A Holistic Design Approach for Integrated Learning in Manufacturing Education

Faisal Aqlan, Daniell DiFrancesca, Qi Dunsworth, Chetan Nikhare, Matthew Swinarski, and Mohammad Rasouli

Abstract

Manufacturing makes a tremendous contribution to the U.S. economy by increasing gross domestic product and creating high-paying jobs as well as supporting all other sectors. The integrated nature of manufacturing is evident in its symbiotic relationship with innovation, national security, and Science, Technology, Engineering, and Mathematics (STEM) education. Moreover, manufacturing is increasingly important to the balanced education of engineers in all disciplines. However, today's manufacturing is undergoing the greatest change in more than 100 years, and the current skills gap causes serious concerns about the ability of manufacturers to fill critical positions. Manufacturing needs a well-trained workforce that possesses skills like problem-solving and critical thinking to make effective decisions at all stages of the manufacturing process. One of the fundamental skills is to make good decisions at early stages that facilitate, not impede, the manufacturing process down the road. Traditional curricula designs tend to focus on a specific discipline, creating a silo effect rather than viewing manufacturing as a connected, systemic process needing decisions made with respect to the entire product development life cycle. This study investigates this belief by 1) examining if students understand product manufacturing as a connected, systemic process, 2) exploring in which manufacturing knowledge area, if any, students are deficient, and 3) analyzing if these knowledge gaps exist for both engineering and business students. To study these possible gaps, this research proposes a holistic design approach for manufacturing education to provide students with an integrated view of how products in the real world metamorphose from an idea into the hands of end-consumers. A dynamic decision making framework integrating product manufacturing topics across engineering and business courses is developed to highlight system thinking and decision making in the context of the entire product life cycle (i.e., product design, manufacturing process, manufacturing system, and business process). Utilizing the Understanding by Design model, we first established clear learning objectives associated with students' basic understanding of manufacturing knowledge in connection with product development life cycle based on Bloom's taxonomy (i.e., remember and understand). Next, the team created an assessment to collect acceptable evidence for the defined learning outcomes. Finally, learning modules were created by an interdisciplinary team of instructors to introduce the related manufacturing topics. A pilot study with current engineering and business undergraduate courses was conducted and pre- and post-survey data was collected and analyzed. The results of the study and insights from the research team are provided at the end of the paper.

Keywords: Manufacturing, product development life cycle, decision making, system thinking, Bloom's taxonomy

1. Introduction

Manufacturing is the application of machines, tools, and labor to transform raw materials into finished goods for sale or use. It makes a tremendous contribution to the economy in the form of increasing gross domestic product (GDP), exports, creating high-paying jobs, supporting all other sectors, and provides a meaningful return on investment. The integrated nature of manufacturing is evident in its symbiotic relationship with innovation, Science, Technology, Engineering, and Mathematics (STEM) education, and national security [1]. Unfortunately, few young Americans choose a manufacturing career [2]. Meanwhile, the current manufacturing workforce is less educated and slower to adapt to new technology compared to other sectors. It is predicted that before 2025, two million manufacturing jobs will be left unfilled due to a widening skills gap [3], which is further impacted by the pandemic. Along with retirement and economic expansion, this skills gap is widened by a lack of programs and curricula designed to attract a skilled manufacturing workforce [1]. Traditional curricula, however, tend to focus on a specific discipline, limiting students from seeing manufacturing as part of a systemic process and places a heavy emphasis on the growth of students' technical knowledge and skills, leaving transferable skills development to the workplace [4]. Nonetheless, today's manufacturing industry values well-rounded employees who can think reflectively and thrive in team environments. Thus, it requires employees to have both technical and professional skills [5]. Communication, system thinking, and problem-solving skills are among the most desired qualities in the workforce [6]. The future of manufacturing depends on effective STEAM education and integrated curricula that provides the emerging workforce with a system view of manufacturing industry and professional skills transferrable to workplace.

To discuss the future of manufacturing, we need to look back at the previous industrial revolutions. Each of these revolutions took at least 80 years to complete, so it is still early to define the ongoing revolution (i.e., Industry 4.0). The building blocks of the future of manufacturing enterprises are innovative materials, advanced technology, new business models, and skilled workforce for intelligent manufacturing [1]. Understanding how manufacturing evolved over the years will help academicians, businesses, and policymakers to prepare future graduates with the knowledge and skills required for the new industrial revolution. The manufacturing landscape has been transformed by the emerging trends in products, processes, materials, and technologies [7]. Over the years, manufacturing has gone through a series of paradigm shifts starting with craft production and ending with today's personalized production. Products, materials, processes, technologies, and information systems have also evolved based on the changing paradigms. Figure 1 shows the pillars of manufacturing, which define the unique characteristics of manufacturing and are the core of manufacturing education. The six pillars of manufacturing are: Product Design, Manufacturing Materials, Manufacturing Processes, Manufacturing Systems, Manufacturing Technologies, and Business Processes (i.e., Information Systems). Table 1 shows the six pillars of manufacturing and their definition. By studying these pillars and their evolution, students can develop the required workforce skills as well as understand the past and present of manufacturing to prepare for its future. This, in turn, will help prepare the next generation of engineers and professionals with the required skill sets to fill the existing skill gaps in manufacturing.

