Work in Progress: Enable Digital Thread and Digital Twin Learning Environment for Cybermanufacturing Education

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Abstract

In the era of Industry 4.0, cybermanufacturing is an emerging technology based on digital manufacturing, Industrial Internet of Things (IIoT), data analytics, and high performance computing to drive the manufacturing industry optimizing productivity, product quality, and business feedback. However, the cybermanufacturing education is not addressed in the current manufacturing education knowledge model. This work-in-progress (WIP) explores how to enable digital thread and digital twin cyberlearning environment for cybermanufacturing education at Virginia State University (VSU).

1 Introduction

In the era of Industry 4.0, cybermanufacturing based on digital manufacturing, Industrial Internet of Things (IIoT), data analytics, and high performance computing are driving the manufacturing industry to optimize productivity, product quality, and business feedback [1]. Two vital competences for cybermanufacturing are digital manufacturing plus data analytics. The success of the companies' implementation of cybermanufacturing systems vitally depend on the ability of employees to act in the context of IIoT, specifically the skills of integrating sensing and control, data analytics with digital manufacturing operations [2, 3]. In response to industries urgent needs, Digital Manufacturing and Design Innovation Institute (DMDII) has released the "Digital Workforce Succession in Manufacturing" report in 2017 [2]. This report describes the job profiles for next generation of manufacturing through the inputs from global leading companies and universities. It heralds the types and levels of manufacturing educational requirement for the future digital workforce for Manufacturing Engineers. According to DMDII, the future manufacturing engineers "design and improve manufacturing systems at the mechanical, electrical, and software levels. Their focus is not just on physical manufacturing systems; also includes the enablement and use of data around manufacturing systems to drive increases in productivity, product quality, and business feedback". Increasing complexity of manufacturing processes and systems creates the need for knowledgeable employees, who are supported by advanced trainings, tools, and learning strategy to develop their skills for factory operations in cyber context. However, the cybermanufacturing education is not addressed in the current manufacturing education knowledge model [4]. This work-in-process paper explores the learning environment for cybermanufacturing education using digital thread and digital twin techniques.

2 Concepts

The digital thread enables data communication and data visualization throughout the product lifecycle from design to production to supply chain and to usage, which is traditionally information siloed. The digital thread concept raises the bar for delivering "the right information to the right place at the right time" [5].

The digital twin digitally replicates a particular physical asset that includes design specifications and engineering models describing its geometry, materials, components and behavior. More important, it also includes the as-built and operational data unique to the specific physical asset that it represents [5]. For example, for a CNC machine tool, its digital twin can refer to models like 3D model with specific geometry on the machine design, toolpath simulation during the CNC machining process, inspection, operation and maintenance data, machining dynamics models, and any deviations from the original design specifications approved due to issues and work-arounds on the specific product unit.

The applications of digital thread and digital twin on manufacturing and its relation with Society of Manufacturing Engineers (SME) four pillars knowledge area is illustrated in Table 1.

Table 1. Digital Thread and Digital Twin's Application on Manufacturing and Relation to SME Four Pillars

Concepts	**Manufacturing applications**	**SME four pillars knowledge area**
Digital Thread	Design, test & evaluation, production, operations, and sustainment service	Product engineering
Digital Twin	monitoring and inspection, diagnosis and maintenance, workforce training	Product engineering, Systems and operation

3 Approaches

We are exploring the approach to enable students with competencies of digital thread and digital twin in the courses of MANE 205-Manufacturing Processes I, MANE 201-Sophomore Lab, and MANE 315-Automation at VSU. The current approach includes: 1) lecture and lab project on digital design and assembly of a product, 2) enable digital thread and digital twin learning laboratorial environment.

3.1 Lecture on Digital Design and Assembly of a Product

At Virginia State University, MANE 205, which is offered in Fall annually, is the gate way course to Manufacturing Engineering program. The MANE 205 traditionally focuses on material properties and some manufacturing processes such as casting and metal forming. The instructor noticed that the course content has a lot overlapping between MANE 205 and ENGR 305-Materials Engineering, also to aware students on digital thread in Manufacturing, so the instructor tentatively replaced some material properties content in MANE 205 with digital design and concurrent engineering in Fall 2018.

