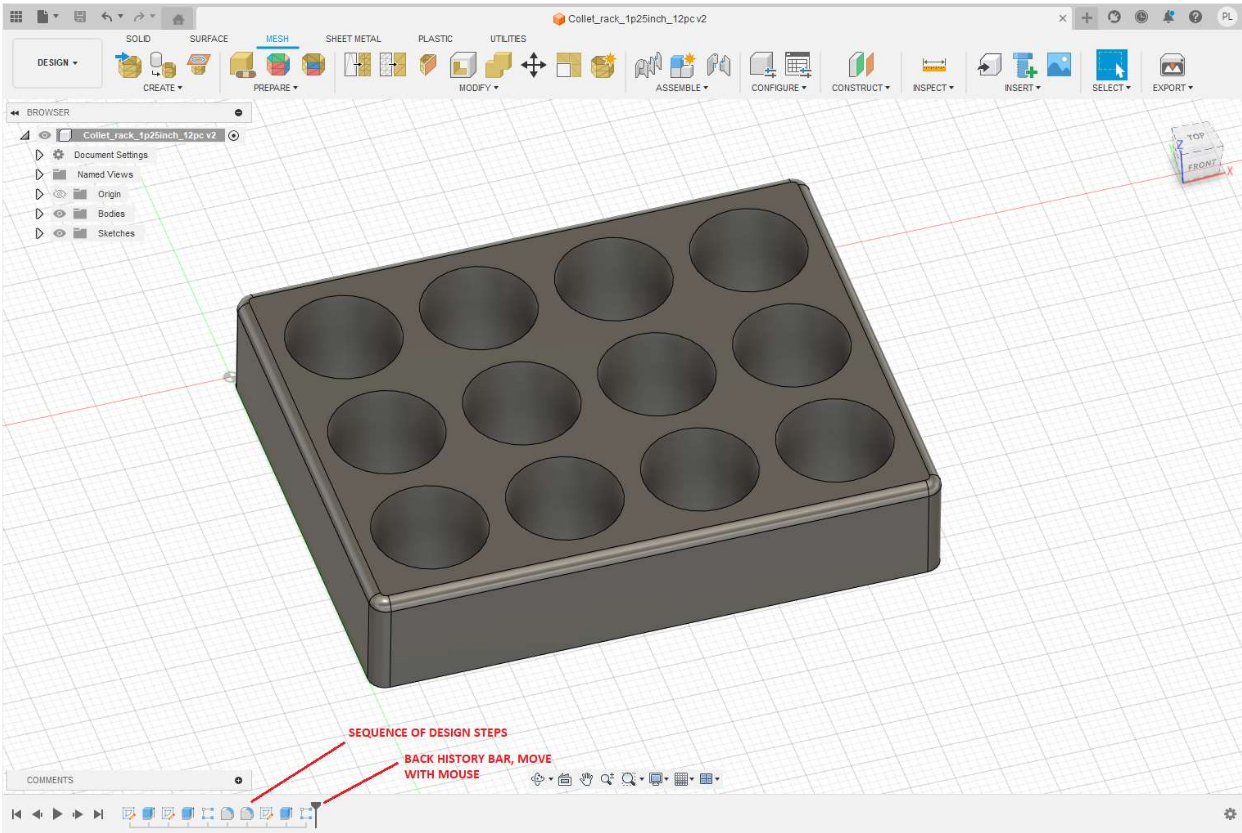
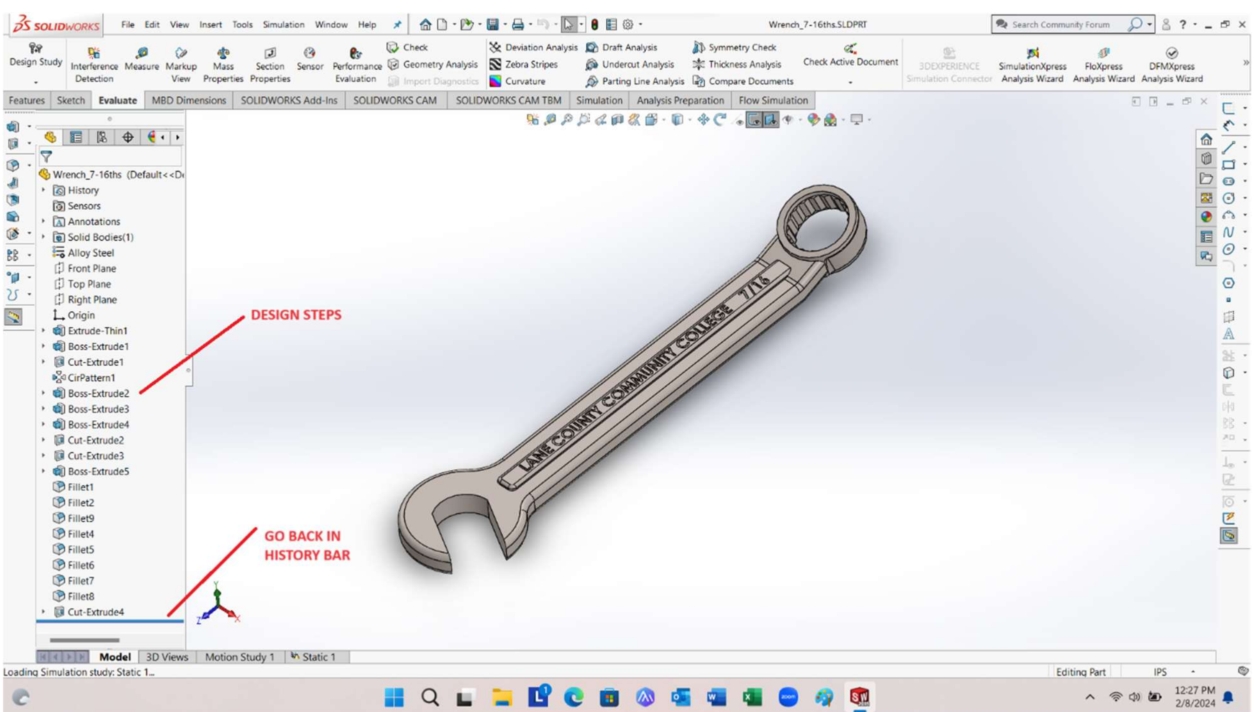


