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Industry 4.0 and Modernizing Manufacturing Education

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Abstract
Industries are encouraged to work together to reduce the time to talent, or the period when an employee transitions from entry-level to being able to effectively contribute to achieving the organization's goals. There is some material related to Industry 4.0, but there is also a need for insight into topics like design for manufacturing, design for sustainability and generative design along with minimal practical exercises for integrating tools like product lifecycle, simulation, and material selection into engineering education. This report provides a step-by-step guide on integrating an Industry 4.0 curriculum into two and four-year institutions alongside outlining the exact content that could be taught in mechanical and manufacturing engineering programs. The American Society of Mechanical Engineers (ASME) and Autodesk suggest a modular approach involving core themes and concepts, case studies, real-world examples, self-assessments, videos, and hands-on exercises for the six modules covering design for sustainability to advanced AI/ML and automation. By providing projects based in the real world and up-to-date content, professors have an easier time integrating this curriculum into their classrooms while inspiring the next generation of engineers.

Introduction and Objectives
The "Fourth Industrial Revolution," or Industry 4.0, refers to the rapid advancements in manufacturing and technological advancement in the 21st century. According to Autodesk's *2024 State of Design & Make* report, more than 77% of design and manufacturing respondents prioritize technology, new products and services, and AI and emerging technologies for future investment [4].

For manufacturing to meet current, fast-paced demands, companies need to determine ways to shorten product development cycles, increase productivity and profitability, reduce costs, and meet customer expectations. To meet these business objectives and gain competitive advantages, new Artificial Intelligence/Machine Learning (AI/ML) driven technologies such as simulation, generative design, design for manufacturing, business intelligence solutions, robotics, design for sustainability, and many more need to be learned and utilized. The *2024 State of Design & Make* report found that 50% of design and manufacturing respondents are specifically using AI to increase productivity, and the ability to implement and work with AI is ranked number one for top skills for the future [4].

However, the complexity of these technologies is constantly changing, and it is difficult to keep up with the continuous upgrades and capabilities. Faculty of 2-year and 4-year institutions are also feeling pressured to implement and teach Industry 4.0 concepts in the classroom along with meeting their course and accreditation objectives. Industries are demanding that an educational transformation be made to change how mechanical engineers, manufacturing engineers, and CNC machinists are learning the skills required to meet modern and future workforce needs.

In fact, many jobs that young people are being trained for today may not exist or may be substantially different by the time these young people enter the workforce. Industry 4.0 is a new era. Education must adapt to this new era for students to be successful in their future careers. If the education ecosystem does not adapt, then the time to talent (time it takes for a recent graduate to become effective in a role) will continue to widen, impacting the profitability and viability of a broad range of industries.

The objective of this report is to: 1. Summarize findings of all barriers with teaching Industry 4.0 hard and soft skills through conducted desk research, faculty interviews, discussion with the Accreditation Board of Education of Technology (ABET), and feedback received from faculty at the 2023 Autodesk Educator Summer Summit. 2. Provide a step-by-step approach to implementing an Industry 4.0 curriculum in the classroom, and 3. Provide a recommendation of the curriculum and specific content that should be taught and implemented in mechanical and manufacturing engineering programs.

Reducing Time to Talent

Industry-related research reports that there is a need to reduce time to talent. Time to talent is defined as the time an entry-level employee joins an organization to the time they can fully contribute towards projects and workflows. Students find it difficult to apply the theories they learn in classrooms in real-world applications. Companies are having to spend extra time and money to train workers with the skills needed to perform well for the job they hire them to do such as computing, data analysis, designing, and modeling. Only 45% of design and manufacturing respondents for the *2024 State of Design & Make* report [4] say their organizations have the necessary skills and resources to design internal training programs, making it difficult for companies to effectively train employees. New, qualified workers adept with Industry 4.0 skills are essential to growth [4]. Reducing time to talent directly impacts both profitability and viability of a business and relationships with new and existing customers.

The most critical roles in manufacturing will be mechanical engineers, manufacturing engineers, and CNC machinists. These three positions will need to have specific hard, soft, and interdisciplinary skills to be successful in their roles and to contribute towards meeting company goals and milestones. So what skills are needed? ASME and Autodesk collaborated on a comprehensive research study that consisted of three phases. The study encompassed the examination of 77 scholarly sources (including Occupational Information Network (ONet) and Burning Glass), the conduction of 30 individual interviews with academics (10 faculty, 20 industry leaders), and gathered responses from a survey distributed to representatives from both academic and industry sectors. Based on the analysis, the following statistics illustrate the specific skills required to address the skills gap.

