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# Advancing Engineering Education to Develop Industry 4.0 Skilled Workforce: Preparing Students for Industry 4.0

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# Advancing Engineering Education to Develop Industry 4.0 Skilled Workforce: Preparing Students for Industry 4.0

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## Abstract

Industry 4.0 that embraces the computerization in smart factories requires improved capacities in science, technology, engineering, and mathematical (STEM) fields. Nevertheless, the present circumstances in engineering education demonstrate some key challenges in preparing students for Industry 4.0, including exponential technological change, interdisciplinary cooperation, digital skills gap, curricular rigidity, lack of hands-on experience, faculty training and development. Thus, this study aims to prepare students and professionals with the necessary skills and knowledge in Industry 4.0 to thrive in the rapidly evolving landscape of the fourth industrial revolution by developing an engineering education ecosystem schematic, proposing some strategies to advance engineering education and develop an Industry 4.0 skilled workforce, and fostering innovation and interdisciplinary learning. A few contributions have been made to advance engineering education for developing Industry 4.0 skilled workforce, including developing engineering education ecosystem schematic to enhance the quality of engineering programs at community colleges through faculty development, curriculum alignment, and resource sharing. and identifying the skill set for Industry 4.0 workforce. By achieving these goals, advancing engineering education for industry 4.0 seeks to empower individuals with the skills, knowledge, and mindset needed to succeed in the digital age and contribute to the advancement of society and economy.

## Introduction

Industry 4.0, also known as the Fourth Industrial Revolution, represents a transformation in the way we produce goods and deliver services. It is characterized by the integration of digital technologies, automation, data exchange, and advanced manufacturing techniques to create smart, interconnected systems that can operate autonomously and adapt to changing conditions. This transformation is impacting various sectors including manufacturing, healthcare, transportation, energy, and agriculture, leading to increased efficiency, productivity, and innovation.

Preparing students for the demands of Industry 4.0 involves a multifaceted approach that integrates various disciplines within STEM (Science, Technology, Engineering, and Mathematics) education. The emergence of

Industry 4.0 presents several challenges for engineering education. Addressing these challenges is crucial to ensure that engineering graduates are adequately prepared to meet the demands of the rapidly evolving technological landscape. Some of the key challenges include: exponential technological change, interdisciplinary cooperation, digital skills gap, curricular rigidity, lack of hands-on experience, faculty training and development, etc..

Therefore, this study aims to prepare students and professionals with the necessary skills and knowledge in Industry 4.0 to thrive in the rapidly evolving landscape of the fourth industrial revolution by developing an engineering education ecosystem schematic, proposing some strategies to advance engineering education and develop an Industry 4.0 skilled workforce, and fostering innovation and interdisciplinary learning.

## Literature Review

Industry 4.0 consists of automation, physical cyber, smart sensors, Artificial Intelligence (AI), Internet of things (IoT), robotics, knowledge, innovation and talent. The Industry 4.0 that embraces the digitalization transformation in smart factories requires improved knowledge, skills and capacities in science, technology, engineering, and mathematical (STEM) fields. Workforce readiness in Industry 4.0 is a critical aspect that involves preparing individuals with the necessary skills and competencies to thrive in the rapidly evolving industrial landscape. A lot of efforts have been made to address engineering education in order to prepare Industry 4.0 skilled workforce.

Das, Kleinke and Pistrui (2020) stated that, unlike in earlier transformations, technological change is happening at an exponential rate; as a result, artifacts, knowledge, and expertise are becoming obsolete at a very fast rate [1]. In this study, they have explored the new model of engineering education and proposed Education 4.0 movement to go hand-in-hand with Industry 4.0. The significant contribution is that an education eco-system was proposed for K-12 perspective students and community perspective students to develop Industry 4.0 skilled workforce. However, this study has not discussed more details in how to build education eco-system and which stakeholders should be get involved. Some critical strategies are also deserved to be developed to encourage the collaboration between these stakeholders, which will be beneficial for both universities, companies and perspective students to develop Industry 4.0 skilled workforce.