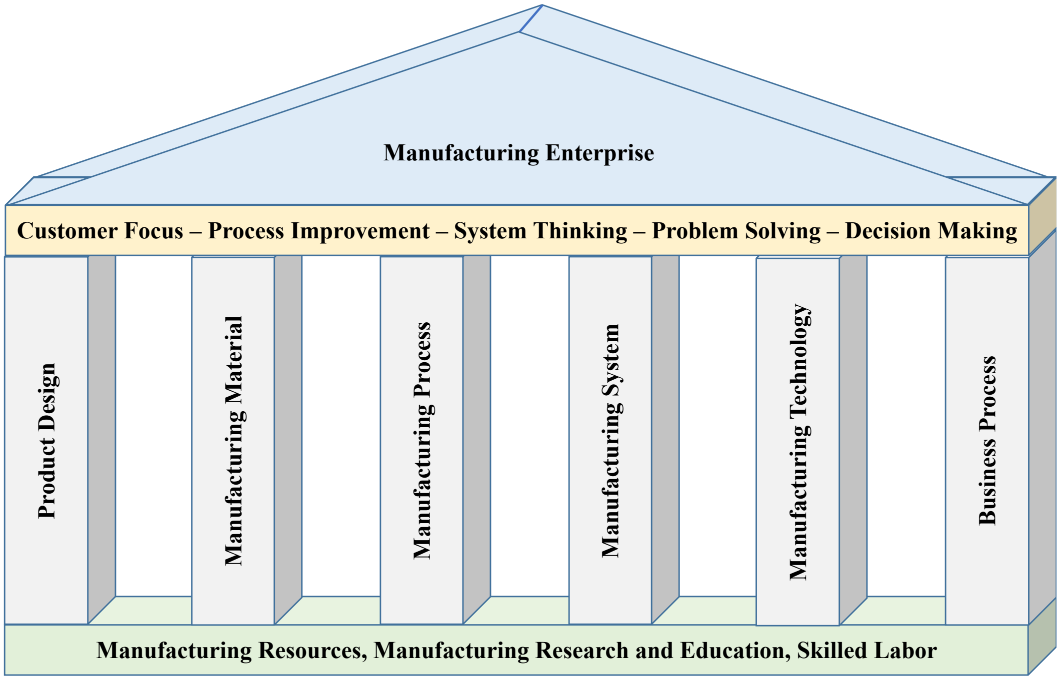


Figure 1. Illustration of the manufacturing pillars

1.1 Product Design

Product design is an integral part of manufacturing. Product Design is the process of defining product characteristics such as dimensions, appearance, materials, tolerances, etc. It starts with clearly defined customer needs, which are translated into measurable target specifications. Concepts of the product will then be generated, selected, tested, and final specifications determined. For a product to make its way successfully to the market, various aspects of design need to be carefully analyzed and modeled.

One main advantage of computer modeling in product design is that various tests can be performed on the model that are otherwise dangerous or costly to be done on actual products. Most real-life systems are nonlinear and have multiple inputs and multiple outputs. Such systems are best dealt with using the state space method [8-9]. However, teaching state space methods to undergraduate students is often difficult due to the mathematical complexity and lack of visual validation [10]. In this study, state space analysis is used to first model the dynamics of a product. Next, modeling is used to improve the design for various conditions of the product including stability while also minimizing the energy consumption.

1.2 Manufacturing Materials

Another key element to be considered is the type of materials used for the chosen design. Common materials used in manufacturing include metals, plastics, ceramics, and composites. Figure 2 shows the evolution of material up to 2020 [11]. Changing the composition of metals can alter the mechanical and metallurgical properties to propose a particular function and performance. Metals can also be mechanically combined to alter the mechanical and metallurgical properties. Composite material signifies that, two or more materials can be combined to form a useful third material. Examples include fiber-reinforced, resin-matrix composite materials that have high strength-to-weight and stiffness-to-weight ratios [12]. Knowledge of polymers and elastomers are important to conceive this kind of innovation. Similarly, ceramics, which are ideal for elevated temperature application, can be made by combining metallic and non-metallic materials through power metallurgy [12].

As mentioned, material selection and processing go together and cannot be separated. Day-to-day consumer products like computers, notebooks, coffee cups, or bicycles are finalized after the needed raw materials are processed in a desired manner. None of these is made of a single material. Rather, they are the assembly of multiple sub-products. Material can be selected before or after the design process based on the design constraints. If the material with a certain property is required for design to function and is not available, then the material design stage is required [Deng and Edwards, 2007]. In this module, students will select the best material for a design part utilizing Ansys Granta EduPack software [www.ansys.com] based on the constraints given for design.

1.3 Manufacturing Processes

Manufacturing processes have always been developed based on the available technologies at the time, from casting, hammering, stamping, forging, rolling and extrusion, to computer-aided-manufacturing, rapid prototyping, and 3D printing. These processes have evolved from individual products to mass manufacturing (globalization) and are now settling down to a mix of mass and custom manufacturing. A product can be a single component or the assembly of sub-components to achieve a desired function. Thus, the manufacturing process can be categorized as processing and assembly operations (Figure 2). Based on the selected material for a design part, probable manufacturing processes can be identified. Depending on the product cost and batch constraints, a manufacturing process can be selected. It is possible that a selected manufacturing process turns out not being able to deliver the expected quality using the selected material. Thus, an upstream decision may need to be modified. In this study, a manufacturing process for a design part with a selected material will be chosen based on the Ansys (CES) Granta EduPack software [www.ansys.com].

