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Practice-Based Learning of Product Lifecycle Data Reuse

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INTRODUCTION

Model-Based Definition (MBD) is an emerging methodology that plays a central role in transforming traditional manual industry practices to automation through machine-to-machine communication. MBD captures and re-uses data in a digital format that seamlessly transfers information to enterprise stakeholders involved in all stages of the product lifecycle.

Practice-based learning with the tools and processes that manage this data gives students the skills to have a competitive advantage for new jobs resulting from these technological changes.

Students gain experiential learning by going through the steps of a product throughout its life, from conception through in-use, as explained in the following sections of this document. Students use Industrial Design software that brings aesthetics, user function, and design together. Computer-Aided Design (CAD) is used to refine product requirements at the engineering design level, including authoring annotations, referred to as Product and Manufacturing Information (PMI), to capture and convey tolerances required for the product to perform its function. Analyses optimize the geometric design for weight reduction. Manufacturing simulations write programs to drive Computer Numerical Control (CNC) machines to automate manufacturing devices such as milling machines. Annotations are re-used to produce inspection plans, verifying as-manufactured products match their digital twin. The final product design is used to generate work instructions for the assembly of parts. Students submit assignments through a Product Data Management (PDM) software that mimics an industry installation driving relationships between data and stakeholders, allowing students to receive feedback and revise designs to rectify discrepancies.

The benefits of teaching such subject matter and the benefits they bring to the workplace are hard to measure, but anecdotal evidence of student placement in the workforce show that and understanding of MBD are what industry needs. Making industry practices part of the knowledge set that students acquire will help drive MBD forward, making manufacturers more competitive.

1 SUBJECT MATTER BACKGROUND

Traditionally, the information required to manage a product throughout its life cycle was captured in various formats, including lightweight and heavyweight CAD packages, 2D drawings output by the CAD systems, analysis data, manufacturing instructions, collected inspection results, and other common document formats including written documents and spreadsheets. The lack of a common language between the functional stages in the product lifecycle introduces an unnecessary risk of data error due to the re-entry of information or data loss through translation. This inefficient transfer of data results in billions of dollars in avoidance costs, mitigation costs, and cost risks across the manufacturing sector. The non-value-added activities associated with repairing or recreating digital data and the accompanying costs associated with those activities create an untenable situation that puts manufacturers at a distinct disadvantage to their competitors. [1]

As the manufacturing industry is beginning to leverage a digital product definition through MBD to improve methods of communication, higher quality products are produced at a reduced development time and a lower cost. In a study with International TechneGroup Incorporated (ITI) and the Department of Navy, Naval Air Warfare Center Aircraft Division (NAWCAD), implementation of a Model-Based Definition [2] showed a savings of more than $3M annually. Incorporating real-world experience in this area into a student's plan of study will help industry reap MBD benefits sooner and will generate advocates for these modernized methods upon entry into the workforce.

2 INDUSTRIAL DESIGN

Before the Industrial Revolution, artisans produced products by learning a trade and passed their knowledge and expertise through apprenticeships. The need for mass production of standard parts during the Second World War changed this. Designers were faced with the additional challenge of making products easy to manufacture. Today designers must consider even more factors as product designs are influenced by many other factors, including ease of assembly, packaging, aesthetics, and a user-centric experience, to name a few. The pairing of industrial factors and innovative design often begins with 2D sketches, which have a way to convey thoughts in a graphic form that words cannot. As industry moves to reduce redundant authoring of information, computer-aided software is being used more and more for this task.

Students create concept models with the industrial design process in mind. A freeform design of a perfume bottle showing in Fig. 1. is used to allow students to experiment with the organic shapes that are a result of the software. A more advanced design for the cover of a tire air pressure gauge shown in Fig. 2. is developed in the context of an assembly, exploring the methods to capture creative design solutions while keeping the ability to assemble the cover to other components in mind.

These exercises allow students to understand there is more to capturing technical requirements of product design. First-hand experience designing with mindfulness of the artistic elements involved in making the product appealing in the marketplace are industry skills not typically taugh to engineering students.

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Fig. 1. Industrial design of a perfume bottle in NX Realize Shape.

Fig. 2. Industrial design of a tire air pressure gauge in NX Realize Shape.