To help student learning of digital thread, a course project on digital design of water pump was assigned. This pump project was enlightened by the modeling, fabrication, and evaluation of a centrifugal pump in "Living with the Lab" at Louisiana Tech University [6, 7]. The students in MANE 205 are mostly sophomore, who only took the design area course of Engineering Graphics. So the instructor broke down the course project into the mini-projects of 1) design of impeller, 2) design of pump body and face plate, 3) drawing of motor and water hose adapter, and 4) digital assembly of the pump. There were 10 students enrolled in the MANE 205 in Fall 2018, and they were grouped into 5 design teams. The project turned out successful for every design team, the students can understand the design under constraints of cost, material, process, etc. They also had the first experience on collaborative concurrent design, which is key to the success of digital thread. An example of the student design on water pump is illustrated in Figure 1 (a).

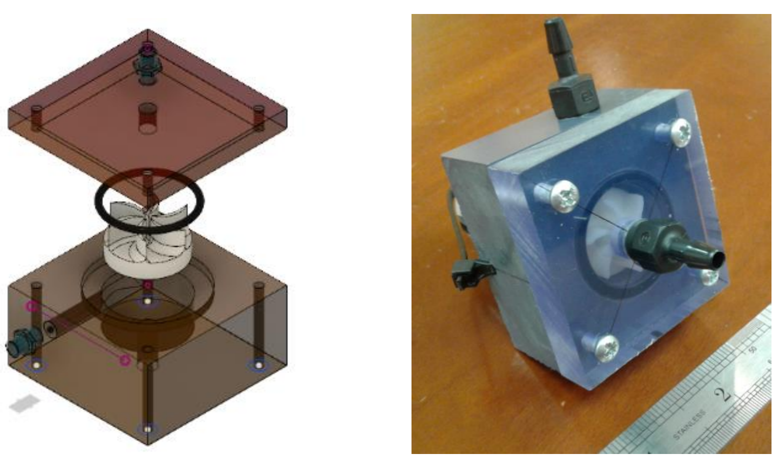
3.2 Lab Project to Implement the Digital Design

The MANE 205-Manufacturing Processes I, as a gateway course for manufacturing engineering at VSU, should arouse students' interest to manufacturing. However, there is no individual laboratory section for MANE 205. In the last two years, the instructor has included two experimentations on 1) tensile test, and 2) coordinate measurement machine (CMM), also has applied the project based learning (PBL) approach, in the course. Students were requested to propose a project related to manufacturing process around the midterm, and then to deliver the project in the rest of the semester. This practice has greatly aroused students' interest to hands-on experience, also improved the learning outcome for the class. However, the problem with this PBL practice is that students' project proposals sometimes are too broad without a clear deliverable objective or not close to manufacturing processes.

Through the support from National Science Foundation, the MANE 201-Sophomore Lab is newly offered in Spring 2019. This lab course aims to provide students with hands-on experience on a variety of manufacturing processes, including turning, milling, 3D printing, drilling, tapping, measuring, inspection, and assembly etc. Through the semester of classes, a real product is customized and prototyped. Students work as teams to deliver the tasks and product. Problem analyzing and solving techniques for the students will be developed. These are the fundamentals for students to learn digital manufacturing and digital thread. The prototyping of the pump designed in MANE 205 is the main focus of MANE 201. The covered topics and schedule is as below Table 2. A final prototype is illustrated in Figure 1 (b).