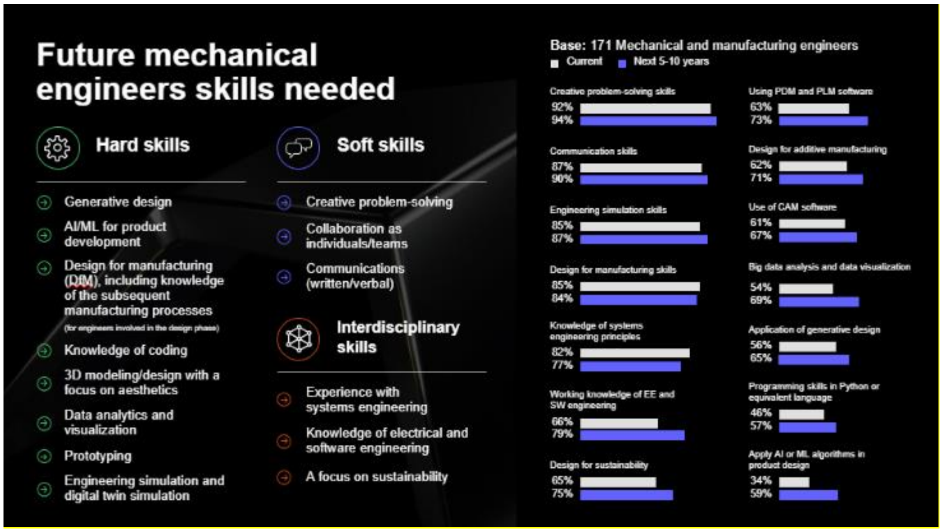

Figure 1: Future Mechanical Engineer Skills Needed [3],[9]

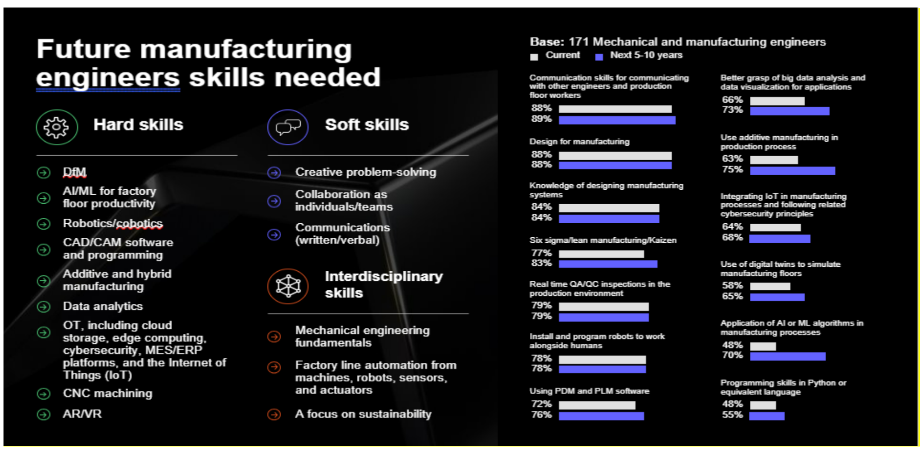

Figure 2: Future Manufacturing Engineer Skills Needed [3],[10]

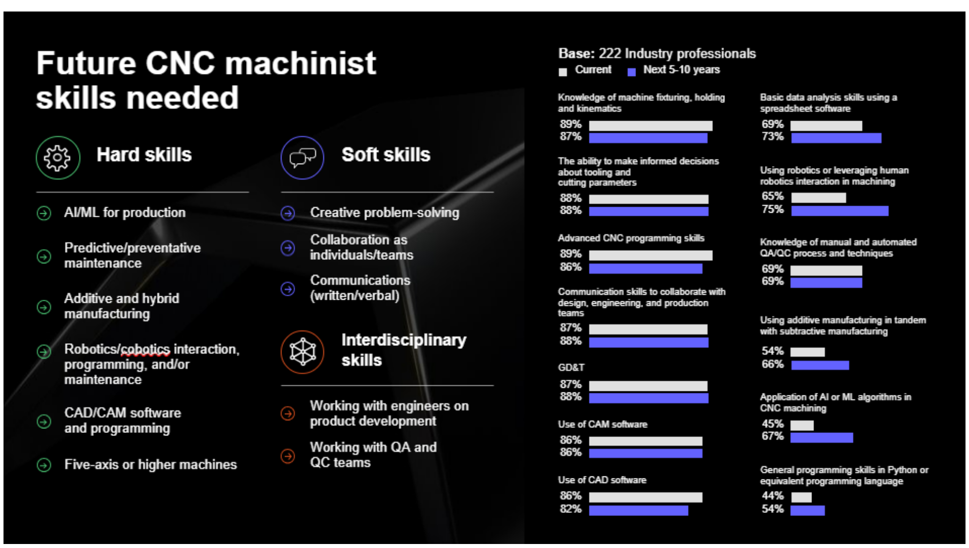

Figure 3: Future CNC Machinist Skills Needed [3],[11]

The top hard skills needed for all three positions are design for manufacturing (DfM) and AI/ML. The soft skills that are needed are problem solving, collaboration, and communication. And the interdisciplinary skills needed for each role are:

Mechanical Engineers

- AI/ML
- Design for manufacturing
- Generative design for manufacturing
- Integrated CAD/CAM

Manufacturing Engineers

- AI/ML
- CNC machining
- Robotics
- Integrated CAD/CAM

CNC Machinist

- AI/ML
- Robotics
- Integrated CAD/CAM

The Role of Educators

Educators play a very significant role in ensuring that the skills gap across all three roles is closed by providing the necessary education and training so that students are workforce ready. This can be achieved in many ways such as 1) introducing projects with more real-world applications, 2) have a stronger emphasis on hands-on learning, 3) partner up with engineering and manufacturing employers on new types of certification programs for modernized software, technology, and machines, and 4) working with government agencies for specific workforce development programs. All these methods impact the goal of reducing time to talent.