3 ENGINEERING DESIGN

Computer-Aided Design models have been the medium to capture the geometric shape of products since the 1990s and continues to be. The 2015 Hardware Design Engineer study [3] found that nearly 6 in 10 individuals with design decision-making responsibility are using CAD applications very frequently and very consistently today [4]. MBD is expanding the use of a CAD model also to carry the technical details required to manufacture and support a product throughout its life. This allows information to be delivered to suppliers using up-to-date information via mediums such as a 3D PDF that can easily be updated when a change to the design is made. These documents allow the viewer to see information from a 3D perspective, without requiring experience to interpret 2D views and without the cost of an expensive CAD license and hardware. Interaction with the geometry allows the viewer to rotate, spin, and zoom the model and highlight geometry to reveal the required details to perform their job.

Students are provided with the 3D PDF document shown in Fig. 3. which is output by a leading software vendor that provides tools that "allows subject matter experts to author fit-for-purpose technical content" [5] used by companies such as Boeing, NAVAIR, and GE Power. Companies use the 3D PDF format to deliver technical data packages in a format derived by the Department of Defense used by the majority of companies implementing MBD.

Students interact with the document to gather information about the model and generate the design shown in Fig. 4. in CAD. As revisions are inevitable, it is vital to reliably update geometry without causing relationships to other geometry to become broken when a change occurs.

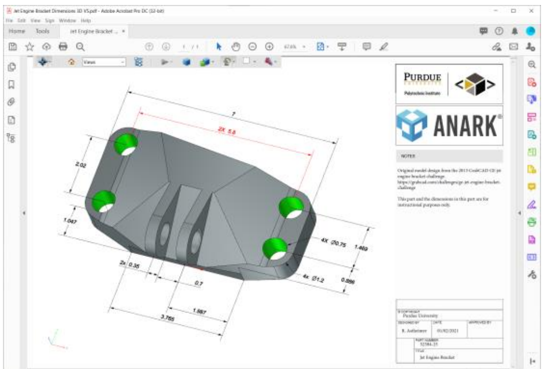

Fig. 3. 3D PDF containing detailed CAD model information from Core Workstation.

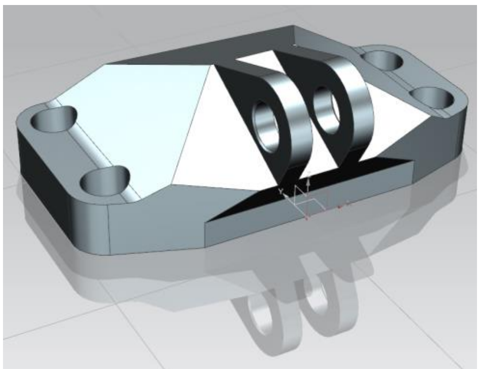

Fig. 4. Geometry representation in NX CAD.

When the CAD model is complete, students generate another 3D PDF, this time verifying data interoperability. The 3D PDF in Fig. 5. is a comparison report to visually convey the difference between the student CAD model and the answer model. A list of differences between the two models mimics verifying a revision made to a product or verifying the content exported to a derivative format.

Industry uses 3D PDF format to exchange information and verify that only anticipated changes were made and that exported data did not inadvertently lose information about the product. Familiarity with this data format allows students to hit the ground running when entering the workforce.

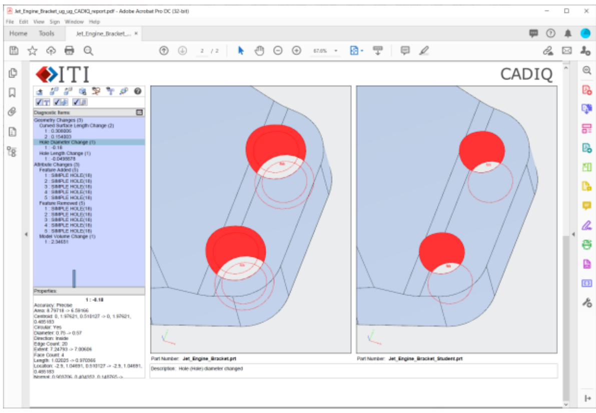

Fig. 5. 3D PDF report generated by CADIQ listing the differences between the student CAD model and the answer model.

