Teaching Engineering Students Manufacturing Through the Use of an Integrated CAD/CAM Workflow

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ABSTRACT

Traditional engineering curriculums place a premium on education related to design and analysis. Often, this leads to little or no formal education related to manufacturing. However, as manufacturing is becoming more technologically advanced, engineers must develop an awareness of the ever changing capabilities available to them as designers. Therefore, to become better-rounded, it is crucial that engineers gain familiarity with manufacturing. This paper explores how CAD/CAM technology is being used at Purdue University's Artisan and Fabrication Laboratory to foster manufacturing experience through hands-on learning opportunities. Specifically, it describes the development and implementation of an integrated CAD/CAM workflow that allows students to obtain experiential learning while building on their design knowledge. This approach was built on a CATIA v5 architecture, and features a custom user environment, tool and process catalogs, and machine simulation. Further, the implementation focused on the creation of online learning modules, teaching assistant training, consultations, and staff validation. The result is a functional workflow that allows for engineering students to gain experience with manufacturing using a project-based learning perspective.

1. INTRODUCTION

With recent advances in manufacturing technology, it is becoming increasingly more crucial for young engineers to gain experience in manufacturing fields. No longer are design and manufacture seen as two distinct phases in a product's lifecycle. Rather, the barriers between design and manufacture have become blurry, largely due to the technological advances of CAD/CAM software. This offers the opportunity to leverage these advances, and offer experiential learning to students with the aid of CAD/CAM software. To this end, traditional design taught in a university setting can be augmented with manufacturing experience that is directly related to a student's designs. The goal being to educate engineering students to become better/more informed designers through manufacturing experience.

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2. BACKGROUND

The Artisan and Fabrication Laboratory (AFL) at Purdue University (seen in Figure 1) provides engineering students, faculty, and staff with hands-on access to a state-of-the-art manufacturing facility. The mission of the AFL is multifaceted, but highly focused on student learning. Essentially, students are provided the ability to manufacture their own parts while being overseen by laboratory staff that provide expert training on not only machine operation, but also on safety best-practices. The laboratory is designed to mimic what students will see in industry, providing the opportunity for students to become more well-rounded designers/engineers.

Figure 1: The Artisan and Fabrication Laboratory.

As the AFL is a student-based operation, it employs a unique model that features a staff that is mostly comprised of students. A full-time staff supervisor with significant industry experience in manufacturing is used to supervise the lab safety, train the student staff, and ensure efficient operation of the lab. The student staff (graduate and undergraduate teaching assistants and volunteers) then provide the primary interaction with the students using the lab. This staff development and skill set diversification model ensures the lab is able to efficiently handle a wide range of student projects.

The AFL seeks to utilize CNC equipment whenever possible because (1) the vast majority of engineering students will never operate a manual mill or lathe to produce parts in industry, and (2) engineers are more likely to interact with those who process parts rather than process parts themselves. This helps bridge the gap between computer-aided design (CAD) that is a part of engineering core curriculum and the experiential learning opportunities offered by the AFL. Using CNC equipment allows students to focus on the high-level aspects of manufacturing while avoiding the roadblocks presented by the fine nuances of machine operation. Because of this adopted approach, the computer-aided manufacturing (CAM) link between design and manufacture becomes increasingly crucial. While many off-the-shelf CAM packages exist, few are completely integrated within a CAD package. This presents a scenario where students are required to learn CAM and a new user interface simultaneously. To alleviate this concern, an integrated CAD/CAM package is desirable.

2.1 Selection of a CAD/CAM Package

Ultimately, CATIA v5 (now referred to simply as CATIA) was identified as the CAD/CAM package that offered the most upside for implementation. This is largely due to the fact that CATIA is seen as an integrated engineering tool, allowing for not only design and manufacture, but also kinematics, analysis and project management. Further, many Purdue students learn CATIA as part of the required curriculum. To this end, it is possible to leverage learning and build upon an existing knowledge base.