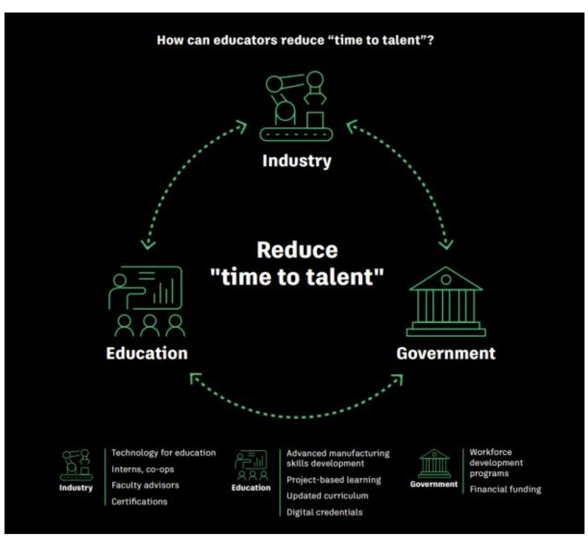

Figure 4: How Can Educators Reduce Time to Talent? [5]

Faculty Feedback
ASME had the pleasure of presenting the above research findings to 37 faculty and educator attendees at the 2023 Autodesk Educator Summer Summit. After the presentation, ASME and others present participated in a discussion/listening session. They also provided insights on current challenges, how Industry 4.0 curriculum can be implemented in their classrooms, and the resources needed for implementation. The central themes were the following:

1. There has always been a focus on grades, scores, and G.P.A.s, and students are afraid of making mistakes and embracing innovation. It is difficult to retrain students' minds within 2-4 years. Therefore, hard, and soft skills need to be introduced at the K-12 stage.
2. Bringing real-world problems into the classroom via capstone problems and other hands-on exercises is not only the most effective way to spark interest in engineering, but also teaches soft skills like problem solving and collaboration.
3. With so much screen time on mobile phones, computers, and other electronic devices, engaging with students and incorporating soft skills into lesson plans is very difficult.
4. Internships and paid employment are great opportunities and motivators. However, a strong, skills-focused program can easily mold future engineers as well.

Faculty agrees with industry leaders and representatives that academia and companies should collaborate to not only stay abreast of the latest developments in manufacturing, but also provide a pathway for students to take advantage of mentorships and career opportunities. Another resource that educators seek is the ability to create video content. Videos are the new way of learning as they provide a real-world, interactive, and immersive experience. Video field trips are also a great way to experience other industries, cities, and countries when the budget is limited. However, universities do not have the proper resources to produce such videos.

Nevertheless, even though faculty agrees with industry leaders and industry advisory boards, the consensus is that that the resistance is coming from other academic leaders of universities. Part of the resistance to change is the belief that the introduction of new concepts may risk their accreditation status for their engineering programs. After receiving similar feedback from multiple faculty members in various universities, ASME and Autodesk took the initiative to speak to ABET to address these concerns.

ABET's Perspective; Criteria for Accrediting Engineering Programs
ABET, or the Accreditation Board for Engineering and Technology, is a non-profit, non-governmental organization that accredits college and university programs in applied and natural science, computing, engineering, and engineering technology. ABET works to ensure that these programs meet the quality standards necessary to prepare graduates for successful careers in their chosen fields post-graduation.

To address the concern that a program's ABET accreditation will potentially be in danger if innovative changes in curriculum are implemented, the ABET criteria was reviewed for any language that may suggest this is the case.

The introduction to the 2023-2024 Engineering Accreditation Commission (EAC) criteria states that it is "intended to foster the systematic pursuit of improvement in the quality of engineering education that satisfies the needs of its constituencies in a dynamic and competitive environment [6]."

According to Criterion 3, Student Outcomes, graduates should be:

- Prepared to enter professional practice. The program must have documented student outcomes that support the program's educational objectives.
- Be able 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 [6].

According to Criterion 5, Curriculum, curriculum must include "a broad education component that complements the technical content of the curriculum and is consistent with the program educational objectives [6]." Specific criteria are 30 semester credit hours of math and basic science. There is another minimum 45 semester credit hours available for programs to include appropriate topics in design and utilizing modern engineering tools.

In the Self-Study report, Table 5-1 Curriculum [6], there is an option to check a column if the courses contain significant design and suggests that credit is given in this area. This is the space where programs can supplement their courses with innovative practices.

In reviewing the criteria, if the minimum requirements are met as stated, there are no other factors that prevent a program from using education tools that will enhance students' learning experience.

Director and Program Evaluator Interviews

To better understand the relationship between ABET Accreditation and curriculum changes, the interview stage of this process began with an in-depth conversation with Jane Emmet, Director of Accreditation Operations at ABET. Emmet reiterated that there is no barrier to being innovative in the classroom if core classes and concepts are addressed. There are no criteria that prevent a faculty member from introducing modules into the classroom that would enhance curriculum. ABET encourages input from industry and provides various outlets for programs to showcase how they are addressing the criteria in creative ways.

On the recommendation of Emmet, program evaluators (PEVs) were also interviewed to gain on-the-ground insight of criteria application and what programming has been observed at various institutions who have achieved accreditation. PEVs selected for this interview portion each have at least eight years of program evaluation experience.