3.1 PRODUCT AND MANUFACTURING ANNOTATIONS

When using an MBD approach, the CAD model contains more than just a representation of the geometry. Information traditionally captured on a 2D drawing is now being captured in CAD to facilitate the machine-to-machine communication mentioned previously. The ASME Y14.5 Geometric Dimensioning & Tolerancing: Engineering Drawing and Related Documentation Practices[1] standard defines the practices to specify tolerance requirements on a product. The ASME Y14.41 Digital Product Definition Data Practices[2] defines how to properly apply the ASME Y14.5 information in a 3D CAD model, such that they are related to relevant features on the geometry and can be re-used by a machine to automate processes.

Students are introduced to both of the previously mentioned standards to complete an assignment capturing tolerance information in a CAD model. Fig. 6. shows a hole diameter dimension with tolerance information applied. When the dimension is selected, it turns orange in color, and the geometry that this information applies to is highlighted in green, making the interpretation of information unambiguous.

To further apply their knowledge, students work with the Purdue Formula SAE (Society of Automotive Engineers) racing team to help improve a student-built vehicle that competes against other universities. In Spring 2021, students evaluated the fit between the sprocket and differential shown in Fig. 7. to reduce interference during assembly. Students suggest modifications to the components to improve fit without

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1 *https://www.asme.org/codes-standards/find-codes-standards/y14-5-dimensioning-tolerancing?productKey=N00518:N00518*

2 *https://www.asme.org/codes-standards/find-codes-standards/y14-41-digital-product-definition-data-practices*

compromising performance due to slack between the parts given knowledge of how each component is manufactured and its material.

In Manufacturing, the ability to select fabrication processes and parameters is not possible without knowledge of how these processes impact the tolerances that are attainable. Students gain a better appreciation of how

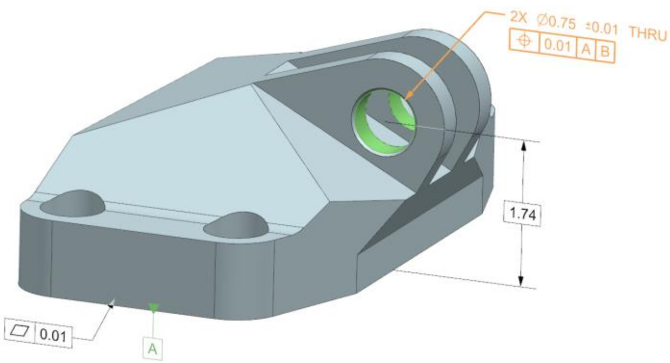

Fig. 6. Tolerancing of a hole in 3D following ASME Y14.5 and ASME Y14.41 standards.

Fig. 7. Purdue SAE team sprocket and differential in NX.

4 ANALYSIS

There are a variety of analyses available to evaluate improvements to a product. For many, structural analysis, dynamic interaction between products, fatigue, and durability when exposed to a load are the scenarios associated with the word analysis. However, a newer type of analysis, referred to as generative design, is used to optimize a design to reduce the volume of the product, which directly affects weight. This type of analysis is introduced because it is common for students to design a solution and then stop thinking about the problem, but there are many other factors that need to be considered. While material reduction is often thought to be the best way to improve a product and reduce weight, such changes may result in a part that is more time-consuming to manufacture, requires specialized machinery or skills, or is more challenging to assemble. Trade-offs must be made to account for more than just the design of the product.

Students use Generative Design to experiment with derivative design solutions by applying material properties, defining where product geometry cannot change, and indicating the loads the product is subjected to. Fig. 8. shows one derivative design of the bracket that was designed earlier in the semester.

Generative design skills “turn students into A-list job candidates” [6] with the drive to see the future of design and manufacturing from a new and modernized point of view.