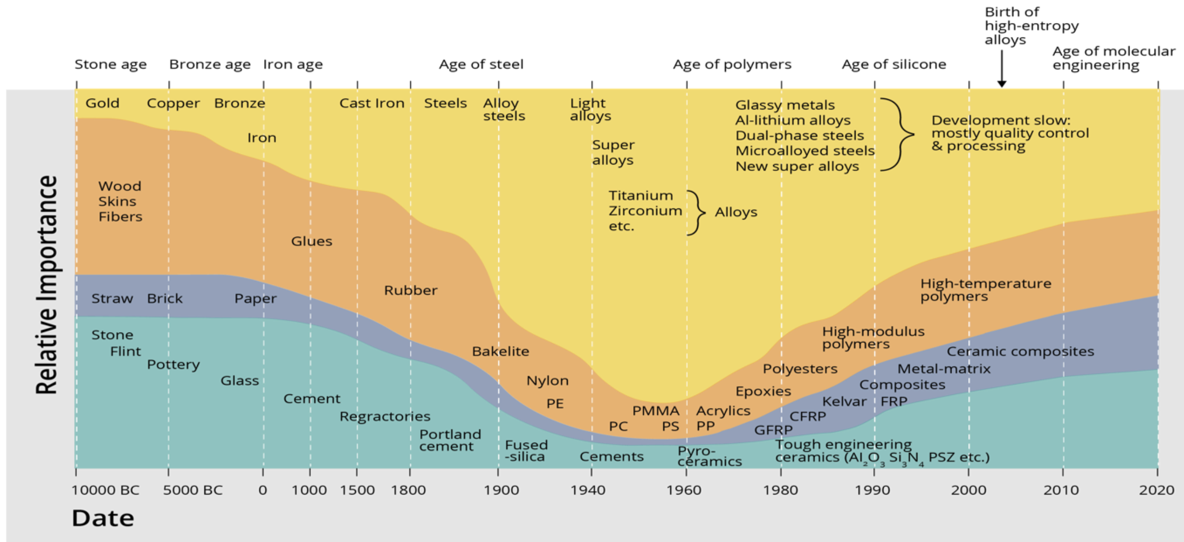


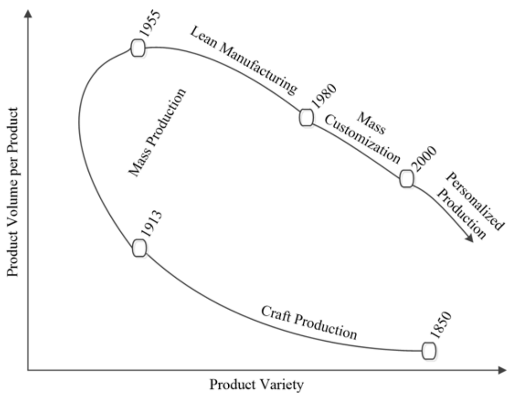
Figure 2. Evolution of engineering materials (Adapted from [11])

1.4 Manufacturing Systems

Manufacturing has evolved through several paradigms that are induced by new market and economy conditions, technology advancement, and social needs [14]. The evolution of manufacturing paradigms is shown in Figure 3. The five main paradigms are craft production, mass production, lean production, mass customization, and personalized production. Drivers for the paradigms include globalization, technological advancements, and societal needs. Understanding different manufacturing paradigms allows the extrapolation of future trends through analysis and specification of the key drivers behind the changes [15].

1.5 Manufacturing Technologies

The evolution of manufacturing technologies started with Industry 1.0, which began in the 18th century with the use of steam power and mechanization of production. Industry 2.0 began in the 19th century through the discovery of electricity and the introduction of assembly line production by Henry Ford. The Third Industrial Revolution, Industry 3.0, began in the ’70s in the 20th century through partial automation using memory-programmable controls and computers. We are currently experiencing the Fourth Industrial Revolution, Industry 4.0, characterized by the application of information and communication technologies to industry. The internet has created a pipeline that allows information to travel quickly and cheaply between buildings, factory locations, and different manufacturers at different levels in the supply chain. Industry 4.0 has grown out of several needs, on top of the list is the need to reduce production cost. Manufacturing technology has advanced side-by-side with the paradigms (i.e., craft production, mass production, lean manufacturing, mass customization, and personalized production) from Industry 1.0 to Industry 4.0, see Figure 4.



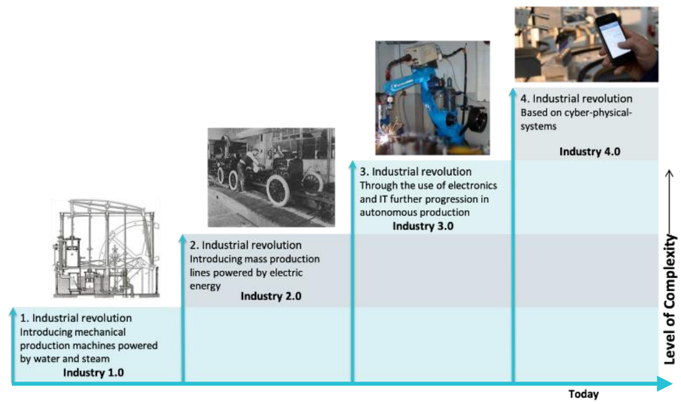


Figure 3. Manufacturing paradigms

Figure 4. Evolution of manufacturing technologies

1.6 Process and Information Systems

Business processes and information systems have been and will continue to be a critical part of supporting operations of modern manufacturing, the evolution of which is shown in Figure 5. The foundation for today's systems can be traced back to the 1960s when companies first introduced computer systems for inventory control. But it was not until the emergence of Enterprise Resource Planning (ERP) systems which allowed intra-companies processes to share information more effectively and efficiently, did organizations see significant larger scale company benefits. ERP systems automate and integrate business processes that can be found in a production environment, including business processes that take place to support manufacturing. They integrate organizational information regarding sales and distribution, procurement, inventory, financial and managerial accounting, and human resources.

As more companies acquired ERP systems, these systems were enhanced to support inter-company processes by extending information sharing and integration to external entities of organizations including suppliers and customers. By helping to integrate information sharing across the entire supply chain, ERP systems, known as ERP II or Extended ERP, enable companies to better plan their production requirements and optimize complex transportation logistics for raw materials and parts from suppliers and finished product to customers, resulting in improvements in the production and delivery of good. Shang and Seddon [16] based on their research of 233 ERP success stories published on the World Wide Web found that ERP systems lead to both managerial benefits, such as better resource management and improved decision making and planning, and operational benefits, such as improved costs, productivity, cycle time, quality, and customer service, as well as, strategic, IT Infrastructure, and organizational benefits.