In summary, feedback from interviews to address the innovation concern included:

- ABET doesn't approve classes. They approve programs so there is room for faculty innovation.
- Mechanical engineering criteria developed by ASME EAC and ETAC Commission members are broadly defined, leaving opportunity to supplement coursework as needed without the risk of negative impact on a certain criterion.

- Ensuring students have flexibility in their program is key. Mechanical engineering electives are free electives that can be taken in business, public policy, education, and sciences, which allows additional room for innovation in the electives portion of the program.
- Personalize the learning experience for students to meet their goals and fill the skills gap, including developing business acumen.
- Provide useful capstone experiences that enhance the learning experience for students.
- Having student artifacts leads to improvements in assessments.
- Institutions should develop industry advisory boards.
- Make engineering topics related to everyday life problems the industry faces.
- Connect with new faculty to ensure they fully understand the accreditation process and the criteria, in addition to training on innovative curriculum ideas that would complement the core courses they teach.

Schools with Innovative Programs

Weaving innovative practices into the classroom is not a new concept. Many universities have found ways to prepare students for their careers and comply with ABET accreditation criteria. One way to encourage more programs to move away from antiquated ways of teaching engineering, to be more inventive, and release the fear of losing ABET accreditation is to provide examples of programs that have shown success in navigating the two. Research was conducted on accredited universities with innovative programs. The following are a few examples:

- We have feedback from multiple universities that have nine accredited undergraduate engineering programs. The universities' engineering schools have designed their programs to be industry focused while maintaining accreditation through industry-sponsored design projects. To adequately prepare students with the skills industry needs, each engineering program has an industry advisory council and provides opportunities for students to conduct team-based research and design projects.
- A university in Minnesota is an ABET accredited program specifically for students transferring from a community college or the equivalent. The program prepares students through coursework in the context of co-operative, work-based learning where students work closely with industry partners on design projects in their last two years.
- A team of faculty at a university in New Jersey recently received a prestigious national award for their innovative practices. They developed an immersive digital game to be used as an educational and training tool to help students envision themselves as a chemical engineer. In the game, the player is asked to make decisions and solve problems as if they are working as an engineer in the field, providing some hands-on learning while not leaving the classroom.

Student Competitions and "Hands-On" Experience

Faculty, industries, and ABET are in consensus that hands-on learning and incorporating projects with real-world applications is not only the best way to expose students to engineering, but also gives students the ability to practice problem solving skills and collaborate with engineering students and colleagues from other disciplinaries. This helps instill other skills such as communication and project management. While real-world projects remain the best way to facilitate students' application of knowledge, it can be difficult to source enough industry-driven, real-world projects to meet the needs of the student population. Student competitions offer an easily accessible and scalable alternative for hands-on experiences.

There are many existing competitions that promote hands-on learning to gauge an interest in STEM fields such as the Annual Aviation Design Challenge hosted by the General Aviation Manufacturers Association, the National Science Bowl hosted by the U.S. Department of Energy, and the MathWorks Math Modeling Challenge. As a way of supporting this method of learning, ASME and Autodesk partnered for the 2024 ASME Extended Reality Challenge (XRC): Sustainability Innovations for Ocean Cleanup Competition. This year's challenge was to design a fully autonomous robot to collect debris from the ocean. Students had to avoid marine obstacles, use Autodesk Fusion or an equivalent software to design their robot, incorporate sustainable materials to construct the robot and/or use a sustainable power source such as solar power, wind, etc.

The objective of this competition was for students to incorporate Industry 4.0 concepts from the first four modules (refer to Section 8) into a virtual reality competition while learning about sustainability and global issues. The competition finals took place on March 16, 2024, during ASME's Engineering Festivals (E-Fest) where prizes and points were awarded based on the performance of the robot, the effectiveness of the design, and how well the students thought about real-world application by considering scalability, the use of modern technologies, product life cycle, and how their design could be integrated into existing infrastructure.

Interviews with Mechanical Engineering Professors

Mechanical engineering professors will play the most significant role in teaching Industry 4.0 concepts to current and prospective engineering students. Before implementing and suggesting new content to teach, it is necessary to gain perspective on:

- Current experiences teaching Industry 4.0 topics in mechanical engineering classes, including needed skills, and keeping current with industry trends
- Hindrances teaching Industry 4.0 skills and techniques, such as lack of experience, resources, resistance from faculty, concerns about accreditation, and other issues
- Impact of industry, faculty, and students in choosing how to teach Industry 4.0 topics
- Resources highly in demand (ex: videos, exercises, instructor guides, projects, etc.)
- Thoughts and areas of improvement of currently available Autodesk projects
- Curricular adoption process.