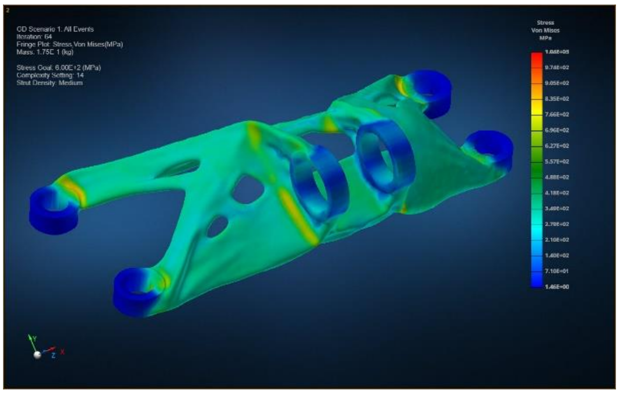

Fig. 8. Optimization of the bracket defined in CAD by students in MSC Apex Generative Design.

5 MANUFACTURING

When designing a product, how the product will be manufactured also has to be considered. There are four categories of manufacturing: subtractive manufacturing, additive manufacturing, cutting, and forming. Within each of these categories are several methods, each offering a solution that is best typically based on the geometry and material of the part. Once the most likely method is selected, the design engineer must validate and verify the logistics of the method.

Students learn how to prepare CAD to generate code to run a subtractive manufacturing device, also known as a milling machine. The milling process takes a stock piece of material and removes material over many passes to achieve the final shape. Fig. 9. shows an example product to be manufactured (displayed in orange) within a piece of stock material (displayed in transparent grey). Manufacturing applications reference geometric details to generate toolpaths that a Computer-Numerically Controlled (CNC) milling machine will take to manufacture the part. The students use the CAD geometry and tolerances defined during the engineering design phase to generate the program to run the CNC machine. The programs can visually play a simulation of the machine cutting to remove material, as shown in Fig. 10. Reports that present information such as completion time for each step in the machining process are generated for student evaluation to optimize the program for speed and quality.

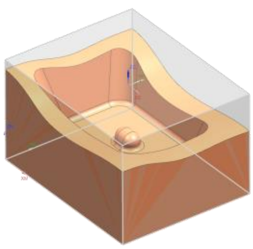

Fig. 9. Product to be machined (orange) with stock material overlaid (transparent grey) in NX.

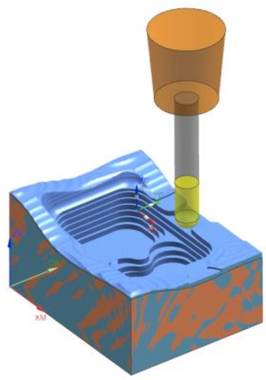

Fig. 10. Simulation of stock milling when producing the final product in NX Manufacturing.

6 METROLOGY

Metrology, the study of measurement, is the next part of the lifecycle where manufactured parts are inspected to verify they match the requirements defined in the CAD model, referred to as a digital twin. Automated inspection devices, coordinate measuring machines (CMM) are used to measure the part and record data.

Students verify that the tolerance information from the design phase was prepared according to the ASME standards introduced earlier. A Bill of Characteristics, shown in Fig. 11., is generated from this data lists each criterion to be measured during an inspection and can be used to generate reports. For example, an ISIR (Initial Sample Inspection Report) document is used for customer approval of an initial sampling of data before mass production begins. Such reports are used by manufacturers worldwide in compliance with standards from organizations such as ISO (International Organization for Standardization) and SAE (Society of Automotive Engineers Aerospace Standards), further emphasizing everyday practices utilized in industry.

7 IN-SERVICE

After a product is produced and inspected, technical documents may also need to be produced, such as assembly instructions or manuals for future maintenance or repair procedures. Detailed technical documents are required to ensure the quality and integrity of the product.

Assembly instructions for a trailer hitch, outlining the steps to assemble a product, required equipment, safety procedures, and notes to assist in locating the required parts. Fig. 12. shows the resulting 3D PDF assembly instructions generated. The students' previous experience of interacting with a 3D PDF earlier in the semester makes it easier to understand the purpose of authoring information to be exported. Information output in such documents is another example that shows students how design decisions made early in the design process impact activities later in the product lifecycle.