The significant contribution of this paper [4] lies in its recognition of the profound impacts of Industry 4.0 on the higher education system, especially, the workforce development of future engineers. Qualitative data from various sources and literature has been utilized to identify critical requirements for STEM education in the transformative contexts, such as IT skills, teamwork, information literacy, flexibility, lifelong learning, adaptability, and the cognitive skills, form a comprehensive framework for addressing the demands of Industry 4.0. While acknowledging the significance of these soft skills in the face of rapidly evolving technologies and interdisciplinary challenges, the researchers have proposed a few valuable insights to reimage STEM education to meet the needs of Industry 4.0. However, this study should make more efforts to explore the connections between STEM education and Industry 5.0. In summary, the development of soft skills highlighted in this study can still be relevant in the contexts of Industry 5.0, where human-centric approaches and the integration of

technology with societal issues are emphasized. The ability to adapt, collaborate, and think critically, as advocated in the paper, can remain valuable as industries continue to evolve into the human-centered paradigm of Industry 5.0.

Buhler, M.M.; Jelinek, T.; Nubel (2022) proposed a paradigm shift in engineering education for the era of the Fourth Industrial Revolution, which accelerated by Artificial Intelligence (AI). With increased uncertainty that makes it impossible to predict, most engineering education and training systems have remained largely static and underinvested for decades and are inadequate for the emerging Industry 4.0 labor market [2]. We need to educate STEM students for a future whose key characteristics are volatility, uncertainty, complexity and ambiguity. Therefore, a STEM curriculum should combine timeless didactic traditions such as Socratic inquiry, mastery-based and project-based learning and first-principles thinking with novel elements, e.g., student-centered active and e-learning with a focus on case studies, as well as visualization/metaverse and gamification elements. In some studies, the newly STEM graduates are not well-prepared and capable of translating technologies into design and operational solutions to deal with industrial system complexities in Industry 4.0 [5].

Some researchers have conducted an analysis of the potential synergy between Industry 5.0 and Society 5.0 and the implications for STEM education [6]. By focusing the needs to place human beings at the center of innovation and integrating technology with societal goals and sustainability, this study aligns with the objectives of the United Nations Sustainable Development Goals, providing a strong basis for the argument. The discussions about the transformative roles of colleges universities in developing workforce innovation are well-supported. The study's recommendations for colleges and universities to utilize new channels of education, innovation and research within the contexts of the Quintuple Helix Model (QHM) and Society 5.0 are practical and forward-thinking. This forward-looking approach proposed in this study is consistent with the evolving Industry 4.0 and Industry 5.0, where focuses on sustainability and the human-centered innovation, providing significant contribution to STEM education in the contexts of Industry 4.0 and Industry 5.0.

The major contribution of this study [7] is its focus on the impacts of Industry 4.0 on higher education by emphasizing the needs to develop and train the qualified workforce to prepare for Industry 4.0. The main strength is that statistical data has been used to underscore the importance of Industry 4.0 in higher because empirical evidence has been provided for the claims made. However, one of the weaknesses of this study is the lack of depth in the literature. While this research presents the importance of Industry 4.0 in higher education, it does not comprehensively explore on the challenges and opportunities that colleges and universities may face. In addition, this study could further discuss potential strategies and solutions to address these opportunities and challenges.

Maria, Shahbodin and Pee (2018) provides the valuable perspectives on the intersections of Education 4.0 and Industry 4.0, with the emphasis on Malaysia's higher education [8]. The major contribution of this study is that this research highlights the perception and awareness of the Malaysian government in preparing and embracing Industry 4.0 and Education 4.0, which is critical for Malaysia to stay aligned with the global technological advancements in Industry 4.0. However, this study could be further improved by providing more specific details regarding Malaysian government's strategies and initiatives for this transition. To further enhance the impacts of

this study, the deeper analyses of the opportunities that higher education system in Malaysia may face in adopting Education 4.0 and Industry 4.0 should be conducted. In addition, more specific examples of how these concepts and strategies will be implemented in the Malaysia should be provided to further strengthen its contribution in the area of STEM education.