ASME in collaboration with Jim Warrick from Beacon Technology Partners, LLC [8] conducted ten in-depth telephone interviews with mechanical engineering professors. The selection of professors was across five countries, and all were engaged in teaching Industry 4.0 concepts in their classrooms. The professors selected were from the following institutions:

Table 1: Roster of Mechanical Engineering Professor Interviewees

Professor Name	Title	University Affiliation	Country
Prof. Dr.-Ing. Bernd Gundelsweiler	Professor Precision Engineering	University Stuttgart	Germany

Sunil Jha	Professor	Indian Institute of Technology Delhi	India
K V Gangadharan	Prof. Mechanical Engineering & Head Centre for System Design	National Institute of Technology Karnataka, (NITK) Surathkal	India
Masahiko Yamazaki	Associate Professor	Nihon University	Japan
Chennakesava Kadapa	Lecturer in Mechanical Engineering	Edinburgh Napier University	United Kingdom
Jun Xia	Senior Lecturer (Associate Professor)	Brunel University London	United Kingdom
Guha Manogharan	Associate Professor of Mechanical Engineering	Penn State	USA

Drivers of Industry 4.0 Educational Practices within Engineering Departments
Below is a summarization of various reasons why these seven professors as well as other professors incorporate Industry 4.0 concepts in their classrooms:

- Small and large manufacturing firms that hire new engineering graduates for entry-level positions seek candidates who are well versed in Industry 4.0 issues and technologies. Institutions with industry advisory boards and/or committees communicate trends, technologies, and current and future requirements to faculty so that professors can teach certain methodologies to impart the new skills that are in such high demand.
- Faculty recruited from the private sector understand what skills are in demand.
- Competition between colleges and universities for prospective engineering students causes them to reevaluate their curricula.
- Alumni are a potent force for change in that recent engineering graduates are invited to share insights and experiences after working in diverse industries. They compare skills that they were taught vs. skills they need to succeed in their fields and make recommendations to faculty on skills they should incorporate in their lesson plans.

Current Industry 4.0 Skills that are Taught and Utilized

There were many commonalities as to which skills are being prioritized and the approach that the professors are taking in teaching skills pertaining to Industry 4.0. One approach, which aligns with the feedback received from the 2023 Autodesk Educator Summer Summit, is that Industry 4.0 is constantly evolving, making it difficult to predict what specific problems students will have to help resolve. Instead of focusing on specific solutions, it is best to focus on methods. According to the professor from Germany, the goal is to give students the necessary tools to solve problems, not answers to test questions.

The second approach is to incorporate hands-on, real-world projects in the syllabi. The professor from Penn State Berks believes that this is the “only way to get students excited about engineering." It is an efficacious way to promote a fusion of theoretical engineering fundamentals with practical applications. Hands-on learning also helps develop soft skills such as communication and collaboration. It promotes "out of the box" thinking and shows that even the most complicated tasks and problems can be simplified when a diverse team is working together.

The third approach is to teach that engineering and business disciplines go together. Students will not forever be students, and universities are responsible for training the future generation of managers, executives, and even CEOs of various engineering industries. If technical skills are required for new innovations, then certain business skills are also necessary to be able to generate revenue from new innovations.

The fourth approach is incorporating more information technology (IT) related topics into the classroom such as data analytics, AI/ML, robotics, coding, programming, etc. Engineering is not only about design, but also about being able to understand and operate the new and upgraded equipment that is being used to produce a product. Professor Gundelsweiler from University Stuttgart said the following to highlight the importance of IT in engineering disciplines:

"Information technology and digital tools are taking engineering curricula by storm, key for Industry 4.0. But in mechanical engineering, integrating them subtly is the challenge. How can we seamlessly merge and analyze data from diverse formats across production lines to optimize efficiency?"

And, lastly, to help prepare the next generation of mechanical engineers, engineering programs utilize internships and emphasize across-the-board sustainability. Thinking about sustainability at every stage of the process from the design, the cost, how much power it will use, the environmental impact, and if there are alternative methods vital to succeed in the new era.

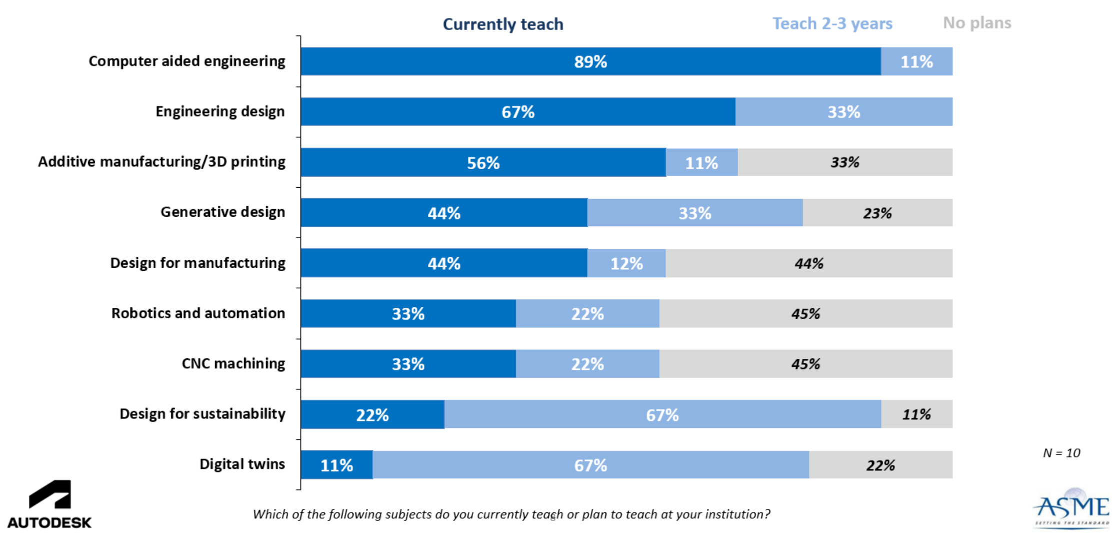

Figure 5: Industry 4.0 Subjects and Topics Being Taught [8]