Table 2 Topics and Schedule in MANE 201

Week	Topic	HW ASSIGNMENT
1	Introduction and safety training	
2	Digital design of pump	HW1
3	Generate bill of materials (BOM) and process planning	HW2
4	3D print of impellers	
5	Fabricate pump body using saw and mill	Lab assignment 1
6	Fabricate face plate using saw and mill	Lab assignment 2
7	CMM inspection of parts	Lab assignment 3
8	Spring break, no class	
9	Fabricate the bushing and sealing using lathe	Lab assignment 4
10	Fabricate the bushing and sealing using lathe	
11	Assemble the parts into pump	Lab assignment 5
11	Assemble the parts into pump	Lab assignment 6
12	Test the assembled pump	
13	Test the assembled pump	Lab assignment 7
14	Summarization of lab activities	



(a) (b)

Figure 1 (a) 3D Model of Water Pump Designed and (b) Prototype of the 3D Model Fabricated by Students [8]

3.3 Enable Digital Thread Learning Laboratorial Environment

To aware students on “digital thread" in product design, manufacturing, quality and inspection, equipment performance and health, across the product lifecycle, the novel integration of data information from product lifecycle cradle-to-gate stage (idea, design, manufacturing, and inspection) has been deployed in the VSU labs and Makerspace with the help of Siemens NX PLM software. The data information framework design addresses the challenges and requirements for introducing cyber-physical infrastructure into manufacturing education. VSU also acquired commercial software SAP enterprise resources planning (ERP), owns fabrication equipment including CNC mill and lathe, 3D printers, computer integrated manufacturing (CIM), and inspection tools such as coordinate measuring machine (CMM). The student projects finished in the lab and Makerspace include digital design and manufacturing of impellers [[9], [10]], NASA mining robotics competition [[11]], etc. since 2015.

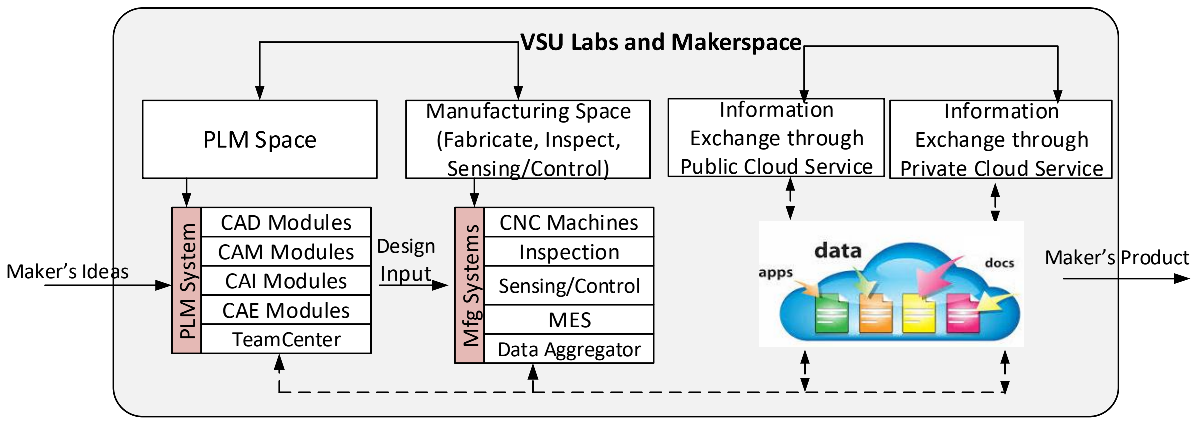


Figure 2 Digital Thread at VSU Labs and Makerspace

3.4 Enable Digital Twin Learning Laboratorial Environment

We are currently exploring different ways to create digital twin to support learning of cybermanufacturing. This is the work-in-progress, we just finished equipment requisition and is working on the implementation. we want to demonstrate our preliminary results in poster in ASEE 2019 annual conference.

4 Summary and Future Work

This WIP paper describes the needs for cybermanufacturing education. The concepts on digital thread and digital twin and its application on manufacturing are illustrated. Our efforts on enabling students with competence in digital thread and digital twin are demonstrated. In the future, we will continue to build the laboratorial tools and environment for digital twin, and then integrate and evaluate these tools in the Manufacturing Engineering curriculum.

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