From the historical perspective, the study summarizes the evolution of STEM education and its integration with the technological advancements, including Industry 4.0 [9]. The concepts and keywords that have shaped higher education in the past two decades were highlighted. The main contribution it that this paper offers a broad overview about the connections between STEM education and technological advancements. However, one of the critiques of this study is that it is lack of the in-depth analysis regarding the impacts of Industry 4.0 on higher education. In addition, this study fails to provide strategies and solutions to address the identified issues regarding the sustainability of future development in higher education.

Some researchers demonstrate how to develop the workforce by proposing smart education in the context of Industry 4.0 and Industry 5.0 [9, 10, 11]. By highlighting the properties of high-tech strategies, real-time data processing, and cyber-physical systems of Industry 4.0, Alias et al (2018) explore some initiatives about technical and vocational education and training related to Industry 4.0 in order to provide the practical guidelines for government policymakers in the era of Industry 4.0 [10]. Some studies mentioned that Industry 4.0 have the pervasive impacts on various aspects of workplaces, such as sensor-driven technologies, intelligent robots, mobile applications, and more [11]. By anticipating the evolving demands in the future job market, this study explores to emphasize the need for skills beyond technology-related by aligning with the principles of STEM education, including creativity, critical thinking, and interpersonal skills [11]. They also suggest that the recognition of evolving nature of skills in the context of Industry 4.0 and forward-thinking perspective are beneficial to adapt to the changing need in job market. Tavares (2021) also presents the impacts of Industry 4.0 on higher education and its alignment with Education 4.0 by emphasizing the needs to develop new learning skills and abilities to empower individuals in the digital age in order to explore how to develop Industry 4.0 skilled workforce [12].

The aim of this study is to prepare students and professionals with the necessary skills and knowledge in Industry 4.0. By investigating the current situation of engineering education in the context of transformative Industry 4.0, we can gain valuable insights into the ways how to develop Industry 4.0 skilled workforce, how to improve learning experiences, how to address existing challenges in engineering education. The following areas deserve further exploration to prepare students for Industry 4.0, such as individualization and virtualization of education, strengthening the project-based and multidisciplinary character of engineering education, and development of interactive educational resources.

## Method

Based on the reviews in Section II above, the following research questions are developed: Which stakeholders should get involved in engineering education to prepare the students for Industry 4.0 in order to develop a skilled Industry 4.0 workforce? What skills are needed for Industry 4.0 skilled workforce to succeed in the digital age

and contribute to the advancement of society and economy? To answer these questions, a stepwise mixed-method research method has been designed in Figure 1.

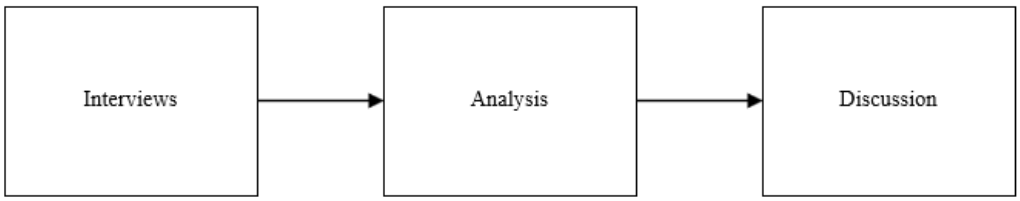


Figure 1. Research Process Overview

To develop engineering education ecosystem and identify the skill set for Industry 4.0 workforce, the interviews were carried out individually and remotely with both the stakeholders who had participated in engineering education in Industry 4.0 and the students. In total, 30 interviews have been conducted, including: 12 students and 18 stakeholders. The stakeholders represent both high schools (3), community colleges (5), universities (5) and industry companies (5). The statements of students and stakeholders were analyzed and discussed to derive the responses to the research questions. The results of this process are presented in Section IV.

## Findings and discussion

### Engineering Education Ecosystem for Industry 4.0

Based on the statements of stakeholders interviewed, Figure 2 shows the engineering education ecosystem for Industry 4.0. There are two paths and four distinct zones in the engineering education ecosystem. The first zone is K-12 prospective students from high schools. The second zone is two-year community colleges, and the third zone is four-year universities and colleges. The fourth zone is the industry companies or the workplace that will employ the students. These four zones are deeply interconnected, forming an ecosystem where changes in one zone can impact the others. There are two paths for K-12 prospective students to perform engineering education in Industry 4.0. Some of them would like to enroll in four-year universities and colleges.