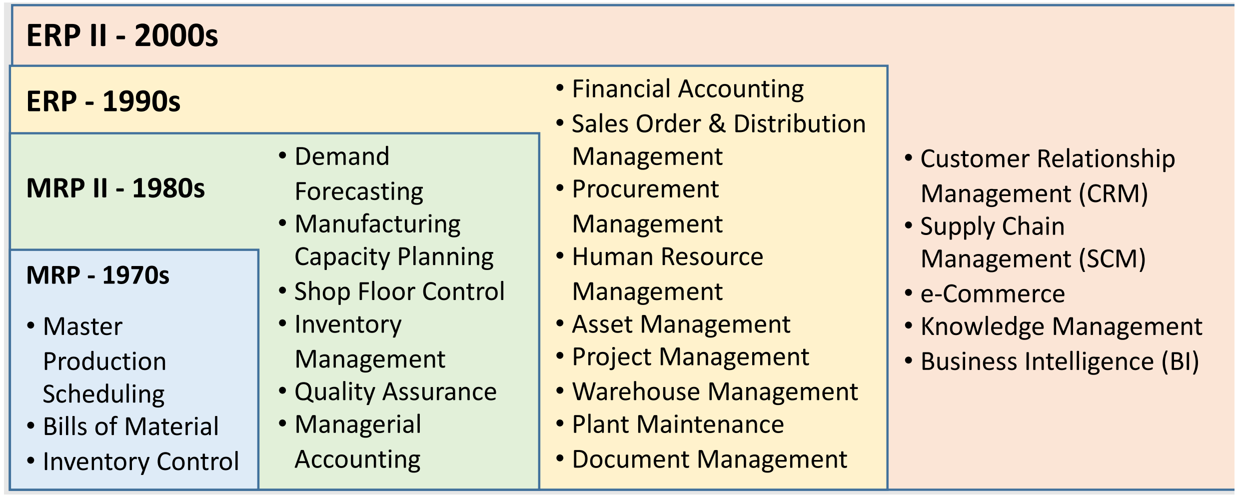


Figure 5. Evolution of manufacturing information systems

2. Relevant Literature

Today's manufacturing jobs are inherently interdisciplinary, and employees are expected to bring multiple skills to the table. To be successful, managers and engineers are asked to consider multiple aspects and evaluate trade-offs when making product and process-related decisions. While industry has become aware of the need to take a holistic view of product development, current engineering students and new graduates fail to make or realize the importance of various design connections [17]. Though traditionally engineering programs have successfully integrated design principles into their curriculum, the problem that remains is the design knowledge associated with each stage of product development life cycle is "siloed" into individual courses [18]. Thus, students transitioning into the real world who are rarely exposed to resolving such conflicts systematically have difficulty making the necessary connections between design for manufacturing, design for assembly, design for producibility, and design for logistics. It is our belief that more effort needs to be made if students are going to learn how to take a more holistic systems approach to product design and development. Students must learn to consider all aspects of the product development life cycle when making their design decisions and address that Design for X (DfX) principles can be complementary and at times contradictory.

Research suggests that to function effectively in modern organizations, professionals must be able to "understand the technical issues facing their organizations and the portfolio of ideas and projects that are in the pipeline at any time" [19] and be able to utilize technology and process to translate these ideas into products and services [20]. A key technology in this regard is ERP systems. ERP systems enable data and process integration across the entire organization [21]. Reports about the value of academic initiatives incorporating ERP in the curricula to promote cross-functional understanding of organizational processes is well documented [22-24]. This research looks to build on this work by demonstrating how knowledge flows and is captured through the entire product development life cycle.

Much of the previous literature has focused on the curriculum change or the presentation method of the course in the class. Even the Accreditation Board for Engineering and Technology (ABET) have changed the evaluation criteria to bring "quality assurance in higher education" [25]. However, only a limited number of studies in literature have discussed the development of learning modules to teach design and manufacturing and the integration of these modules across engineering curricula. The American Society of Mechanical Engineers (ASME) introduced the Vision 2030 task force which focuses on finding the current perception and help define the knowledge skill set needed for the upcoming era [26]. Their survey found a lack of capability among graduate students in project management and business processes. These two elements are considered in this research through learning about the life cycle of a bike from product conceptualization to manufacturing and marketability to illustrate the impact of decisions on the various parts of the life cycle of a product.

Based on the product development life cycle, the current research designs and builds linkages within and between courses in engineering and business curricula to provide students with a compressive and integrated view of how products in the real-world metamorphose from an idea into the hands of end-consumers. Specifically, we will focus on STEM skills used in manufacturing related courses (i.e., product design, manufacturing material and process, manufacturing system, and business process) to explain and demonstrate how decisions in one stage of the product life cycle impact later stages and vice versa. For product design, we focus on graphical and computer modeling of a new product taking into consideration aesthetics, ergonomics, and mechanical properties. Following product design, manufacturing processes show how to successfully produce the components of the product. In manufacturing systems, the required machines and labor are modeled. Finally, information systems, using a modern ERP system, demonstrate how to execute an integrated process and manage information flows to deliver the new product to the end consumer.

The proposed educational model is constructed to provide both depth within a phase of product design and breadth of knowledge across all phases of new product development. As students are introduced to the requisite knowledge associated with a specific product development phase (i.e., product design, manufacturing design, assembly design, facility design, logistics design), they will also be exposed to how current design decisions impact future decisions, and how current situations were impacted by prior design decisions. The instructional modules involve several applied activities allowing students to test and evaluate various solutions while reinforcing the connections between product development stages.

3. Holistic Design Approach for Manufacturing Learning

The holistic design approach for manufacturing learning utilizes the Understanding by Design [27] model to create instructional modules integrated into the undergraduate engineering and business curricula. The instructional objectives are established based on Bloom's taxonomy [28]. The proposed modules provide students with a compressive and integrated view of how products in the real-world metamorphose from an idea into the hands of end-consumers. Figure 6 shows the Bloom's taxonomy side by side with the manufacturing technical and transferable skills that are considered when we develop the instructional modules.

To solve problems at the system level, students need to realize the role each course plays in the context of a product development life cycle. They are also expected to explain how these courses are connected to manufacturing. An overarching lesson explaining the breadth of manufacturing and its building blocks is needed. Next, assessment items corresponding to these learning objectives were created. The assessment focuses on the lower level of Bloom's taxonomy (i.e., remember and understand) to measure students' basic understanding of manufacturing pillars. Guided by the learning objectives and assessments, a series of short video lessons was created by an interdisciplinary team of instructors. Instructors provided their content scripts along with examples, images, tables, and other visuals. Formative assessment items such as self-check questions were built in between the videos to keep students on track. Summative learning assessments were created for students to demonstrate their mastery of the critical concepts. This video series is integrated into current engineering and business undergraduate courses and pre- and post-survey data is collected and analyzed.