Hindrances in Adopting Additional Industry 4.0 Concepts

There are quite a few challenges and hindrances that faculty face in adopting more, if not all, Industry 4.0 concepts in the classroom. The top reasons that were reiterated by the interviewees were the following:

- Time constraints: A significant amount of time is needed to develop a course that teaches valuable knowledge. However, by the time a course is developed, both industry and technology will have evolved.
- Lack of textbooks, lab equipment, capital, and other resources: There are few published textbooks on Industry 4.0 that faculty can use to develop a curriculum. Also, the software and equipment available to teach these concepts costs about $500,000. By the time the investment is made, the resources become outdated.
- Inexperienced faculty: Many professors that are required to teach these courses do not have production and/or manufacturing experience and are forced to teach many concepts to themselves by doing their own research.
- Resistance to change: After teaching for so many years, many more experienced engineering professors become comfortable with the course they developed and do not like to see changes within the curriculum.

However, engineering professors do meet frequently to discuss new topics and teaching methods.

Desired Resources

To be able to effectively teach Industry 4.0 concepts, a “must have” resource is a collection of real-world projects. As mentioned in Section 6.2.2, hands-on, real-world projects not only promote excitement for engineering, but help instill other skills such as project management, leadership, financial forecasting, risk analysis, etc. However, there are many universities that do not have the means to dedicate one or two full courses for students to work on a project. Therefore, having a library of “bite-sized” projects to choose from that take a couple of weeks to complete vs. a whole semester or year would be ideal.

Another resource that would be a significant help are instructional guides and textbooks. Currently, faculty curate their own instructional guides and textbooks. However, it is difficult to measure effectiveness. For example, Professor Masahiko Yamazaki from Nihon University in Japan created his own textbook and hands-on exercises. Having accessible material with ways to track progress would be beneficial for faculty and for students.

Furthermore, engineering professors are eager to see how their peers at other colleges and universities are progressing and how other engineering departments have implemented newer teaching approaches.

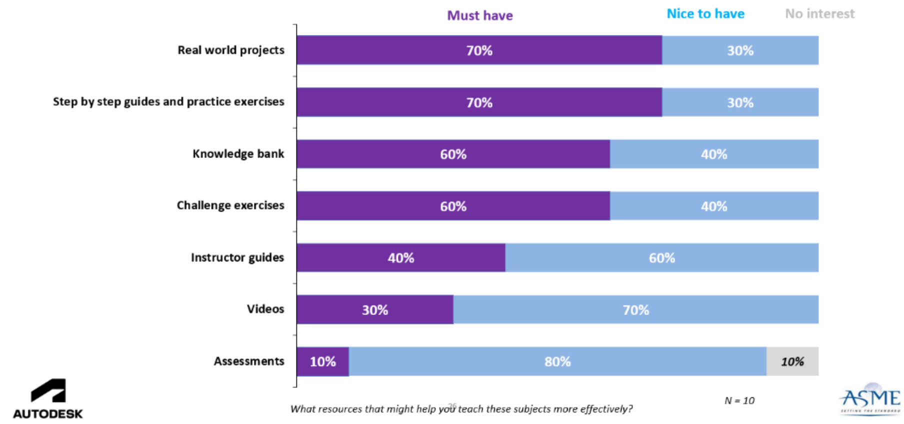

Figure 6: Desired resources [8]

Evaluation of Autodesk Projects

Regarding how the interviewees view Autodesk projects, the feedback was extremely positive. All ten professors stated that they would like access to Autodesk projects and nine out of the ten would give high priority for inserting into their new curriculum. Autodesk offers their teaching material for free to engineering departments and the variety of products that the company offers will benefit the rising generation of engineers.

Module Content Desk Research Common Themes

ASME conducted desk research to gain a better understanding of current online and university curricula, identifying gaps in existing content for learning Industry 4.0. This desk research was intended to supplement the anecdotal subjective findings from the interview research study conducted by ASME and Autodesk. The input from faculty and educators defined what could be improved in teaching Industry 4.0, while this desk research was intended to determine what content already existed for teaching Industry 4.0 and how it was lacking. The research focused on design for sustainability, communication skills for engineers, collaboration skills for engineers, design for manufacturing, and generative design. Tools such as search engines, educational databases, and online libraries were used, as well as university course catalogs and websites. Some keywords and phrases that were used in the search queries included “Industry 4.0,” “sustainability,” “design for sustainability,” “mechanical engineer,” “manufacturing engineer,” “design for engineering,” “generative design,” “artificial intelligence,” “CAD,” “big data,” “digital transformation,” and many more depending on the specific module content being researched. The most common themes and findings while researching all five topics were the following:

1. The abundance of material in each topic necessitates strategies to discern valuable information not only in academia, but also in industries. In all these domains, the task is to sift through the resources for valuable content that contributes to advancements in engineering education and Industry 4.0.
2. The rapid proliferation of resources in the researched domains presents a challenge as faculty’s efforts to create tailored content can swiftly become outdated, driving the need to prioritize core concepts, real-world examples, problem-solving skills, and communication skills to ensure enduring educational value despite rapid changes.