Another path is that the students would like to complete two years of study at the community colleges and then transfer to four-year universities and colleges after they earned an associate degree. In addition, proposed engineering education ecosystem for Industry 4.0 is a closed loop system when industry companies provide feedback to universities and colleges regarding their actual needs in workforce. Yildirim and Tuncalp (2023) pointed out that university-based innovation ecosystem plays an essential role in linking science and technology universities with industrial firms in the digital transformation era [13]. Thus, they propose to build industry and university collaboration for industry 4.0 education through the perspective of policy development.

Proposed engineering education ecosystem for Industry 4.0 takes all stakeholders into account, including the students, industry companies, two-year community colleges, and four-year universities and colleges. Especially, this engineering education ecosystem for Industry 4.0 creates a path for the graduates from two-year community

colleges to get further study in Industry 4.0 through transferring to four-year universities and colleges. Currently, the University of Wisconsin (UW)-Stout establishes a Bachelor of Science (B.S.) in Automation Leadership to fill the needs of industry for leaders in Industry 4.0 and digital transformation. This unique and new degree completion program will prepare graduates for positions in diverse automation and digital leadership roles by providing education that complement their technical training with skills in management, leadership, and quality improvement based on demand from Wisconsin industry leaders. To ensure the students' success in their career, this program has a partnership with the Wisconsin Technical College System aimed at serving place-bound individuals with an Associate of Science degree who are seeking career advancement through a combination of online and local instruction. To consider meet industry companies' needs, this program also partners with the Smart Automation Certification Alliance (SACA) whose goal is to "develop and deploy modular Industry 4.0 certifications." A total of 27 students enrolled in this program and further study will be conducted to evaluate effectiveness of this initiative.