Figure 6. Bloom's taxonomy

At the course level, students are expected to be able to, in depth, design a solid product, choose, and process a material, bring the manufacturing of the product to a larger scale, and keep managing the necessary data to make important business decisions in the process. To achieve these learning objectives, we follow the same Understanding by Design model by mapping out the expected learning objectives and establish logical connections between the concepts essential to the product life cycle. The instructors assess higher-order thinking skills, including analyzing a situation, evaluating the options, and creating an innovative solution. Using the product development cycle as a blueprint, a realm of activities is designed to facilitate the teaching and learning process. The activities include dynamic modeling, simulations, case analysis, with an emphasis on interdependency between decision making and guided team interactions and reflections. The following sections discuss the main steps of the holistic design approach in detail.

3.1 Determining Learning Objectives

The first step of the Understanding by Design model, also known as "backward design", is to set the desired learning outcomes. In our study, these outcomes are related to what student should know, understand, and able to do. To make the interdisciplinary modules easily adaptable to a range of educational settings, we first examined the engineering and business accreditation standards, namely, Accreditation Board for Engineering and Technology (ABET), and Association to Advance Collegiate Schools of Business (AACSB), as well as the bodies of knowledge (BOKs) established by professional societies and institutes including: Institute of Electrical & Electronics Engineers (IEEE), Institution of Engineering & Technology (IET), Society for Manufacturing Engineers (SME), American Society for Mechanical Engineers (ASME), Institute of Industrial & Systems Engineers (IISE), and Association for Information Systems (AIS). Tables 1 shows the alignment of the learning modules and manufacturing concepts to the educational outcomes and standards. The relevant educational outcomes and standards are listed in Table 2.

Table 1. Aligning learning modules with educational outcomes and standards

Module	Example Concepts	Outcomes/ Standards	BOK
Product Design	CAD, product specification; Nonlinear systems modeling and simulation	ABET: 1, 2, 6, 7	IEEE, IET
Materials and Process	Stamping, Tube forming, Novel Processes	ABET: 1, 2, 5, 6	ASME, SME
Methods and Technology	Production Layout, Lean Six Sigma, Factory Dynamics	ABET: 2, 5	IISE, SME
Information System	Bill of material (BOM), Inventory, Warehousing, ERP/MRP/MPR II	AACSB: 4.1, 4.2, 4.3, 4.4	AIS

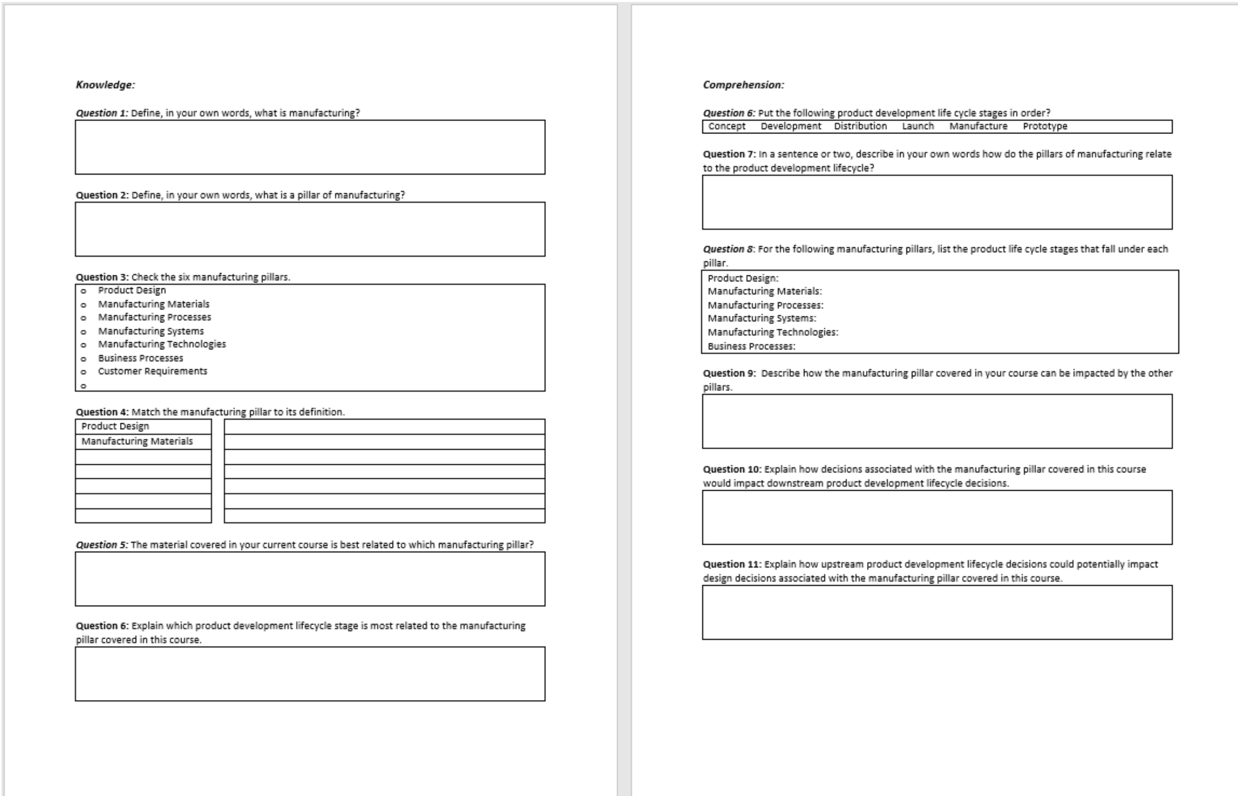
Table 2. Relevant educational outcomes and standards

ABET Relevant Outcomes	Relevant AACSB Standards
(1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. (6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions. (7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	4.1 The school delivers content that is current, relevant, forward-looking, globally oriented, aligned with program competency goals, and consistent with its mission, strategies, and expected outcomes. The curriculum content cultivates agility with current and emerging technologies. 4.2 The school manages its curriculum through assessment and other systematic review processes to ensure currency, relevancy, and competency. 4.3 The school's curriculum promotes and fosters innovation, experiential learning, and a lifelong learning mindset. Program elements promoting positive societal impact are included within the curriculum. 4.4 The school's curriculum facilitates meaningful learner-to-learner and learner-to faculty academic and professional engagement.