In addition, CATIA offers a level of customization that is integral to its application in the AFL. Using the many back-end features contained in this package, the interface and system settings can be tailored to the specific needs of its implementation. This proved crucial in the AFL, as CATIA was customized to use the workflow developed internally, complete with settings that were rigorously tested and validated. The following sections describe how this workflow was designed and implemented.

3. DESIGN OF THE WORKFLOW

As the primary users of the lab are engineering students, and not technicians, the focus was on creating a process that highlights the key facets of manufacturing, without creating confusion due to the finer details. Through this approach, the AFL was able to complete its goal of developing better/more-informed designers/engineers.

There are several key components of the workflow, including the use of a custom CATIA environment, process and tool catalogs, and simulation. This approach allows the user to become acquainted with machine fixturing, CNC processing and the resulting code, without requiring an expert level of knowledge on any of these topics. The following discusses how these key components are used to further student learning.

3.1 A Custom CATIA Environment

While seemingly a trivial element of the workflow, the creation of a custom user environment was likely the single most critical aspect of the entire workflow design. Prior to the creation of such an environment, it was essentially impossible to control an individual's CATIA settings to the degree necessary to maintain consistent interfaces that produced reliable machine code. By creating an environment configured specifically for use with the CAM workflow, it was possible to ensure that a student launched CATIA into an environment that was already fully configured for the tasks they were about to complete. Gone was the need for students to manually point CATIA to required resources or supplementary files. This proved to be the alleviation of one of the largest limitations of the CAD/CAM package.

In addition to custom CATIA settings, the environment also contains a template student's use as a starting point for the CAM work. This template includes full 3D models of the common fixtures used on the AFL machines, which can be seen in Figure 2. The fixture model serves several purposes. First, the students are able to interact with a virtual version of the fixture they will encounter when setting up the actual machines. They will be immediately able to identify if the fixturing approach will be sufficient, or if an alternative approach is required. Further, the fixture model can later be used for simulation and validation of the manufacturing program. If a student were to accidentally program a collision between the tool and fixture, it would be safely identified on the computer and not at the machine. This allows for a possible unsafe scenario to be averted well before any real risks are taken.

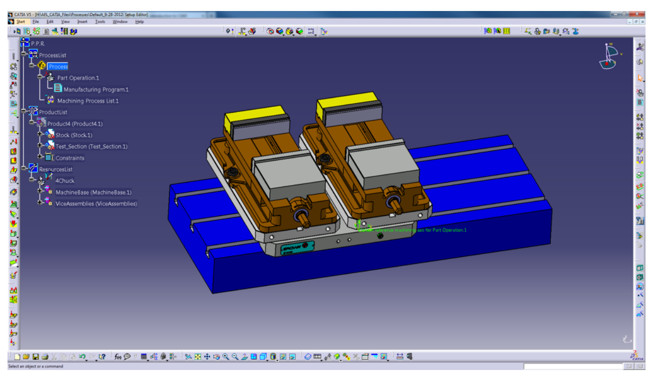

Figure 2: A 3D model is used to replicate the standard machine fixture in the CAD/CAM environment.

3.2 Tool & Process Catalogs

The development of tool and process catalogs was another crucial component of the AFL CAM Workflow design. Using these catalogs, it is possible to ensure that students adhere to a manufacturing approach that is within the capabilities of the lab.

3.2.1 Tool Catalogs

Several tool catalogs were created to reflect the standard tooling kept in the lab's inventory. Use of these catalogs constrained students to the tooling available to them, and served as a more effective way of conveying the tooling capabilities of the lab to the students. Rather than searching for a tool in the lab, a student is able to simply view the appropriate tool catalog in CATIA, and determine if the tool is available. This is not to say that specialty tools cannot be used within the workflow. Rather, it is a method used to convey the standard tooling capabilities to students.

3.2.2 Process Catalog

The real power of the workflow lies in the creation of a process catalog. A process catalog is the key element that aids in the transition from design thinking to manufacturing thinking. While a designer is likely able to identify a pocket on a part, most do not know how a pocket is processed on a CNC machine. This provides the possibility to leverage learning by associating the CNC operations used to cut a pocket with the terminology a student already understands through their design training.