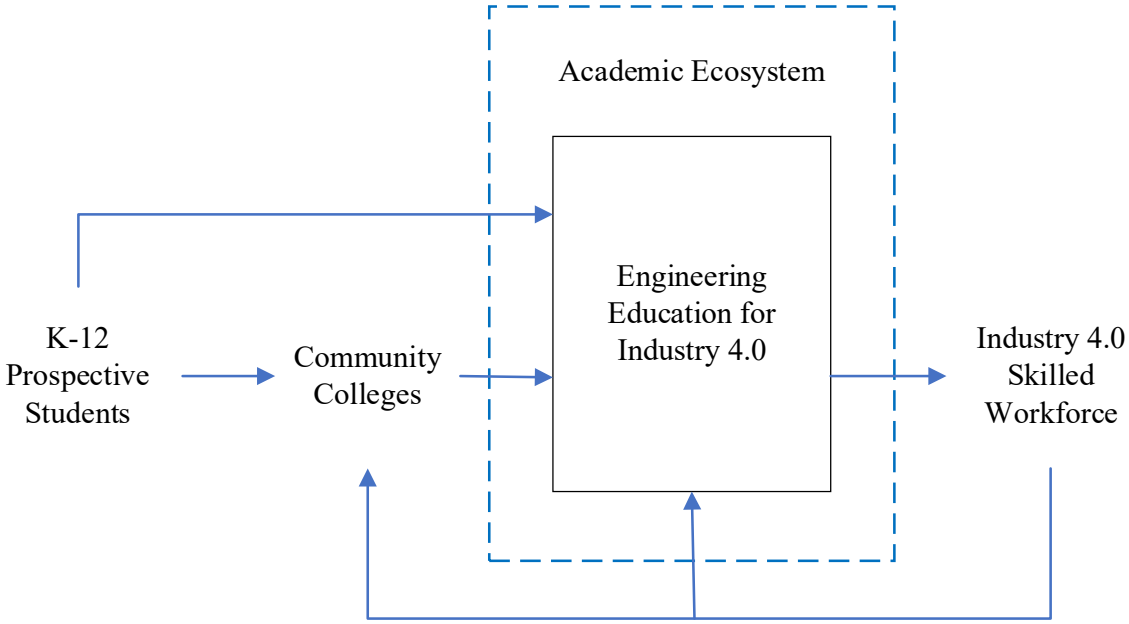


Figure 2. Engineering Education Ecosystem for Industry 4.0

**Skill Set for Industry 4.0 Workforce**

The Industry 4.0 workforce requires a blend of technical, digital, and soft skills to thrive in smart factories, IoT-driven environments, and data-centric industries. Based on the statements of students and stakeholders interviewed, the essential skill sets needed were summarized in Table 1. Five categories of skill sets for Industry 4.0 workforce are identified, including core technical skills, digital and IT skills, soft and cognitive skills, business and operational skills, emerging and future skills.Some researchers propose that Industry 4.0 fundamentally changes how manufacturing and related sectors operate through cyber-physical systems. The required skillset shifts dramatically from traditional industrial roles [14]. Thus, they categorizes five different skills, including the technical, digital, and social skills that are essential for the evolving labor market [16].

Table 1. Skill set for Industry 4.0 workforce

| 1 | Core Technical Skills |
|---|---|
| 1.1 | Advanced Manufacturing & Automation [15] |
| | • Robotics & Mechatronics |
| | • CNC Machining & 3D Printing (Additive Manufacturing) |
| | • PLC Programming & Industrial Control Systems |
| 1.2 | Industrial Internet of Things (IIoT) |
| | • Sensor Technology & Edge Computing |
| | • Cyber-Physical Systems (CPS) |
| | • Smart Factory & Digital Twin Concepts |
| 1.3 | Data Analytics & AI |
| | • Big Data & Predictive Maintenance |
| | • Machine Learning for Manufacturing |
| | • Statistical Process Control (SPC) |
| 1.4 | Cybersecurity for Industry 4.0 |
| | • OT (Operational Technology) Security |
| | • Network Security for SCADA & IoT |
| | • Risk Management in Smart Factories |
| 2 | Digital & IT Skills |
| | • Cloud Computing & Industrial Cloud Platforms |
| | • Programming & Scripting (Python, C++, MATLAB, SQL) |
| | • ERP & MES Systems (SAP, Siemens Opcenter) |
| | • Blockchain for Supply Chain Transparency |
| 3 | Soft & Cognitive Skills [16] |
| | • Problem-Solving & Critical Thinking |
| | • Adaptability & Continuous Learning (Upskilling/Reskilling) |
| | • Collaboration in Cross-Functional Teams |
| | • Human-Machine Interaction (Human-Robot Collaboration) |
| 4 | Business & Operational Skills |
| | • Lean Manufacturing & Six Sigma |
| | • Supply Chain 4.0 (Digital Logistics, Smart Warehousing) |
| | • Project Management (Agile, Scrum for Industry 4.0) |
| 5 | Emerging & Future Skills |
| | • Augmented Reality (AR) & Virtual Reality (VR) for Training & Maintenance |
| | • Quantum Computing for Optimization |
| | • Sustainable Manufacturing & Circular Economy Practices |

In summary, the Industry 4.0 workforce must be versatile, tech-savvy, and agile to keep up with rapid advancements in automation, AI, and smart manufacturing [14].

## Conclusion

Investing in engineering education isn't optional-it's the engine of fourth industrial revolution prosperity. All stakeholders, including governments, high school, colleges, universities and industry must collaborate urgently to scale programs that turn engineers into I4.0 skilled workforce. The main contribution of this study is that proposed engineering education ecosystem for Industry 4.0 gives a guideline to the students, colleges, universities, and companies regarding how to collaborate and get involved in education in order to reduce the gap between the skill needs of industry and higher education. The practice of BS in Automation Leadership at UW-Stout is introduced in this study. Another important contribution is that this study identifies 5 categories of skill sets for Industry 4.0 workforce, which seeks by industrial companies to realize Industry 4.0 and presents a blueprint as a reference for the students to learn and acquire new skills to prepare for Industry 4.0. However, the core challenge is that Industry 4.0 evolves faster than academia. For future research, attention could be paid to the relationship among higher education, labor markets and industry. In summary, engineering education for preparing Industry 4.0 skilled workforce thrives when stakeholders function as an ecosystem. Alignment of goals (e.g., industry defining skills, universities delivering them, governments enabling access) is essential to build a future-ready workforce.

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