3.2 Assessment Instruments

The second step in the backwards design is to determine acceptable evidence for the learning outcomes. To do so, we developed assessment instruments which include a mix of multiple choice and open-ended questions to assess the learning modules. Questions can be written to assess various levels of learning outcomes in Bloom's taxonomy, from remember and understand to application, analysis, and evaluation. Our goal is to create assessment questions that can adequately measure the understanding and transfer of knowledge relative to the desired learning outcomes.

The multiple-choice questions are designed to require students to recall key principles as well as to identify relevant applicable knowledge or cause-and-effect relationships multiple-choice questions consisting of a question stem and a list of suggested alternatives. The stem presents the focus of the learning outcome while the alternatives consist of one correct or best answer and several incorrect or inferior alternatives, known as distractors. The design of the multiple-choice questions also incorporated several best practices including balancing the placement of the correct answer, avoiding question wording clues to the correct answer, listing only plausible distractors, and avoiding negatively phrased questions. But because multiple choice questions do have limitations; for example, they are not an effective way to test students' ability to organize thoughts or articulate explanations, open-ended were also used to capture learning outcomes associated with a student's reasoning and thought process. Samples of the questions developed are provided in Figure 7 below.



Knowledge:

Question 1: Define, in your own words, what is manufacturing?

Question 2: Define, in your own words, what is a pillar of manufacturing?

Question 3: Check the six manufacturing pillars.

- Product Design
- Manufacturing Materials
- Manufacturing Processes
- Manufacturing Systems
- Manufacturing Technologies
- Business Processes
- Customer Requirements

Question 4: Match the manufacturing pillar to its definition.

Product Design	
Manufacturing Materials	

Question 5: The material covered in your current course is best related to which manufacturing pillar?

Question 6: Explain which product development lifecycle stage is most related to the manufacturing pillar covered in this course.

Comprehension:

Question 6: Put the following product development life cycle stages in order?

Concept Development Distribution Launch Manufacture Prototype

Question 7: In a sentence or two, describe in your own words how do the pillars of manufacturing relate to the product development lifecycle?

***Question 8*:** For the following manufacturing pillars, list the product life cycle stages that fall under each pillar.

Product Design:
Manufacturing Materials:
Manufacturing Processes:
Manufacturing Systems:
Manufacturing Technologies:
Business Processes:

Question 9: Describe how the manufacturing pillar covered in your course can be impacted by the other pillars.

Question 10: Explain how decisions associated with the manufacturing pillar covered in this course would impact downstream product development lifecycle decisions.

Question 11: Explain how upstream product development lifecycle decisions could potentially impact design decisions associated with the manufacturing pillar covered in this course.

Figure 7. Example of survey questions for the first two levels of Bloom's taxonomy

3.3 Development of Learning Modules

The third step is to design and develop the learning modules that are integrated into undergraduate engineering and business courses. The learning modules are based on the manufacturing pillars shown in Figure 1. As illustrated in Figure 8, each learning module for a manufacturing pillar consists of six elements that are mapped to the six levels of Bloom taxonomy. The six elements are: (1) video lessons for describing and explaining manufacturing concepts, (2) a product life cycle case to develop a manufacturing comprehension, (3) modeling of manufacturing products and systems, (4) manufacturing simulation, (4) integrative manufacturing simulation, and (6) a senior design project by students from different programs to create a design of a manufacturing enterprise.

The first piece in Figure 8, Manufacturing Concepts, can be offered as part of a lecture or a stand-alone quiz. The second piece, Manufacturing Comprehension, can be offered as an interactive case study or course project. The third piece, Modeling, can be offered as in class activities where students work on developing a mathematical model to analyze the stability of the product or utilize a software to develop a 3D prototype of the product. The fourth and fifth pieces, Manufacturing Simulations, can be offered as in-class activities or labs. The sixth piece, Manufacturing Enterprise Design, can be offered as a senior design project.