3. Interdisciplinary approaches are becoming increasingly important in engineering education and practice. But there is a lack of resources available to learn interdisciplinary communication and collaboration skills and few opportunities for students to exercise them.
4. There is an abundance of material on sustainability but a lack of material linking sustainable practices to each aspect of engineering and looking at the bigger environmental picture of topics such as design for manufacturing and generative design.
5. There is a wide range of available tools and software for life cycle assessment, material selection, digital manufacturing simulation, generative design, data analytics, project management, and more. However, there is a lack of integration of these tools into engineering education to equip students with the understanding and skills to readily employ them.
6. There is a general lack of hands-on exercises and self-assessments for students to practice and test their understanding of Industry 4.0 concepts, both within higher education curricula and online resources.
7. Prominent online platforms like Udemy (offers both free and paid courses), Coursera (free to audit but have paid enrollment), edX (free to audit but paid enrollment), LinkedIn Learning (only paid options, but offers free 1-month trial included with LinkedIn Premium), and MIT Open Courseware (free) host a variety of courses on all the researched topics, spanning foundational knowledge to advanced technical skills. The courses that require payment have graded assignments throughout and provide certificates upon completion.

Current Curricula

Design for Sustainability: The research revealed a surplus of existing material on product life cycle, ESG scores, life cycle assessment, circular economy and circular design, sustainable materials, and energy consumption. Common themes among university curricula include courses and degree programs on renewable energy, assessing environmental impact, green materials, and the importance of product life cycle considerations.

Communication Skills for Engineers: Researching educational resources on communication skills for engineers revealed an emphasis within university curricula on group projects, creating and delivering presentations, and technical writing. Online resources primarily focus on working as a part of and managing teams, and leadership skills.

Collaboration Skills for Engineers: Research on current university offerings for teaching and encouraging collaboration skills among engineers revealed the implementation of team projects with real-world scenarios, collaborative workspaces, and collaborative data-sharing platforms. Analysis of online resources revealed many courses on basic collaboration and project management skills as well as many options for project management and data-sharing software.

Design for Manufacturing (DfM): The research revealed many available guides and articles on DfM, including breakdowns of key principles. University curricula offer some courses specifically based on this concept and limited opportunities to practice DfM and observe how design changes affect manufacturability and environmental impact. A gap identified in these resources is the connection between designing for manufacturing and sustainability.

Generative Design: Research on current generative design resources revealed content on the theoretical foundation and concept of generative design and its use in prototyping and lightweighting. Universities are inhibited by limited access to generative design software, preventing hands-on learning.

Challenges for Future Module and Content Development

The main challenges for developing teaching content for Industry 4.0 concepts will be to:

1. Implement sorting mechanisms for the proliferation of materials on the topics identified by this research and discerning valuable information,
2. Develop course content that is unique and does not replicate existing curricula, and
3. Ensure content does not become outdated by continuously keeping pace with rapid evolution of technologies and updating, as necessary.

Some effective strategies to combat these challenges are to emphasize core concepts, integrate current examples and real-world case studies, teach problem-solving strategies, and implement communication and collaboration skills in all hands-on projects.

Recommended Module Content

The American Society of Mechanical Engineers and Autodesk suggest a modular approach which incorporates core themes and concepts, case studies which highlight real-world scenarios, assessment questions, engaging videos, and selected hands-on exercises which can be completed by utilizing the Autodesk Fusion software. The first four modules have been developed and will be available on Autodesk's learning management system. Module 1: Design for Sustainability is currently live and can be accessed by students and faculty [2]. Modules 2-4 are available for download on Autodesk's ShareFile site until they are live [1]. Modules 5 and 6 are currently available on Autodesk's learning management system. The last two modules are currently being developed and are estimated to be completed by July 24, 2024. All the modules will be available for faculty and student use by spring 2025. The modules will cover unique material specific to Industry 4.0 and will have a strong focus on skills required for each role (mechanical engineer, manufacturing engineer, and CNC machinist) to be successful as discussed in Section 2.1. Tables 1 and 2 below summarize the themes and content that will be covered in each module.

Table 2: Themes and Content for Modules 1-6 (both Student and Faculty Use)

Module	Learning Objectives
Module 1 – Design for Sustainability	• The triple bottom line • How supply chain impacts our environment • Impact of a product lifecycle tool on design solutions • How to have a mindset for sustainability • Ethical considerations
Module 2 – Introduction to Industry 4.0 & Technologies	• History of major industrial revolutions • What is Industry 4.0 and remaining challenges from Industry 3.0