FIGURE 1: DESIGN HISTORY ACCESS, FUSION 360 (COLLET HOLDER)

FIGURE 2: DESIGN HISTORY ACCESS, SOLIDWORKS (WRENCH)



In the figures, 1 and 2, there is a "back in history" bar. SolidWorks and Fusion 360 differ in the layout, but both have this bar. If clicked on with a mouse it can be pulled backwards in the history, revealing how the model was designed step by step. Anyone can see and modify the sketches and CAD tool parameters. The design history is the creation of the designer work and not the program. Since files are typically shared in a transfer format, this work product is not available. When shared in native format on Skills Commons, it is available.

The down side to any software company provided learning videos is the "NPR Car Talk" type obfuscation that comes with promoting the capability. The company selling the CAD program wants to educate its users, but it also needs to market the program's capability. For example, a number of Fusion 360's self-learning videos demonstrate various CAD tools within the context of a complex reciprocating saw assembly. Such an assembly shows the capability of the program, but the complexity to a beginning CAD student is not necessary. The practical need for educators is to have examples that keep it simple (KISS). By Introducing the use of CAD tools on simpler, more recognizable parts, the focus is back on the CAD tool. Let the complexity develop over time and experience.

The value of Skills Commons is to share materials in support of learning. In that light the key submissions for CNC Machining are the CAD and CAD+CAM files that can be shared. Each file is supported by a PowerPoint presentation walking through the development steps. In most cases those steps are saved in the development timeline built into the program. The timelines allow a designer to go back and change an earlier step (like a sketch) and have the change carry through the timeline. An instructor can download the PowerPoint and CAD files from the Skills Commons site and modify them as desired. They were created under the Oregon SCC Grant Symposium Project for the purpose of sharing, license free.

The intent is to have a series of examples that demonstrate all the CAD programs tools, and how to the CAM program. A number of CAD program features are less valuable in a CNC lab, but would be more useful in other industries. A student who wants to gets certified via an AutoDesk exam, would need to be familiar with using all of the tools. For example. the program does have some free-form or direct design features. Please remember to never evoke "free-form" in a production machining environment. The term does appropriately apply in art and industrial design industries.

The CAD-CAM files are more about taking a CAD model and creating the cutting program. They have the type of machining identified, tools selected, stock sized, and origin positioned. The user can run a machining simulation to verify what the program does. The associated Power Point will cover the assumptions on how the stock is held (typically vise), and other particulars not necessarily in the file. The files will need the user to identify the maker/model of the specific machine to use, in order to "post" the G-code program. Again, the models are simple to focus on program tools. They can be modified on both CAD and CAM sides by whomever downloads them.

All submissions can be used independently. There is a set of early CAD examples for designing a Hasp, but these can be downloaded and used independently. The third and last of the set contains the timeline for the prior two.

All examples or exercises are loosely assigned a period within a class when they might APPLY: Beginning, Middle, or End of a term. That is just suggested for CNC Lab use. Generally, a "BEG" is introductory, like making sketches and extruding shapes. A “MID” level exercise assumes some prior experience with the program, and would cover using “construction” planes and lines. An “END” is for completeness. An END exercise is for tools that are not particularly useful to a CNC Lab, but could be a question on an AutoDesk Certification exam; such as direct modeling (no timeline), working in free form (surfaces), or converting STL files to solid models. An art class for example may see the free form tools as an earlier lesson.

CAD and CAM are useful across multiple industries; Production (CNC) Machining, Engineering, Architecture, Industrial Design and Art. The “BEG”, “MID”, and “END” is loosely assigned for a machining. For art, the priority could be different, and free-form modeling may be an earlier topic.

Summary

Programming CNC machines reduces the total productions costs associated with safety, quality, speed(time), and precision. Newer machines and programs can execute more advanced part designs, which yields other desired benefits in product cost and performance. Some of the machines in the College CNC lab need to be newer, like 5 axis programs on Mills and Y axis with live tooling on CNC lathes. Not every machine needs to be the newest, most capable. Older CNC machines, if not worn out, are certainly good for first year students to program and make parts. If a lab operates two students per machine, the number of machines determines lab size.

Advanced technology implies the best current performance, especially in costs of production. A community college should provide training in these advanced skills. Students must have plenty of practice machine time on varieties of parts and materials. A student that hasn’t compiled machine time will find certifications difficult. A student with a machine time attracts employers. Between the college’s machines and students, employers looking to improve (every employer) will see the practicalities of their path forward. The student evolves and their community evolves.

What helps colleges then are a library of parts to learn to design and produce. The CAD and CAM file submissions are a start. The larger the instructor’s pallet of example, the better. This is a call to other college programs to submit similar examples, with CAD/CAM files native to the software they use.

Oregon SCC Grant Consortium Project

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