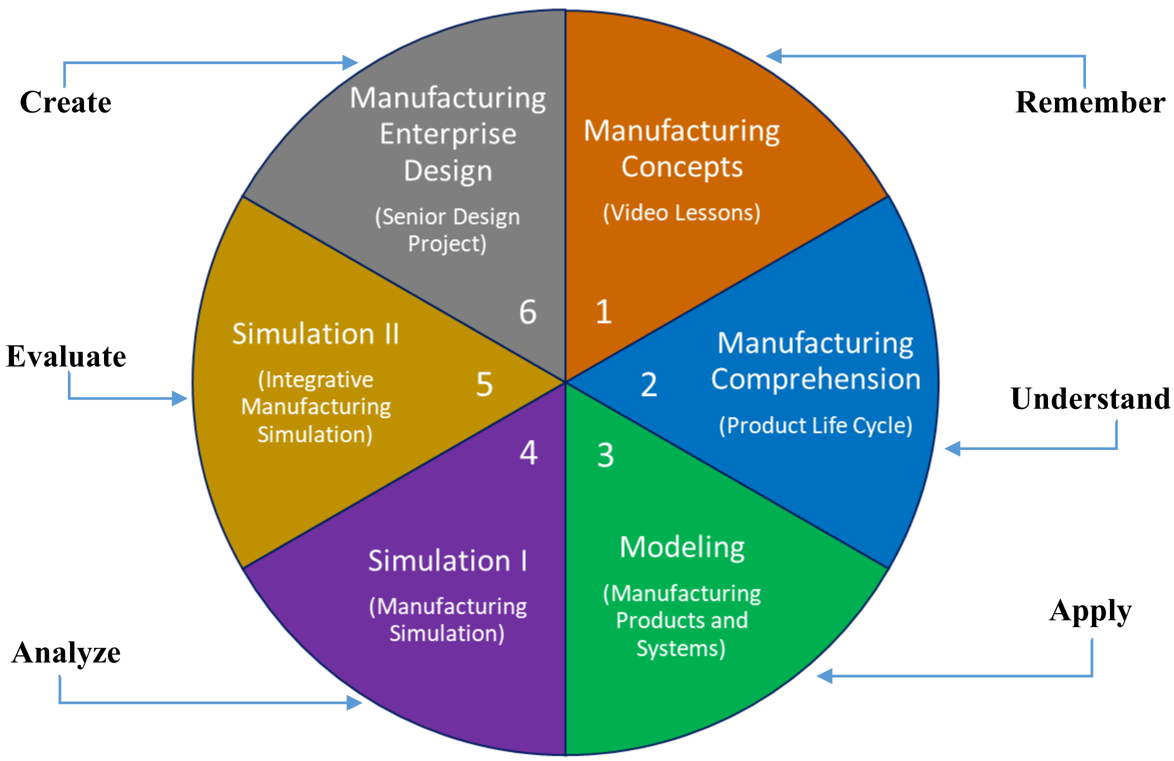


Figure 8. Key pieces of the learning module

4. Pilot Study

The proposed framework for teaching product manufacturing to undergraduate engineering and business students aims to integrate both technical knowledge and professional skills that are needed by students to succeed in the workplace. This process will prepare engineering graduates for the new manufacturing evolution. In this section, we present a pilot study of implementing the first component of the learning modules in undergraduate engineering and business courses – the series of video lessons introducing manufacturing and the connections between manufacturing pillars and how they are relevant to the courses (see sample screenshots in Figure 10). We call this video series the "breadth lesson."

In-depth learning modules are being developed and will be implemented in different manufacturing courses in engineering and business. Shown in Figure 9, the objective to integrate manufacturing knowledge across the product life cycle involves creating core learning modules including Product Design, Material & Process, System & Technology, and Information System. While each module focuses on topics related to its specific area, each will also cover the introductory topics from other modules. This approach provides both depth within a phase of product design and breadth of knowledge across all phases of new product development. In addition to teaching the technical skills, the modules also integrate various professional skills such as teamwork, communication, and system thinking. Through this approach it is hypothesized that students will develop real-world knowledge, techniques, and skills in STEM, thus better preparing them for the modern work environments.

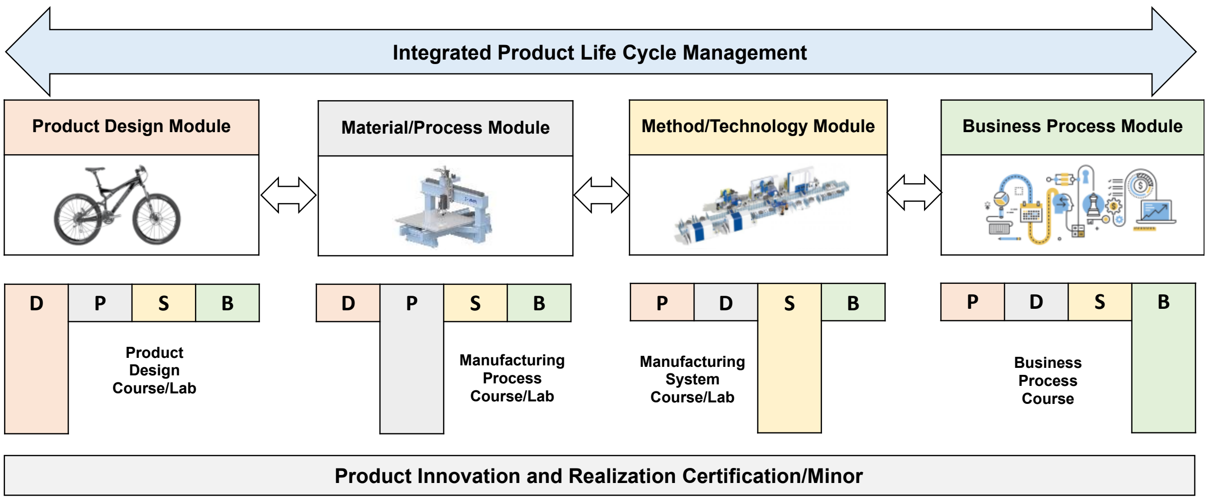


Figure 9. Manufacturing learning integration (D= Design, P= Process, S= System, B= Business)

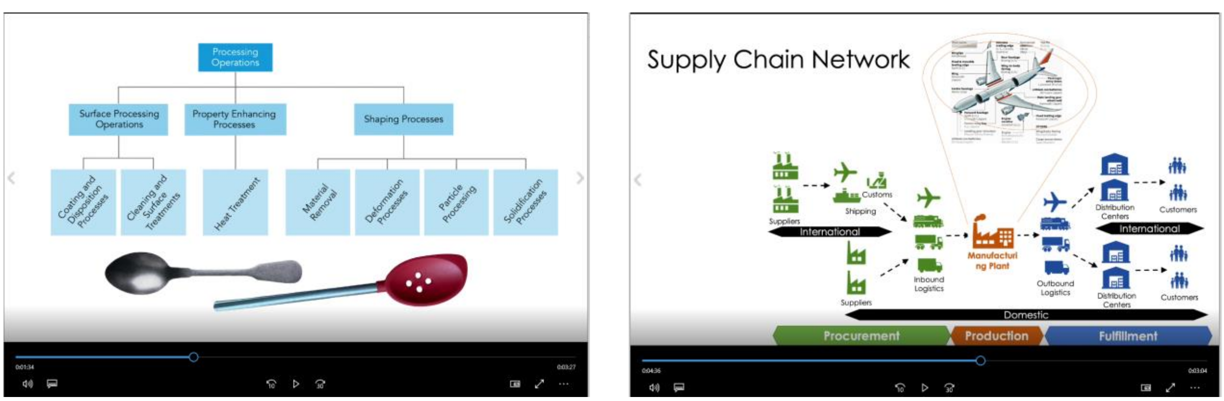


Figure 10. Snapshots from the videos

The focus of the modeling section is to study the balancing and steering behavior of a bicycle. Impacts of bicycle components, elasticity of the bicycle parts, tire-road interaction and the complexity of the rider model are considered in the modeling phase. The forces between the wheels and ground, acceleration and braking as well as balancing and steering are considered in the model. Second order differential equations are derived first to shed light on the basic behavior of a bicycle. After model linearization, impacts of different components including the front fork are studied both in state space and in Laplace domain. Stabilization via the steering angle for manual control is then studied. Maneuvering challenges and effects of rider lean will then be analyzed. For further and more accurate studies, a nonlinear fourth order model in state space is developed.