This approach led to the creation of a process catalog that is comprised of a series of processes used to machine geometry commonly used by designers. Each process was developed, tested, and fine-tuned to provide accurate milling with minimal intervention by the student. Basically, the student simply identifies a feature on the part to which they would like to apply a process from the catalog. Once the process is applied, CATIA automatically generates the operations and tool paths required to mill the geometry, using parameters contained within the process. These parameters include values such as depth of cut, climb vs. conventional cutting, tool overlap, and other figures that are seen as extraneous to the designer.

In essence, the student is able to apply a process to a specific geometrical feature without having to be concerned with how exactly that feature will be milled. They do not need to learn some of the art of machining that is only obtained through years working in the field. Further, the AFL staff does not need to be concerned with validating the parameters used in student work, as the prescribed parameters have already been thoroughly tested and validated. Above all else, this provides a level of safety to the students, staff and machinery.

3.2.3 Integration of Tool & Process Catalogs

The two types of catalogs used in the AFL CAM workflow are inextricably linked. To even further streamline the CAM work that is completed by students, many of the processes were designed to query the tool catalogs and automatically select the optimal tool for the cut. Again, this is an approach that drastically simplifies the validation step of the workflow, as the need to analyze the manufacturing program for optimal tool preservation and machine operation time is drastically reduced.

3.3 Simulation

Once a part has been fully CAM processed, the next step is to simulate the resulting tool paths. CATIA offers several simulation options that complement the approach used by the AFL workflow. Each type of simulation offers a different benefit to the user. When used together, the simulations provide a full virtual look into the actual movements of the machine with respect to the stock and fixture.

Two types of simulation are suggested for use in CATIA. First, a tool path simulation may be used to see a graphical representation of the path taken by the tip of the cutting tool. Using this simulation, a student can easily observe the movement of the tool, and identify any inefficiency in the machine operation. This can then be communicated to a member of the lab staff, and an alternative approach can be determined. However, the primary use of this simulation method is for learning purposes. By viewing the simulation, a student can associate the generated tool path with the applied process to gain an understanding of how specific geometrical features are machined.

The second type of CATIA simulation that is viewed by students is the video simulation. The video simulation contains a full rendering of the machine fixture and the material that is being machined. Essentially, it is a simulation of what the student will see when the part is run on an actual CNC machine. This type of simulation can be used to easily identify gouges on the part, collisions between the tool and fixture, and other possibly problematic scenarios. Identifying these issues during the simulation stage helps secure the safety of the lab, and reduces the amount of lost time and frustration associated with faulty machine code. Further, it maintains the accessibility of the AFL, as machine time is not spent running code that produces faulty parts. This keeps the machines open to students who have successfully processed a part, and have shown the resulting code to produce a good part.

Finally, an additional simulation option is available outside of the CAD/CAM package. Once manufacturing code has been generated, CNC simulators are used to test the code. These simulators are exact replicas of the controls used by the AFL machines, and can be used to test the actual outputted code. This type of simulation does not provide a terribly accurate visual representation of the resulting tool paths, but it does test the quality of the outputted manufacturing code. This verifies that the entire manufacturing program will run on the CNC machine without any alarms, errors, or other issues that may otherwise result in delays at the machine.

4. IMPLEMENTATION

The full implementation of the AFL CAM Workflow includes more than just the information contained in the CAD/CAM package. From the inception of this project, it was understood that a major factor in the successful implementation was the training system built around workflow. This includes not only training for the students, but also training for the teaching assistants that provide direct support to the students. Four key components encompass the implementation: the development of online learning modules, teaching assistant training, the use of Pre-CAM Consultations, and staff validation of the manufacturing programs.

4.1 Learning Modules

Proper use of the workflow is communicated to students through two main avenues: interaction with the AFL staff and through a set of online learning modules. The online modules feature video screen capture of a part being processed in CATIA. This serves to educate the student on the “button clicks” required to complete tasks within the

CAD/CAM package. This provides a useful introduction to students in a self-paced environment. Using this approach, students can self-evaluate their use of the workflow and ask more targeted questions when meeting with AFL staff. The modules range in length from five minutes to forty minutes, and are delivered via the AFL website. This allows students to learn the material as their schedule permits, and does not constrain them to the operation hours of the lab.