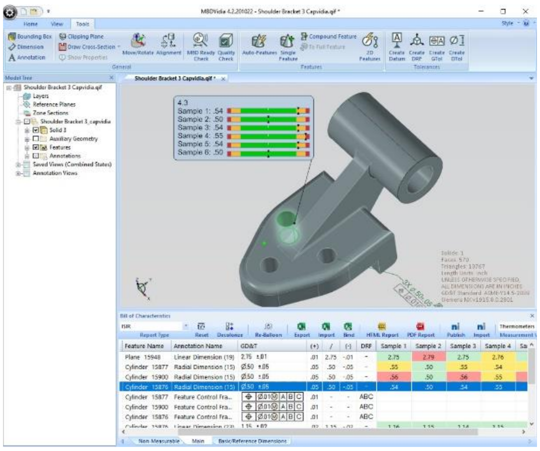

Fig. 11. Bill of Characteristics in MBDVidia.

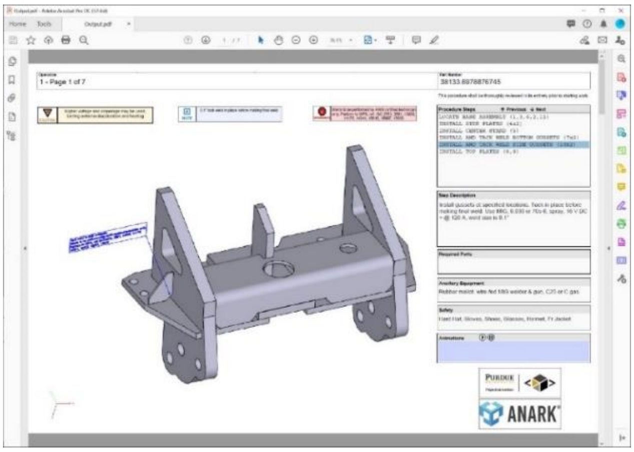

Fig. 12. Work instructions for a trailer hitch assembly generated from Core Workstation.

8 DATA MANAGEMENT

Product Lifecycle Management (PLM) processes are at the heart of success at companies manufacturing a physical product or providing a service. These processes are put in place to guide and manage the steps to product realization and ensure product integrity while gaining a competitive advantage. The main phases of a lifecycle served as the basis for the activities in this course to mimic industry practices.

Product Data Management (PDM) systems are the tools that enforce PLM processes and manage the data. By storing product details in PDM, it acts as a central source of information where information in all formats can be linked and quickly located.

Students use PDM software (shown in Fig. 13.) to submit assignments, receive feedback, and manage assignment revisions for the duration of the semester.

Using industry solutions to manage assignment submissions gives students experience using the systems central to work activities in industry. This valuable experience also gives them a competitive advantage when applying for a job.

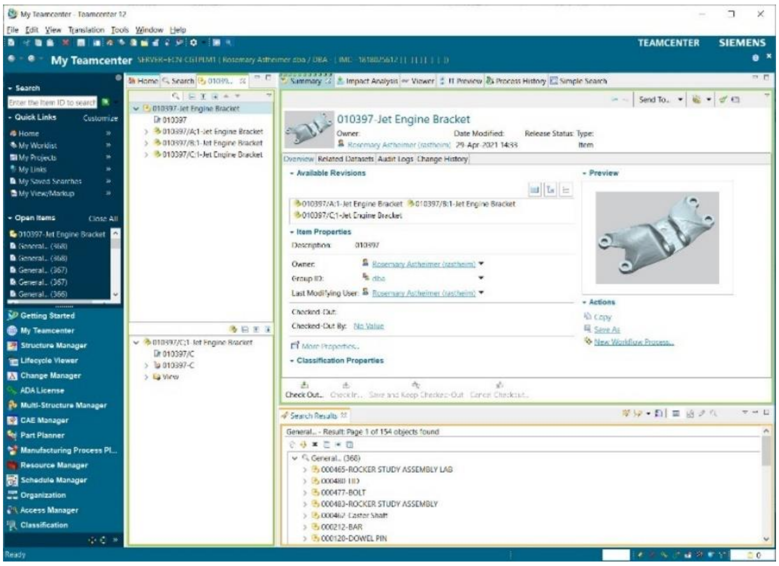

Fig. 13. CAD file in Teamcenter that has undergone three revisions.

9 SUMMARY

The subjects and activities presented in this paper are critical for students to understand the job functions, processes, and skills required to perform various tasks in a manufacturing industry. Incorporating learning experiences in the classroom to cultivate the skills used on a daily basis in industry is a key factor in making students competitive when applying for positions in the field.

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