	• Top technologies that comprise Industry 4.0 and examples of how they are used in the real-world • Pace of change for Industry 4.0 and skills required at each stage • Skills gaps for the three critical roles in manufacturing • How future generations will enact the change
Module 3 – Industry 4.0 & Business	• The business and economic drivers that are sparking change towards Industry 4.0 • How businesses and teams are changing • The impact that teams have on operations • The outcomes and data that will matter and impact day-to-day work • What is enterprise resource planning (ERP) • The effect of Industry 4.0 on both creation and displacement of jobs • How technology has played a role in decreasing manual labor and having more of a work-life balance • Setbacks caused by the pandemic and recession
Module 4 – Digital Literacy & Data Skills	• Overview of the manufacturing process and how we got to the era of digital manufacturing. • What is digital literacy and how it ties with digital manufacturing • How manufacturing is slowly transitioning to smart manufacturing and the top technologies driving this change • Role of big data • Differentiation between digital twins and simulation and how they optimize manufacturing processes • How cloud computing is used to store and process data • Creation and evolution of digital platforms • Role of digital literacy and data skills in real-time collaboration
Module 5 – The Evolution of Critical Roles in Manufacturing (in development)	• How manufacturing is changing with the adoption of Industry 4.0 and its emerging technologies • The role manufacturing plays in the global economy

	• The three main roles within manufacturing sector and how these roles are evolving • Case studies of how roles and emerging technologies such as AI, ML, robotics, and more are changing the landscape • Challenges that manufacturing industry is facing today • How to overcome these challenges • The benefits and disadvantages of generative AI • Insight into future roles and job titles that industries will create
Module 6 – Real-World Industry 4.0 Success Stories (in development)	• Delves into the real-world implementation of Industry 4.0 technologies within manufacturing • Detailed case studies of two leading companies and how Industry 4.0 technologies have revolutionized their production processes

All the modules will have self-assessment questions embedded throughout the lessons to gauge understanding of content and provide feedback to both ASME and Autodesk on topics that need attention.

First Four Modules – Student Feedback
Students who registered for E-Fest Digital and who completed all four modules were asked to participate in a survey to evaluate all four courses. The survey results showed that 85.70% of the respondents are "very satisfied" with the course (four Industry 4.0 learning modules), while 14.29% reported being "somewhat satisfied." Interestingly, there were no responses indicating "not very satisfied" or "not at all satisfied." Students expressed their enjoyment in learning about diverse topics such as sustainability, additive manufacturing, business strategies, innovation, and simulation. Furthermore, 50% of students "strongly agree" about applying the content to their jobs, while 50% "somewhat agree." The most impressive statistic was that 71.4% of respondents thought that the length of time and pace of the course and media integration to be "excellent," with an additional 28.57% stating that they were "good." Overall, the feedback from students suggests a high level of satisfaction with the four modules.

Step-by-Step Implementation of Curriculum in Classrooms
According to Autodesk's Transforming Manufacturing Education report [5], universities and educators can follow the step-by-step approach listed below to update current engineering programs to integrate Industry 4.0 requirements.

Step 1: Define the Industry 4.0 skills, technologies, and subjects to teach

- Reference the “Future of Manufacturing Whitepaper [3] for the current and future of mechanical engineer, manufacturing engineer, and CNC machinist skills.
- Identify the Industry 4.0 skills and technologies you will target to update your program.
- Connect with industry, technology, and learning partners to stay current on the new skills and tools in the industry.

Step 2: Determine the technologies needed to teach the skills

- Understand what technology is needed to teach Industry 4.0 skills.
- Find education programs from technology companies, industry firms, and government agencies to help fund new equipment or software.
- Learn how technology companies can support educators with training Industry 4.0 skills.

Step 3: Prepare yourself, your curricula, your classrooms, and labs

- Connect with technology partners to help identify the required technology, tools, and equipment.
- Identify gaps between your current training and equipment and Industry 4.0 requirements.
- Add new equipment or utilize current equipment to support new learning requirements.
- Contact technology partners for professional development training.
- Tap industry partners who can provide industry insights, technology training, and peer connections.

Step 4: Create initial Industry 4.0 skill development learning content

- Focus on specific Industry 4.0 skills needed to complement your curricula.
- Look for ways to incorporate Industry 4.0 skills into existing coursework with newly created or updated content or projects.
- Explore Autodesk projects, learning content, and role-aligned certifications to help get started.
- Connect with educator forums like the Fusion Educator Forum to get ideas and establish peer-to-peer connections.

Step 5: Expand the learning content catalog with scope, subject, and series

- Organize Industry 4.0 skill development content and competency levels.
- Consider interdisciplinary skills and knowledge development.
- Look for ways to partner with local industry and other technology departments inside and outside of your institution.
- Build a learning library with unique learning objectives and assemble content into coursework and project-based learning.
- Seek approval for new Industry 4.0 courses.
- See the Autodesk Educator Resource Center for courses, learning paths, and certifications.

Conclusion

Industry 4.0 era is here! Faculty, students, and industry leaders will all need to work together to reduce time to talent and ready current and future mechanical engineers, manufacturing engineers, and CNC machinists while keeping up with the constant advancements and innovative production processes. Nevertheless, the one common theme that all the conversations and interviews unveiled is that the best way to teach Industry 4.0 concepts is through the implementation of hands-on and real-world based projects. It is the most effective method to learn the complexities of the workforce in a way that encourages knowledge expansion and provides a safe environment to make mistakes and experiment with various solutions. Therefore, it is vital to provide thought provoking projects and valuable, up-to-date content for all engineering professors to incorporate in their classrooms and inspire the next generation of engineers.

Figure 7: Summarization of Industry 4.0 and Modernizing Manufacturing Education Paper

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