4.2 Teaching Assistant Training

The first users of the workflow were AFL teaching assistants for a variety of reasons. First, they served as the initial evaluators of the workflow. As many had previously not conducted any CAM work, they were capable of identifying difficulties in the implementation and possible areas where the workflow could be refined. Concurrently, they were receiving valuable training on the workflow so they could later aid students in learning the material. This model proved successful, as many of the teaching assistants who received the initial training are now some of the most capable users of the package.

Formal training consisted of three two-hour small group sessions that focused on different aspects of the workflow. Following each session, each teaching assistant completed a small project based upon the material taught in the preceding session. This served to reinforce the material taught during the session, and provided a scenario similar to what a teaching assistant would encounter when helping students.

Prior to attending the training sessions, teaching assistants viewed the learning modules to gain a basic understanding of the workflow. Thus, the focus of the training sessions was not on the mechanics of the interface in CATIA, but rather the underlying methodology used in the workflow. Ultimately, the purpose of the training sessions was not only to raise the level at which the teaching assistants use the workflow, but to also ensure they could accurately conduct Pre-CAM Consultations.

4.3 Pre-CAM Consultations

Prior to beginning formal work on a CAM project, students must consult with a member of the AFL staff. During the Pre-CAM Consultation, the staff member views the model(s) provided by the student and discusses the manufacturing approach that will be used to machine the part. This includes a discussion on the proper stock size, the proper fixturing approach, the order in which processes should be applied, among other topics. The purpose behind this consultation is to provide the student with a starting point to begin the CAM work. Also, it ensures they also follow the AFL processes and policies early in the project cycle.

Formal feedback is provided to students during the Pre-CAM Consultation via an interactive PDF form. This form includes a cover sheet that outlines the basics of the fixturing approach, stock size and setup parameters, and subsequent pages that describe each process in the order it should be applied. Students are then asked to take this form and use it as a roadmap during the processing of their part.

4.4 Validation

The validation process used at the AFL ensures that CAM projects processed by students adhere to the manufacturing approach and safety policies put in place in the lab. Essentially, it is a check by a member of the AFL staff that the student-generated process is accurate, complete, and, above all else, safe. All validations are conducted by a senior member of the AFL staff (supervisor, graduate teaching assistant, or adequately trained undergraduate teaching assistant).

The validation process includes a review of the applied processes, the tools used, and the resulting simulations. A member of the AFL staff views all three simulations to verify the student's part has been adequately processed. While the student will likely focus on whether the resulting part meets their specification, the staff reviewer will be specifically concerned with the safety of the process. Essentially, the reviewer will confirm that the outputted code will operate safely, and not result in any collisions or other unsafe scenarios.

5. SUMMARY

This paper describes the development and implementation of a CAM workflow at Purdue University's Artisan and Fabrication Laboratory. This workflow is integral to the laboratory's mission of providing engineering students with the manufacturing knowledge required to make them better informed designers/engineers. The integrated CAD/CAM approach was developed and implemented through the use of CATIA v5. This package was chosen due to its capability, as well as the opportunity to leverage learning that is already happening at Purdue University. The CAM workflow was developed using several key aspects: the creation of a custom CATIA environment, the use of tool and process catalogs, and the use of simulation. Learning modules, teaching assistant training, consultations and staff validation were key to the full implementation of the workflow. This method has proven successful in providing experiential learning opportunities to engineering students at Purdue.

6. FUTURE WORK

Further advances can be made to develop this workflow in additional software packages. While the majority of students visiting the AFL are competent in CATIA, there are a non-trivial amount of students that have no prior experience with the package. Expanding the workflow to support other packages would remove this limitation. As the workflow is more a methodical approach to teaching CAM in a university setting, and not a direct implementation of CATIA, this approach could likely be replicated using other CAD/CAM packages.

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