4.1 Participants

After the video and assessment items were developed, the video and aligning assessments were piloted with a group of upper-level undergraduate students (N = 50). Ten participants were removed from the data set because embedded timing data indicated they did not watch the videos. The remaining sample was majority male (70%; Female 15%; Not selected 15%) and white (80%; Asian/Pacific Islander 2.5%; Hispanic 2.5%; Not selected 15%). This sample was comprised of 62.5% Engineering majors, 22.5% Business majors, and 15% with no reported major.

4.2 Materials

The breadth lesion (Video chapters 1 – 5). The Pillars of Manufacturing Video Lesson was broken into five short segments for students to watch (Chapter 1 = 5:25; Chapter 2 = 1:31; Chapter 3 = 2:43; Chapter 4 = 2:05; Chapter 5 = 5:27). After watching each chapter, participants answered a few knowledge-check items to monitor student comprehension and engagement during that segment. The items were scored for accuracy and totaled for each video segment.

Engineering Identity. Engineering Identity is measured using an eleven-item Likert Scale survey [29]. This was only administered to Engineering majors and showed strong reliability ($\boldsymbol{\alpha}$ = .92).

Engineering Efficacy. Engineering Efficacy is a validated five-item survey answered on a 7-point Likert scale ($\boldsymbol{\alpha}$ = .85; [30]).

Business Efficacy. Business efficacy was measured using an adapted version of the Engineering Efficacy survey ($\boldsymbol{\alpha}$ = .81). The word “Engineering” was replaced with “Business” and all other items remained the same.

Final Knowledge Assessment. A 10-item multiple choice assessment was created to measure final knowledge of the pillars of manufacturing ($\boldsymbol{\alpha}$ = .65).

4.3 Procedures

Students currently enrolled in three engineering and business courses were invited via a link in Qualtrics to participate in this pilot study for course extra credit. Those who selected to participate began by completing a short pre-survey including a demographic questionnaire, engineering efficacy survey, and identity survey. The breadth video lesson was divided into five chapters covering the manufacturing pillars (chapter 1: design; chapter 2: material; chapter 3: process; chapter 4: system and technology; chapter 5: information system). After completing the video chapters and its check-up questions, students completed the final knowledge test. Time spent on each video chapter was documented to monitor engagement with the content videos. At any point of the video lesson, students are able to pause, replay a selected portion, and use the screen captioning to read the transcripts.

4.4 Analysis

Means and standard deviations are shown in Table 3. Exploratory analysis began with Pearson Correlations to identify potential relationships between variables. As shown in Table 4, there were some significant correlations between variables. For the purpose of this pilot study, it is most notable that there was not a correlation between Video chapters 2 and 3 and the Final knowledge assessment. This suggests the measures need to be altered to better align content coverage and assessment items more closely.

Table 3. Means and standard deviations

	N	M	SD	Maximum Score
Engineering Identity	25	62.12	9.82	77
Engineering Efficacy	25	25.64	4.57	35
Business Efficacy	9	31.11	2.67	35
Video chapter 1	40	12.93	1.64	15
Video chapter 2	40	3.83	0.38	4
Video chapter 3	40	7.08	0.97	8
Video chapter 4	40	8.15	2.08	12
Video chapter 5	40	1.9	0.59	3
Final Knowledge	33	8.03	1.74	10

In order to examine whether there was a difference between business and engineering students in terms of understanding the content of the breadth lesson, independent samples t-tests were conducted comparing assessment performance between Engineering and Business majors. There were no significant differences between the two majors for the video chapters (Video 1: $t(32) = 1.57$, $p = .13$; Video 2: $t(32) = 1.44$, $p = .21$; Video 3: $t(32) = .67$, $p = .51$; Video 4: $t(32) = 1.66$, $p = .11$; Video 5: $t(32) = -0.92$, $p = .36$;] or the final knowledge assessment [$t(31) = .96$, $p = .48$]. This suggests the accessibility of the specific content covered is not impacted by prior knowledge.

Table 4. Correlations between assessments, efficacy, and identity

	1	2	3	4	5	6	7	8	9
1. Engineering Identity	1								
2. Engineering Efficacy	.72**	1							
3. Business Efficacy	.	.	1						
4. Video 1	0.01	0.2	.53*	1					
5. Video 2	-0.34	-0.23	0.32	.31*	1				
6. Video 3	-0.15	-0.08	0.03	0.04	0.04	1			
7. Video 4	.41*	0.19	0.33	.35*	-0.11	0.12	1		
8. Video 5	-0.35	-0.13	0.4	0.2	0.16	0.24	0.17	1	
9. Final Knowledge	0.05	.45*	.52*	.36*	-0.03	0.2	.37*	.61**	1

** = $p < .01$ (two-tailed); * = $p < .05$ (two-tailed)

5. Conclusion and Future Work

This study presented a holistic design approach based on Bloom's taxonomy and Understanding by Design model to integrate manufacturing learning in undergraduate engineering and business courses. Learning modules corresponding to the manufacturing pillars are developed based on the backward design model and mapped to the levels of Bloom's taxonomy. The first element of the learning modules is a series of videos containing embedded self-check questions for manufacturing concepts. This element was tested in this study and data was collected from undergraduate engineering and business courses. The next steps of this study include refining the video series of the overall introduction to manufacturing. First, assessment items will be aligned more closely to the learning objectives, particularly in areas where an assessment item negatively correlated with a video chapter. Second, the video lesson series can use more aural and visual cues by adding sound effects or animation to facilitate learning. At the course level, the team will continue to finalize learning modules and activities in each course to strengthen student problem-solving skills technically and professionally. Next steps of this research will also include the design and development of depth modules for manufacturing education to teach the domain knowledge. It will also include the integration of professional skills such as teamwork and communication.

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